TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS AND COMMERCIAL AND INDUSTRIAL EQUIPMENT:

RESIDENTIAL FURNACE FANS

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U.S. Department of Energy
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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This notice of proposed rulemaking (TSD) is a stand-alone report that provides the technical analyses and results supporting the information presented in the notice of proposed rulemaking (NOPR) for residential furnace fans. This TSD reports on the preliminary activities and analyses conducted in support of the NOPR.

1.2 SUMMARY OF THE NATIONAL BENEFITS

DOE's analyses indicate that the proposed standards would save a significant amount of energy. The cumulative energy savings for residential furnace fan products purchased in the 30-year period that begins in the first full year of compliance with new standards (2019–2048) amount to 4.58 quads.[a] This is equivalent to approximately 23 percent of total U.S. residential energy use in 2012.

The cumulative net present value (NPV) of total consumer costs and savings for the proposed residential furnace fan standards in 2012$ ranges from $8.51 billion (at a 7-percent discount rate) to $26.16 billion (at a 3-percent discount rate). This NPV expresses the estimated total value of future operating-cost savings minus the estimated increased product costs for residential furnace fans purchased in 2019–2048, discounted to 2013.

In addition, the proposed standards would have significant environmental benefits. The energy savings would result in cumulative emission reductions of 429.78 million metric tons (Mt)[b] of carbon dioxide (CO_2), 230.9 thousand tons of nitrogen oxides (NO_X), 313.46 thousand tons of sulfur dioxide (SO_2),and 1.77 tons of mercury (Hg).[c]

The value of the CO_2 reductions is calculated using a range of values per metric ton of CO_2 (otherwise known as the Social Cost of Carbon, or SCC) developed by an interagency process. The derivation of the SCC values is discussed in section Chapter 10. DOE estimates that the present monetary value of the CO_2 emissions reduction is between $2.247 and $35.56 billion, expressed in 2012$ and discounted to 2013. DOE also estimates the net present monetary value of the NO_X emissions reduction, expressed in 2012$ and discounted to 2013, is $0.109 billion at a 7-percent discount rate and $0.314 billion at a 3-percent discount rate.

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[a] A quad is equal to 10^{15} British thermal units (BTU).

[b] A metric ton is equivalent to 1.1 short tons. Results for emissions other than CO_2 are presented in short tons.

[c] DOE calculates emissions reductions relative to the Annual Energy Outlook 2012 (AEO 2012) Reference case, which incorporated projected effects of all emissions regulations promulgated as of January 31, 2012.

Table 1.2.1 summarizes the national economic costs and benefits expected to result from today's proposed standards for residential furnace fans.

Table 1.2.1 Summary of National Economic Benefits and Costs of Proposed Residential Furnace Fans Energy Conservation Standards (TSL 4)

Category	**Present Value** Billion, 2012$	**Discount Rate**
Benefits		
Operating Cost Savings	11.6	7%
	32.0	3%
CO_2 Reduction Monetized Value ($12.9/t case)*	2.2	5%
CO_2 Reduction Monetized Value ($40.8/t case)*	11.5	3%
CO_2 Reduction Monetized Value ($62.2/t case)*	18.8	2.5%
CO_2 Reduction Monetized Value ($117/t case)*	35.6	3%
NO_X Reduction Monetized Value (at $2,639/ton)**	0.1	7%
	0.3	3%
Total Benefits†	23.2	7%
	43.8	3%
Costs		
Incremental Installed Costs	3.1	7%
	5.8	3%
Net Benefits		
Including CO_2 and NO_X Reduction Monetized Value	20.1	7%
	38.0	3%

* The CO_2 values represent global monetized values of the SCC, in 2012$, in 2015 under several scenarios. The first three cases use the averages of SCC distributions calculated using 5%, 3%, and 2.5% discount rates, respectively. The fourth case represents the 95th percentile of the SCC distribution calculated using a 3% discount rate. The SCC time series used by DOE incorporate an escalation factor.
** The value represents the average of the low and high NO_X values used in DOE's analysis.
† Total Benefits for both the 3% and 7% cases are derived using the series corresponding to SCC value of $40.8/t.

The benefits and costs of today's proposed standards, for products sold in 2019-2048, can also be expressed in terms of annualized values. The annualized monetary values are the sum of: (1) the annualized national economic value of the benefits from consumer operation of products that meet the proposed standards (consisting primarily of operating cost savings from using less energy, minus increases in equipment purchase and installation costs, which is another way of representing consumer NPV); and (2) the annualized monetary value of the benefits of emission reductions, including CO_2 emission reductions.[d]

Although combining the values of operating savings and CO_2 emission reductions provides a useful perspective, two issues should be considered. First, the national operating savings are domestic U.S. consumer monetary savings that occur as a result of market transactions, whereas the value of CO_2 reductions is based on a global value. Second, the assessments of operating cost savings and CO_2 savings are performed with different methods that use different time frames for analysis. The national operating cost savings is measured for the lifetime of residential furnace fans shipped in 2019–2048. The SCC values, on the other hand, reflect the present value of some future climate-related impacts resulting from the emission of one ton of carbon dioxide in each year. These impacts continue well beyond 2100.

Estimates of annualized benefits and costs of the proposed standards are shown in Table 1.2.2. The results under the primary estimate are as follows. (All monetary values below are expressed in 2012$.) Using a 7-percent discount rate for benefits and costs other than CO2 reduction (for which DOE used a 3-percent discount rate along with the SCC series corresponding to a value of $40.8/ton in 2015), the cost of the residential furnace fan standards proposed in today's rule is $231 million per year in increased equipment costs, while the benefits are $872 million per year in reduced equipment operating costs, $571 million in CO2 reductions, and $8.24 million in reduced NOX emissions. In this case, the net benefit amounts to $1,451 million per year. Using a 3-percent discount rate for all benefits and costs and the SCC series corresponding to a value of $40.8/ton in 2015, the cost of the residential furnace fans standards proposed in today's rule is $290 million per year in increased equipment costs, while the benefits are $1585 million per year in reduced operating costs, $571 million in CO2 reductions, and $15.56 million in reduced NOX emissions. In this case, the net benefit amounts to $1,882 million per year.

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[d] DOE used a two-step calculation process to convert the time-series of costs and benefits into annualized values. First, DOE calculated a present value in 2013, the present year used for discounting the NPV of total consumer costs and savings, for the time-series of costs and benefits using discount rates of three and seven percent for all costs and benefits except for the value of CO_2 reductions. For the latter, DOE used a range of discount rates, as shown in Table 1.2.2. From the present value, DOE then calculated the fixed annual payment over a 30-year period (2019 through 2048) that yields the same present value. The fixed annual payment is the annualized value. Although DOE calculated annualized values, this does not imply that the time-series of cost and benefits from which the annualized values were determined is a steady stream of payments.

Table 1.2.2 Annualized Benefits and Costs of Proposed Standards for Residential Furnace Fans (TSL 4)

	Discount Rate	Primary Estimate*	Low Net Benefits Estimate	High Net Benefits Estimate
		million 2012$/year		
Benefits				
Operating Cost Savings	7%	872	710	1082
	3%	1585	1264	2011
CO_2 Reduction Monetized Value ($12.9/t case)*	5%	139	117	171
CO_2 Reduction Monetized Value ($40.8/t case)*	3%	571	477	702
CO_2 Reduction Monetized Value ($62.2/t case)*	2.5%	877	732	1079
CO_2 Reduction Monetized Value ($117/t case)*	3%	1761	1471	2167
NO_X Reduction Monetized Value (at $2,639/ton)**	7%	8.24	6.97	9.99
	3%	15.56	13.03	19.09
Total Benefits†	7% plus CO_2 range	1,019 to 2,641	834 to 2,188	1,263 to 3,259
	7%	1,451	1,194	1,794
	3% plus CO2 range	1,740 to 3,362	1,394 to 2,748	2,201 to 4,197
	3%	2,172	1,754	2,732
Costs				
Incremental Product Costs	7%	231	273	201
	3%	290	346	250
Net Benefits				
Total†	7% plus CO_2 range	788 to 2,410	561 to 1,915	1,062 to 3,058
	7%	1,220	921	1,593
	3% plus CO_2 range	1,450 to 3,072	1,047 to 2,402	1,951 to 3,947
	3%	1,882	1,407	2,482

* This table presents the annualized costs and benefits associated with residential furnace fans shipped in 2019−2048. These results include benefits to consumers which accrue after 2048 from the products purchased in 2019−2048. Costs incurred by manufacturers, some of which may be incurred in preparation for the rule, are not directly included, but are indirectly included as part of incremental equipment costs. The Primary, Low Benefits, and High Benefits Estimates utilize projections of energy prices and housing starts from the AEO 2012 Reference case, Low Estimate, and High Estimate, respectively. Incremental product costs reflect a constant product price trend in the Primary Estimate, an increasing price trend in the Low Benefits Estimate, and a decreasing price trend in the High Benefits Estimate.

** The CO_2 values represent global values of the SCC, in 2012$, in 2015 under several scenarios. The first three cases use the averages of SCC distributions calculated using 5%, 3%, and 2.5% discount rates, respectively. The fourth case represents the 95th percentile of the SCC distribution calculated using a 3% discount rate. The SCC values increase over time. The value for NO_X (in 2012$) is the average of the low and high values used in DOE's analysis.

† Total Benefits for both the 3% and 7% cases are derived using the series corresponding to SCC value of $40.8/t in 2015. In the rows labeled "7% plus CO2 range" and "3% plus CO2 range," the operating cost and NOX benefits are calculated using the labeled discount rate, and those values are added to the full range of CO2 values.

1.3 OVERVIEW OF STANDARDS FOR FURNACE FANS

The U.S. Department of Energy (DOE) is initiating its first rulemaking to consider new energy conservation standards for furnace fans, as required under the Energy Policy and Conservation Act (42 U.S.C. 6295(f)(4)(D), EPCA) which provides as follows:

Notwithstanding any other provision of this chapter, if the requirements of subsection (o) of this section are met, not later than December 31, 2013, the Secretary shall consider and prescribe energy conservation standards or energy use standards for electricity used for purposes of circulating air through duct work.

Such language could be interpreted as encompassing electrically-powered devices used in any residential HVAC product to circulate air through ductwork. At the present time, DOE is only proposing to cover in this rulemaking those circulation fans that are used in residential furnaces and modular blowers. The following list describes DOE's proposed scope of coverage for this rulemaking in more detail.

- Included products: the furnace fans used in weatherized and non-weatherized gas furnaces, oil furnaces, electric furnaces, and modular blowers.
- Excluded products: other products that incorporate furnace fans, such as central air conditioner (CAC) blower-coil units, through-the-wall air handlers, small duct high-velocity (SDHV) air handlers, energy recovery ventilators (ERVs), heat recovery ventilators (HRVs), draft inducer fans, exhaust fans, or hydronic air handlers.

There are no current DOE standards for residential furnace fans. In June 2010, DOE initiated this rulemaking by publishing a notice of public meeting and availability of the framework document. 75 FR 31323 (June 3, 2010) The framework document, *Rulemaking Framework Document for Residential Furnace Fans*, describes the procedural and analytical approaches DOE anticipated using to evaluate the establishment of new energy conservation standards for these products. The framework document is available at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41. Subsequently, DOE held a public meeting on June 18, 2010 ("June 2010 public meeting") to discuss procedural and analytical approaches to the rulemaking. On July 10, 2012, DOE published a notice of public meeting and availability of the preliminary analysis TSD. FR 77 40530. The preliminary TSD is also available at the website above. EPCA directs DOE to establish test procedures in conjunction with new or amended energy conservation standards, including furnace fans. (42 U.S.C. 6295(r)) To fulfill this requirement, DOE is simultaneously conducting a test procedure rulemaking for furnace fans. On May 15, 2012, DOE published a test procedure NOPR in the Federal Register to initiate the test procedure rulemaking for furnace fans. 77 FR 28674. DOE subsequently published a test procedure supplemental notice of proposed rulemaking (SNOPR) on May 25, 2013. 77 FR 31444

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

Under EPCA, when DOE is studying new or amended standards, it must consider, to the greatest extent practicable, the following seven factors (42 U.S.C. 6295 (o)(2)(B)(i)):

1) the economic impact of the standard on the manufacturers and consumers of the affected products;

2) the savings in operating costs throughout the estimated average life of the product compared to any increases in the initial cost or maintenance expense;

3) the total projected amount of energy savings likely to result directly from the imposition of the standard;

4) any lessening of the utility or the performance of the products likely to result from the imposition of the standard;

5) the impact of any lessening of competition, as determined in writing by the Attorney General, that is likely to result from the imposition of the standard;

6) the need for national energy conservation; and

7) other factors the Secretary considers relevant.

Other statutory requirements are set forth in 42 U.S.C. 6295 (o)(1)–(2)(A), (2)(B)(ii)–(iii), and (3)–(4) and 42 U.S.C. 6316(e).

DOE considers interested party participation to be a very important part of the process for setting energy conservation standards. Through formal public notifications (*i.e.*, *Federal Register* notices), DOE actively encourages the participation and interaction of all interested parties during the comment period in each stage of the rulemaking. Beginning with the framework document and during subsequent comment periods, interactions among interested parties provide a balanced discussion of the information that is required for the standards rulemaking.

Before DOE determines whether or not to adopt a proposed energy conservation standard, it must first solicit comments on the proposed standard. (42 U.S.C. 6313(a)(6)(B)(i)) Any new or amended standard must be designed to achieve significant additional conservation of energy and be technologically feasible and economically justified. (42 U.S.C. 6313(a)(6)(A)) To determine whether economic justification exists, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the seven factors listed above. (42 U.S.C. 6295 (o)(2)(B)(i))

After the publication of the framework document, the energy conservation standards rulemaking process involves three additional, formal public notices, which DOE publishes in the *Federal Register*. The first of the rulemaking notices is a NOPM, which is designed to publicly vet the models and tools used in the preliminary rulemaking and to facilitate public participation before the NOPR stage. The second notice is the NOPR, which presents a discussion of comments received in response to the NOPM and the preliminary analyses and analytical tools; analyses of the impacts of potential amended energy conservation standards on consumers, manufacturers, and the Nation; DOE's weighting of these impacts of amended energy conservation standards; and the proposed energy conservation standards for each product. The third notice is the final rule, which presents a discussion of the comments received in response to the NOPR; the revised analyses; DOE's weighting of these impacts; the amended energy conservation standards DOE is adopting for each product; and the effective dates of the amended energy conservation standards.

In June 2010, DOE published a notice of public meeting and availability of the framework document. 75 FR 31323 (June 3, 2010) The framework document, *Rulemaking Framework Document for Residential Furnace Fans*, describes the procedural and analytical approaches DOE anticipated using to evaluate the establishment of new energy conservation standards for these products. This document is available at: http://www1.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans_framework.html. Subsequently, DOE held a public meeting on June 18, 2010 ("June 2010 public meeting") to discuss procedural and analytical approaches to the rulemaking. In addition, DOE used the public meeting to inform and facilitate involvement of interested parties in the rulemaking process. The analytical framework presented at the public meeting described the different analyses, such as the engineering analysis and the consumer economic analyses (*i.e.*, the life-cycle cost (LCC) and payback period (PBB) analyses), the methods proposed for conducting them, and the relationships among the various analyses.

Table 1.4.1 Analyses Under the Process Rule

Preliminary Analyses	NOPR	Final Rule
Market and technology assessment	Revised preliminary analyses	Revised NOPR analyses
Screening analysis	Life-cycle cost sub-group analysis	
Engineering analysis	Manufacturer impact analysis	
Energy use determination	Utility impact analysis	
Markups for equipment price determination	Emissions analysis	
Life-cycle cost and payback period analysis	Employment impact analysis	
Shipments analysis	Regulatory impact analysis	
National impact analysis		
Preliminary manufacturer impact analysis		

During the June 2010 public meeting, interested parties commented about numerous issues relating to each one of the analyses listed in Table 1.4.1. Comments from interested parties submitted during the framework document comment period elaborated on the issues raised during the public meeting. DOE attempted to address these issues during its preliminary analyses and summarized the comments and DOE's responses in chapter 2 of the preliminary TSD.

As part of the information gathering and sharing process, DOE organized and held interviews with manufacturers of the residential furnace fans considered in this rulemaking as part of the engineering analysis. DOE selected companies that represented production of all types of products, ranging from small to large manufacturers, and included the Air-Conditioning, Heating and Refrigeration Institute (AHRI) member companies. DOE had four objectives for these interviews: (1) solicit manufacturer feedback on the draft inputs to the engineering analysis; (2) solicit feedback on topics related to the preliminary manufacturer impact analysis; (3) provide an opportunity, early in the rulemaking process, to express manufacturers' concerns to DOE; and (4) foster cooperation between manufacturers and DOE.

DOE incorporated the information gathered during the engineering interviews with manufacturers into its engineering analysis (chapter 5 of the preliminary TSD) and the preliminary manufacturer impact analysis (chapter 12 of the preliminary TSD). Following the publication of the preliminary analyses and the NOPM public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis conducted for the NOPR. DOE incorporated the information gathered during the NOPR manufacturer interviews with into its engineering analysis (chapter 5) and the manufacturer impact analysis (chapter 12).

DOE developed an LCC spreadsheet that calculates the LCC and PBP at various energy efficiency levels. DOE also developed a national impact analysis spreadsheet that calculates the national energy savings (NES) and national net present values (NPVs) at various energy efficiency levels. This spreadsheet includes a model that forecasts the impacts of amended energy conservation standards at various levels on product shipments. All of these spreadsheets are available on the DOE website for furnace fans: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41 .

On July 10, 2012, DOE published the NOPM and availability of the preliminary TSD. 77 FR 40530. The preliminary TSD provides technical analyses and results that support the information presented in the preliminary NOPM and the executive summary for residential furnace fans. The preliminary TSD also provides a detailed description of all of the analyses discussed in the paragraphs above. The preliminary TSD is available on DOE's website at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41. Following publication of the NOPM and the preliminary TSD, DOE held a public meeting on July 27, 2012 to facilitate discussion about the preliminary analyses that were performed for the NOPM and described in the preliminary TSD. In addition to the public meeting, a written comment period was open until September 10, 2012 to allow interested parties to provide new comments or elaborate on any comments made at the public meeting.

In addition to revising the various preliminary analyses, DOE also performed an LCC subgroup analysis, manufacturer impact analysis, utility impact analysis, employment impact analysis, and regulatory impact analysis for the NOPR.

1.5 STRUCTURE OF THE DOCUMENT

This preliminary TSD outlines the analytical approaches used in this rulemaking. The TSD consists of fourteen chapters, an environmental assessment, a regulatory impact analysis, and appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to this rulemaking and outlines the structure of the document.
Chapter 2	Analytical Framework: describes the rulemaking process.
Chapter 3	Market and Technology Assessment: characterizes the market for the considered products and the technologies available for increasing product efficiency.

Chapter 4	Screening Analysis: identifies all the design options that improve efficiency of the considered products and determines which technology options are viable for consideration in the engineering analysis.
Chapter 5	Engineering Analysis: discusses the methods used for developing the relationship between increased manufacturer price and increased efficiency.
Chapter 6	Markups Analysis: discusses the methods used for establishing markups for converting manufacturer prices to customer product costs.
Chapter 7	Energy Use Analysis: discusses the process used for generating energy-use estimates for the considered products as a function of standard levels.
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the methods used to analyze effects of standards on individual customers and users of the products and compares the LCC and PBP of products with and without higher efficiency standards.
Chapter 9	Shipments Analysis: estimates shipments of the products over the 30-year analysis period that is used in performing the national impact analysis (NIA), including how shipments may vary under alternative standard levels.
Chapter 10	National Impact Analysis: assesses the national energy savings, and the national net present value of total consumer costs and savings, expected to result from specific, potential energy conservation standards.
Chapter 11	Consumer Subgroup Analysis: discusses the effects of potential standards on different subgroups of consumers.
Chapter 12	Manufacturer Impact Analysis: discusses the effects of standards on the finances and profitability of product manufacturers.
Chapter 13	Emissions Analysis: discusses the effects of standards on three pollutants—sulfur dioxide (SO_2), nitrogen oxides (NO_x), and mercury—as well as CO_2 emissions.
Chapter 14	Monetization of Emissions Reductions: discusses the basis for estimated monetary values used for the reduced emissions of CO_2 and NO_x that are expected to result from each of the TSLs considered.

Chapter 15	Utility Impact Analysis: discusses selected effects of potential standards on electric utilities.
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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

The Energy Policy and Conservation Act (EPCA), as amended (42 USC 6291 et. seq.), requires that when prescribing new or amended energy conservation standards for covered products, the U.S. Department of Energy (DOE) must promulgate standards that achieve the maximum improvements in energy efficiency that are technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) This chapter provides a description of the analytical framework that DOE is using to evaluate new energy conservation standards for residential furnace fans. This chapter sets forth the methodology, analytical tools, and relationships among the various analyses that are part of this rulemaking. For example, the methodology that addresses the statutory requirement for economic justification includes analyses of life-cycle cost (LCC); economic impact on manufacturers and users; national benefits; impacts, if any, on utility companies; and impacts, if any, from lessening competition among manufacturers.

The analyses performed as part of the preliminary analysis stage and reported in the preliminary technical support document (TSD) are listed below.

- A market and technology assessment to characterize the relevant products, their markets, and technology options for improving their energy efficiency, including prototype designs.
- A screening analysis to review each technology option and determine if it is technologically feasible; is practicable to manufacture, install, and service; would adversely affect product utility or product availability; or would have adverse impacts on health and safety.
- An engineering analysis to develop relationships that show the manufacturer's cost of achieving increased efficiency.
- A markups analysis to develop distribution channel markups that relate the manufacturer production cost (MPC) to the cost to the consumer.
- An energy use analysis to determine the annual energy use of the considered products in a representative set of users.
- A life-cycle cost (LCC) and payback period (PBP) analysis to calculate the savings in operating costs at the consumer level throughout the life of the covered products compared with any increase in the installed cost for the products likely to result directly from imposition of a standard.
- A shipments analysis to forecast product shipments, which are then used to calculate the national impacts of standards on energy, net present value (NPV), and future manufacturer cash flows.

- A national impact analysis (NIA) to assess the aggregate impacts at the national level of potential energy conservation standards for the considered products, as measured by the NPV of total consumer economic impacts and the national energy savings (NES).
- A preliminary manufacturer impact analysis (MIA) to assess the potential impacts of energy conservation standards on manufacturers' capital conversion expenditures, marketing costs, shipments, and research and development costs.

In this Notice of Proposed Rulemaking (NOPR), DOE presents the results of the above analyses, incorporating any revisions to the analyses based on comments and new information received. DOE also presents results of the following additional analyses in the NOPR:

- A consumer subgroup analysis to evaluate variations in customer characteristics that might cause a standard to affect particular consumer sub-populations (such as low-income households) differently than the overall population.
- An MIA to estimate the financial impact of standards on manufacturers and to calculate impacts on competition, employment, and manufacturing capacity.
- An emissions analysis to assess the effects of the considered standards on emissions of carbon dioxide (CO_2), sulfur dioxide (CO_2) nitrogen oxides (NO_x), and mercury (Hg).
- An emissions monetization that estimates the economic value of reductions in CO_2 and NO_X emissions from the considered standards.
- A utility impact analysis to estimate selected effects of the considered standards on electric utilities.
- An employment impact analysis to assess the impacts of the considered standards on national employment.
- A regulatory impact analysis (RIA) to evaluate alternatives to amended energy conservation standards in order to assess whether such alternatives could achieve substantially the same regulatory goal at a lower cost.

DOE developed this analytical framework and documented its findings in the Rulemaking Framework for Furnace Fans (June 1, 2010). On June 3, 2010, DOE published the Notice of Public Meeting and Availability of the Framework Document for furnace fans in the *Federal Register*. 75 FR 31323. In conjunction, DOE posted the Framework Document to the DOE website.[1] DOE presented the analytical approach to interested parties during a public meeting held on June 18, 2010.

In response to the publication of the Framework Document and the Framework public meeting, DOE received numerous comments from interested parties regarding DOE's analytical approach. DOE published the preliminary analysis on July 10, 2012 (77 FR 40530), addressing

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[1] The June 1, 2010 furnace fan Framework Document is available at the following link: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41

key comments received from interested parties. DOE subsequently held a public meeting on July 27, 2012, to present the preliminary analysis and to seek public comment. The preliminary analysis and preliminary TSD are available at:
http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41

This TSD contains details of the NOPR analyses conducted for residential furnace fans.

2.2 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant product markets and existing technology options, including prototype designs, for the considered products.

2.2.1 Market Assessment

When DOE begins an energy conservation standards rulemaking, it develops information that provides an overall picture of the market for the products considered, including the nature of the products, market characteristics, and industry structure. This activity consists of both quantitative and qualitative efforts based primarily on publicly-available information. The market assessment examined manufacturers, trade associations, and the quantities and types of products offered for sale.

DOE recognizes that there may be limited public information on national shipments, manufacturing costs, channels of distribution, and manufacturer market shares of furnace fans. This type of data is an important input for analyses that determine if energy conservation standards are economically justified and will result in significant energy savings. Therefore, DOE encourages interested parties to submit data that will improve DOE's understanding of the furnace fan market. These data may be provided under a confidentiality agreement with DOE's contractor responsible for this part of the rulemaking analysis, Navigant Consulting, Inc. (Navigant). In other rulemakings, Navigant works with confidential data provided by manufacturers and other organizations in preparing aggregated results for DOE's analysis. These aggregated results do not divulge the sensitive, individual raw data, but enable other interested parties to comment on the aggregated dataset.

Alternatively, interested parties may submit confidential data to DOE, indicating in writing which data should remain confidential. Interested parties must submit confidential information to DOE according to the procedures outlined in 10 CFR 1004.11. Pursuant to 10 CFR 1004.11, any person submitting information that he or she believes to be confidential and exempt by law from public disclosure should submit two copies. One copy of the document shall include all the information believed to be confidential, and the other copy shall have the information believed to be confidential deleted. DOE will make its own determination about the confidential status of the information and treat it accordingly.[2]

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[2] Factors that DOE considers when evaluating requests to treat submitted information as confidential include: (1) a description of the items; (2) whether and why such items are customarily treated as confidential within the industry; (3) whether the information is generally known by or available from other public sources; (4) whether the

DOE reviewed relevant literature and interviewed manufacturers to develop an overall picture of the residential furnace fan industry in the United States. Industry publications and trade journals, government agencies, and trade organizations provided the bulk of the information, including: (1) manufacturers and their market shares; (2) shipments by product type (*e.g.*, non-weatherized gas furnace, oil furnace); (3) product information; and (4) industry trends. The analyses developed as part of the market and technology assessment are described in chapter 3 of the TSD.

DOE has used the most reliable and accurate data available at the time of each analysis in this rulemaking.

2.2.2 Technology Assessment

DOE typically uses information relating to existing and past technology options and prototype designs as inputs to determine what technologies manufacturers use to attain higher performance levels. In consultation with interested parties, DOE develops a list of technologies for consideration. Initially, these technologies encompass all those it believes are technologically feasible. Chapter 3 of the TSD includes the detailed list of all technology options DOE identified for further consideration in this rulemaking.

DOE developed its list of technologically feasible technology options for the considered products through consultation with manufacturers of components and systems, and from trade publications and technical papers. Since many options for improving product efficiency are available in existing units, product literature and direct examination provided additional information.

2.3 SCREENING ANALYSIS

The purpose of the screening analysis is to evaluate the technologies identified in the technology assessment to determine which technologies to consider further and which technologies to screen out. DOE consulted with industry, technical experts, and other interested parties in developing a list of energy-saving technologies for the technology assessment. DOE then applied the screening criteria to determine which technologies were unsuitable for further consideration in this rulemaking. Chapter 4 of the TSD, the screening analysis, contains details about DOE's screening criteria.

As presented in further detail below, the screening analysis examines whether various technologies: (1) are technologically feasible; (2) are practicable to manufacture, install, and service; (3) have an adverse impact on product utility or availability; and (4) have adverse

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information has previously been made available to others without obligation concerning its confidentiality; (5) an explanation of the competitive injury to the submitting person which would result from public disclosure; (6) a date after which such information might lose its confidential character; and (7) why disclosure of the information would be contrary to the public interest.

impacts on health and safety. In consultation with interested parties, DOE reviewed the list of residential furnace fan technologies according to these criteria. In the engineering analysis, DOE further considers the efficiency-enhancement technologies that it did not eliminate in the screening analysis.

1. *Technological feasibility.* DOE screens out technologies that are not incorporated in commercially-available products or working prototypes.

2. *Practicability to manufacture, install, and service.* If DOE determines that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market by the time of the compliance date of the standard, it will not consider that technology further.

3. *Adverse impacts on product or equipment utility or availability.* If DOE determines a technology has a significant adverse impact on the utility of the product for significant consumer subgroups or results in the unavailability of any covered product type with performance characteristics (including reliability), features, size, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not consider that technology further.

4. *Adverse impacts on health or safety.* If DOE determines that a technology will have significant adverse impacts on health or safety, it will not consider that technology further.

As described in section 2.2.2 above, DOE develops an initial list of technology options from the technologies identified as technologically feasible in the technology assessment. Then DOE, in consultation with interested parties, reviews the list to determine if these options are practicable to manufacture, install, and service, would adversely affect product utility or availability, or would have adverse impacts on health and safety. In the engineering analysis, DOE further considers technology options that it did not screen out in the screening analysis.

2.4 ENGINEERING ANALYSIS

The engineering analysis (chapter 5 of the TSD) establishes the relationship between manufacturing production cost and efficiency for each product class of residential furnace fans. This relationship serves as the basis for cost-benefit calculations in terms of individual consumers, manufacturers, and the Nation. Chapter 5 discusses the product classes analyzed, representative baseline units, incremental efficiency levels, methodology used to develop manufacturing production costs, cost-efficiency curves, impact of efficiency improvements on the considered products, and methodology used to extend the analysis to low-shipment-volume product classes. To determine the cost to consumers of furnace fans at various efficiency levels, DOE estimated manufacturing costs, markups in the distribution chain, installation costs, and maintenance costs.

In the engineering analysis pertaining to residential furnace fans, DOE evaluated a range of product efficiency levels and associated manufacturing costs. The purpose of the analysis is to estimate the incremental increase to selling prices that would result from increasing efficiency levels above the baseline model in each product class. The engineering analysis considers technologies not eliminated in the screening analysis. The LCC analysis uses the cost-efficiency relationships developed in the engineering analysis.

DOE typically structures its engineering analysis around one of three methodologies: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels without regard to the particular design options used to achieve such increases; and/or (3) the reverse-engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from tear-downs of the product being analyzed. In this rulemaking, DOE used an efficiency-level approach in conjunction with a design option approach to identify incremental improvements in efficiency for each product class. An efficiency level approach enabled DOE to identify incremental improvements in efficiency for efficiency-improving technologies that furnace fan manufactures already incorporate in commercially-available models. A design option approach enabled DOE to model incremental improvements in efficiency for technologies that are not commercially available in residential furnace fan applications. In combination with these approaches, DOE used a cost-assessment approach to determine the manufacturing production cost (MPC) at each efficiency level identified for analysis. This methodology estimates the incremental cost of increasing product efficiency.

The cost-assessment is based on reverse engineering data and was validated by manufacturer input. First, DOE used information gathered from manufacturers and/or data from the market and technology assessment to identify baseline units and representative models. DOE selected a set of units at the baseline and higher efficiencies for teardown analysis based on this information. The baseline unit serves as a starting point for the analysis, and the units selected for teardown analysis span a range of manufacturers, functionality, and efficiencies for commercially available products. DOE developed estimates of MPC for the each of the units selected for teardown by disassembling each unit, developing a bill of materials, and using this information as input for a manufacturing cost model.

2.5 MARKUPS ANALYSIS

DOE uses manufacturer-to-customer markups to convert the manufacturer selling price estimates from the engineering analysis to customer prices, which are then used in the LCC and PBP analysis and in the manufacturer impact analysis. Retail prices are necessary for the baseline efficiency level and all other efficiency levels under consideration. DOE estimates these retail prices by applying manufacturer-to-customer markups to the manufacturer selling price calculated as part of the engineering analysis.

Before developing markups, DOE defines key market participants and identifies distribution channels. Generally, the furnace distribution chain includes six market participants: (1) distributors; (2) dealers; (3) general contractors; (4) mechanical contractors; (5) installers; and (6) builders. For the markups analysis, DOE combined mechanical contractors, dealers, and installers in a single category labeled "mechanical contractors," because these terms are used interchangeably by the industry. Because builders serve the same function in the HVAC market as general contractors, DOE included builders in the “general contractors” category.

2.6 ENERGY USE ANALYSIS

The purpose of the energy use analysis is to determine the annual energy consumption of furnace fans in representative U.S. homes and to assess the energy savings potential of increased fan efficiency. DOE estimated the annual energy consumption of furnace fans at specified energy efficiency levels across a range of climate zones based on heating and cooling energy use data from Energy Information Administration’s (EIA) 2009 Residential Energy Consumption Survey (RECS 2009).[3] The annual energy consumption includes the electricity use by the fan in heating, cooling and constant circulation, and standby operating modes, as well as the energy use change in natural gas, liquid petroleum gas (LPG), electricity, or oil use for heat production as result of the change in the amount of useful heat provided to the conditioned space as a result of the furnace fan. The annual energy consumption of furnace fans is used in subsequent analyses, including the LCC and PBP analysis and the national impact analysis.

2.7 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

In determining whether an energy efficiency standard is economically justified, DOE considers the economic impact of potential standards on customers. The effect of new or amended standards on individual customers usually includes a reduction in operating cost and an increase in purchase cost. DOE uses the following two metrics to measure consumer impacts:

- LCC (life-cycle cost) is the total customer cost of an appliance or product, generally over the life of the appliance or product, including purchase and operating costs. The latter consist of maintenance, repair, and energy costs. Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.
- PBP (payback period) measures the amount of time it takes customers to recover the assumed higher purchase price of a more energy-efficient product through reduced operating costs.

DOE analyzed the net effect of potential furnace fan standards on consumers by calculating the LCC and PBP using the engineering performance data, the energy-use data, and the markups. Inputs to the LCC calculation include the installed cost to the consumer (purchase price plus installation cost), operating expenses (energy expenses, and, if applicable, repair costs and maintenance costs), the lifetime of the product or other defined period of analysis, and a discount rate. Inputs to the payback period calculation include the installed cost to the consumer and first-year operating costs.

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[3] U.S. Department of Energy: Energy Information Administration, *Residential Energy Consumption Survey: 2009 RECS Survey Data,* 2013. (Last accessed March, 2013.) <http://www.eia.gov/consumption/residential/data/2009/>

DOE performed the LCC and PBP analyses using a spreadsheet model combined with Crystal Ball (a commercially-available software program used to conduct stochastic analysis using Monte Carlo simulation and probability distributions) to account for uncertainty and variability among the input variables. Each Monte Carlo simulation consists of 10,000 LCC and PBP calculations. The model performs each calculation using input values that are either sampled from probability distributions and household samples or characterized with single point values. The analytical results include a distribution of 10,000 data points showing the range of LCC savings and PBPs for a given efficiency level relative to the base-case efficiency forecast.

2.8 SHIPMENTS ANALYSIS

DOE uses forecasts of product shipments to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE develops shipment forecasts based on an analysis of key market drivers for each product.

The vast majority of furnace fans are shipped installed in furnaces, so DOE estimated furnace fan shipments by projecting furnace shipments in three market segments: (1) replacements; (2) new housing; and (3) new owners in buildings that did not previously have a gas furnace.

To forecast furnace replacement shipments, DOE developed retirement functions for furnaces from the lifetime estimates and applied them to the existing products in the housing stock. The existing stock of products is tracked by vintage and developed from historical shipments data.

To forecast shipments to the new housing market, DOE utilized forecasted new housing construction and historic saturation rates of various furnace and cooling product types in new housing. DOE used *AEO 2012* for forecasts of new housing. Furnace saturation rates in new housing are provided by RECS 2009 and the U.S. Census Bureau's *Characteristics of New Housing*.[4]

2.9 NATIONAL IMPACT ANALYSIS

The NIA assesses the NES and the NPV from a national perspective of total consumer costs and savings expected to result from new or amended energy conservation standards at specific efficiency levels. DOE determined the NPV and NES for the standard levels considered for the furnace fan product classes analyzed. To make the analysis more accessible and transparent to all interested parties, DOE prepared a MS Excel spreadsheet that uses typical values (as opposed to probability distributions) as inputs. To assess the effect of input uncertainty on NES and NPV results, DOE has developed its spreadsheet model to conduct sensitivity analyses by running scenarios on specific input variables.

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[4] Available at: http://www.census.gov/const/www/charindex.html.

Analyzing impacts of potential energy conservation standards for residential furnace fans requires comparing projections of U.S. energy consumption with new or amended energy conservation standards against projections of energy consumption without the standards. The forecasts include projections of annual appliance shipments, the annual energy consumption of new appliances, and the purchase price of new appliances.

A key component of DOE's NIA analysis is the energy efficiencies forecasted over time for the base case (without new standards) and each of the standards cases. The forecasted efficiencies represent the annual shipment-weighted energy efficiency of the products under consideration during the forecast period (*i.e.*, from the assumed compliance date of a new standard to 30 years after compliance is required).

To estimate the impact that standards may have in the year compliance is required, DOE has generally used a "roll-up" scenario, a "shift" scenario, or both in its standards rulemakings. Under the "roll-up" scenario, DOE assumes: (1) product efficiencies in the base case that do not meet the standard level under consideration would "roll-up" to meet the new standard level; and (2) product efficiencies above the standard level under consideration would not be affected. Under the "shift" scenario, DOE retains the pattern of the base-case efficiency distribution but re-orients the distribution at and above the new minimum energy conservation standard. DOE concluded that the "roll-up" scenario is more reasonable for furnace fans.

2.9.1 National Energy Savings Analysis

The inputs for determining the national energy savings for each product analyzed are: (1) annual energy consumption per unit; (2) shipments; (3) product or equipment stock; (4) national energy consumption; and (5) site-to-source conversion factors. DOE calculated the national energy consumption by multiplying the number of units (stock) of each product (by vintage or age) by the unit energy consumption (also by vintage). Vintage represents the age of the product. DOE calculated annual NES based on the difference in national energy consumption for the base case (without new efficiency standards) and for each higher efficiency standard. DOE estimated energy consumption and savings based on site energy and converted the electricity consumption and savings to source (primary) energy using annual conversion factors derived from the most recent version of the National Energy Modeling System (NEMS). Cumulative energy savings are the sum of the NES for each year over the timeframe of the analysis.

DOE has historically presented NES in terms of primary energy savings. Per DOE's 2011 Statement of Policy for Adopting Full Fuel Cycle (FFC) Analyses, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses. DOE calculated FFC energy and emission impacts by applying conversion factors generated by DOE's developed model to the NEMS-based results used by DOE. For this NOPR analysis, DOE calculated FFC energy savings using a NEMS-based methodology described in appendix 10-B. Chapter 10 of this TSD presents both the primary NES and the FFC energy savings for the considered standard levels.

2.9.2 Net Present Value Analysis

The inputs for determining NPV are: (1) total annual installed cost; (2) total annual savings in operating costs; (3) a discount factor to calculate the present value of costs and savings; (4) present value of costs; and (5) present value of savings. DOE calculated net savings each year as the difference between the base case and each standards case in terms of total savings in operating costs versus total increases in installed costs. DOE calculated savings over the lifetime of products shipped in the forecast period. DOE calculated NPV as the difference between the present value of operating cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 and 7 percent to discount future costs and savings to present values.

For the NPV analysis, DOE calculates increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more-efficient products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expresses savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base efficiency case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

2.10 CONSUMER SUBGROUP ANALYSIS

A consumer subgroup comprises a subset of the population that may be affected disproportionately by new or revised energy conservation standards. The purpose of a subgroup analysis is to determine the extent of any such disproportional impacts. For this NOPR, DOE examined impacts on low-income consumers and senior-only households.

2.11 MANUFACTURER IMPACT ANALYSIS

The manufacturer impact analysis (MIA) estimates the financial impact of potential energy conservation standards on residential furnace fan manufacturers, as well as calculates the impact of such standards on employment and manufacturing capacity. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA relies on the government regulatory impact model (GRIM), an industry-cash-flow model customized for these industries. The GRIM inputs are information on the industry cost structure, shipments, and revenues. This includes information from many of the analyses described above, such as manufacturing costs and prices from the engineering analysis and shipments forecasts. The key GRIM output is the industry net present value (INPV). Different sets of input assumptions (scenarios) will produce different results. The qualitative part of the MIA addresses factors such as product characteristics, characteristics of particular firms, and market and product trends, and it also includes assessment of the impacts of standards on manufacturer subgroups. Chapter 12 of the TSD describes the MIA in further detail.

DOE conducts each MIA in three phases. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. DOE performed preliminary manufacturer interviews for the preliminary analysis as part of its Phase I activities. In Phase II, DOE prepares an industry cash-flow model and interview questionnaire to guide subsequent discussions. In Phase III, DOE interviews manufacturers and assesses the impacts of standards quantitatively and qualitatively. DOE assesses industry and subgroup cash flow and NPV using the GRIM. DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden based on manufacturer interview feedback and discussions.

2.12 EMISSIONS ANALYSIS

In the emissions analysis, DOE estimates the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg) from potential energy conservation standards for the considered products. In addition, DOE will estimate emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as "upstream" emissions. Together, these emissions account for the full-fuel-cycle (FFC). In accordance with DOE's FFC Statement of Policy (76 FR 51282 (Aug. 18, 2011)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE conducted the emissions analysis using emissions factors derived from data in EIA's *Annual Energy Outlook 2012*, supplemented by data from other sources. EIA prepares the Annual Energy Outlook using NEMS. Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remains in effect. See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR; also known as the Transport Rule). 76 FR 48208 (August 8, 2011). The *AEO 2012* NEMS assumes the implementation of the CSAPR.[5]

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[5] On December 30, 2011, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue administering CAIR (see *EME Homer City Generation v. EPA*, No. 11-1302, Slip Op. at *2 (D.C. Cir. Dec. 30, 2011)). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, No. 11-1302, 2012 WL 3570721 at *24 (D.C. Cir. Aug. 21, 2012). The court again ordered EPA to continue administering CAIR. AEO 2012 had been finalized prior to this decision, however. DOE

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the adoption of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2015, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for HCl as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2012* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (e.g., as a result of energy efficiency standards). Emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2015 and beyond.

CSAPR established a cap on NO_X emissions in eastern States and the District of Columbia. Energy conservation standards are expected to have little or no physical effect on these emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by CSAPR. Therefore, DOE estimates NO_X emissions reductions from potential standards in the States where emissions are not capped.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For this rulemaking, DOE estimated mercury emissions reductions using emissions factors based on *AEO 2012*, which incorporates the MATS.

With regard to the impact of standards on particulate matter (PM), the great majority of ambient PM associated with power plants is in the form of secondary sulfates, which are

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understands that CAIR and CSAPR are similar with respect to their effect on emissions impacts of energy efficiency standards.

produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO_2 and NO_x. The monetary benefits that DOE estimates for reductions in SO_2 and NO_x emissions resulting from standards are in fact primarily related to the health benefits of reduced indirect PM. Power plants may also emit particulates from the smoke stack. These direct, or primary, PM emissions can be difficult to quantify, and DOE is not able to quantify them at this time.

2.13 MONETIZATION OF EMISSIONS REDUCTION BENEFITS

DOE estimates the monetary benefits likely to result from the reduced emissions of CO_2 and NO_X that are expected to result from each of the standard levels considered.

In order to estimate the monetary value of benefits resulting from reduced emissions of CO_2 emissions, DOE uses the most current Social Cost of Carbon (SCC) values developed by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

At the time of this analysis, the most recent interagency estimates of the potential global benefits resulting from reduced CO_2 emissions in 2015, expressed in 2012$, were $12.9, $40.8, $62.2, and $117.0 per metric ton avoided.[6] For emission reductions that occur in later years, these values grow over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE gives preference to consideration of the global benefits of reducing CO_2 emissions. To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. For NO_x emissions, available estimates suggest a very wide

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[6] *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Technical Model Update for the Social Cost of Carbon (SCC)*. Interagency Working Group on Social Cost of Carbon, United States Government, Internal EPA Draft, February 13, 2013.

range of monetary values, ranging from $468 to $4,809 per ton in 2012$).[7] In accordance with U.S. Office of Management and Budget (OMB) guidance, DOE conducts two calculations of the monetary benefits derived using each of the economic values used for NO_x, one using a real discount rate of 3 percent and another using a real discount rate of 7 percent.[8]

DOE did not monetize estimates of SO_2 and Hg reduction in this rulemaking.

2.14 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards for furnace fans on the electric utility industry, DOE uses a variant of the EIA's National Energy Modeling System called NEMS-BT.[9] NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for the purpose of preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2035 and is available to the public.

The utility impact analysis is a comparison between the NEMS-BT model results for the base case and standard cases. The utility impact analysis reports the changes in installed capacity and generation that result from each standard level by plant type. DOE models the anticipated energy savings impacts from potential amended energy conservation standards using NEMS-BT to generate forecasts that deviate from the *AEO* Reference Case.

2.15 EMPLOYMENT IMPACT ANALYSIS

The adoption of energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered products. DOE evaluates direct employment impacts in the MIA.

Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to standards. DOE defines indirect employment impacts from standards as net jobs eliminated or created in the general economy as a result of increased spending driven by increased product prices and reduced spending on energy.

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[7] For additional information, refer to U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, Washington, DC.

[8] OMB, Circular A-4: Regulatory Analysis (Sept. 17, 2003).

[9] For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview 2000*, DOE/EIA-0581 (March 2000), available at: http://tonto.eia.doe.gov/ftproot/forecasting/05812000.pdf. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT. ("BT" refers to DOE's Building Technologies Program, under whose aegis this work is performed.)

The indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.[10] The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

2.16 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a regulatory impact analysis (RIA) pursuant to Executive Order 12866, "Regulatory Planning and Review," 58 FR 51735 (Oct. 4, 1993). The RIA evaluates potential non-regulatory policy alternatives, comparing the costs and benefits of each to those of the proposed standards. The RIA is subject to review under the Executive Order by the Office of Information and Regulatory Affairs (OIRA) at the Office of Management and Budget.

DOE recognizes that non-regulatory policy alternatives can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the potential future impacts of current initiatives.

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[10] Roop, J. M., M. J. Scott, and R. W. Schultz, ''ImSET: Impact of Sector Energy Technologies,'' PNNL–15273. Pacific Northwest National Laboratory (2005).

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter details the market and technology assessment that the U.S. Department of Energy (DOE) has carried out in support of the notice of proposed rulemaking for energy conservation standards for residential furnace fans. It consists of two sections: the market assessment and the technology assessment. The goal of the market assessment is to develop a qualitative and quantitative characterization of the residential furnace fan industry and market structures, based on publicly available information and data and information submitted by manufacturers and other interested parties. The key result of the technology assessment is a list of technologies that can improve the efficiency of residential furnace fans.

Because furnace fans are a component used in central residential heating, ventilation and air-conditioning (HVAC) products, DOE gathered relevant market information for those products. The majority of furnace fans covered in this rulemaking are components of residential furnaces. In addition, data are more extensive and readily available for residential furnaces compared to the other HVAC products that use furnace fans covered in this rulemaking. As a result, DOE relied heavily on residential furnace information to assess the furnace fan market. Little market data is available for electric furnaces/modular blowers. AHRI does not include information regarding electric furnaces/modular blowers in either its furnaces or central air conditioner (CAC) products databases.

3.1.1 Product Definitions and Scope of Coverage

EPCA gives DOE authority to consider and prescribe new energy conservation standards or energy use standards for electricity used for purposes of circulating air through duct work. (42 U.S.C. 6295(f)(4)(D)) Consequently, DOE proposes to define a “furnace fan” as any electrically-powered device used for the purposes of circulating air through duct work. DOE considers a typical furnace fan as consisting of a fan motor and its controls, an impeller, and a housing, all of which are components of an HVAC product that includes additional components, such as the cabinet.

DOE recognizes that a significant number of products may fit its broad interpretation of the statutory language. Figure 3.1.1 shows the various combinations of HVAC products that are used to construct typical residential HVAC systems. The boxes outlined in red represent HVAC products that include a furnace fan according to DOE's interpretation of the statutory language.

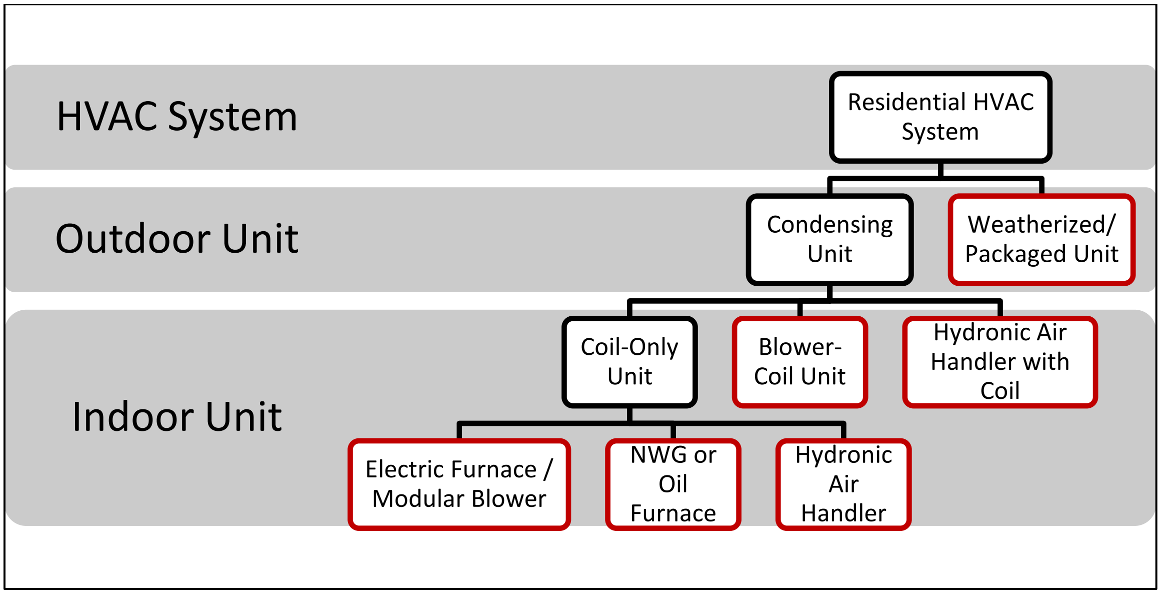

Figure 3.1.1: Residential HVAC System Component Combinations

At the present time, however, DOE is only proposing test procedures for those circulation fans that are used in residential furnaces and modular blowers. The following list describes the furnace fans which DOE proposes to address in this rulemaking.

- <u>Products addressed in this rulemaking</u>: furnace fans used in weatherized and non-weatherized gas furnaces, oil furnaces, electric furnaces, and modular blowers.
- <u>Products not addressed in this rulemaking</u>: furnace fans used in other products, such as split-system CAC and heat pump air handlers, through-the-wall air handlers, SDHV air handlers, ERVs, HRVs, draft inducer fans, exhaust fans, or hydronic air handlers.

DOE is not considering in this rulemaking fans used in any non-ducted products, such as whole-house ventilation systems without duct work, CAC condensing unit fans, room fans, and furnace draft inducer fans because these products do not circulate air through duct work. DOE did not prioritize furnace fans used in CAC blower-coil units, SDHV air handlers, and through-the-wall air handlers because the electrical energy consumption of these furnace fans is included in the SEER and HSPF metrics that DOE uses to regulate residential CAC and heat pump products.

The furnace fans considered in this rulemaking are used in HVAC products that can be broadly classified as either a furnace or central air conditioner (CAC). 77 FR 28677 Therefore, using the identified scope of coverage, the energy conservation standard will be broadly applicable to HVAC products with heating input capacities less than 225,000 Btu per hour and cooling capacities less than 65,000 Btu per hour. These specifications are consistent with the DOE definitions for residential "furnace" and "central air conditioner" (10 CFR 430.2).

Figure 3.1.2 depicts the market share by shipments of HVAC products that include furnace fans. The slices outlined in black represent products that are not addressed in this rulemaking. The proposed scope of coverage of this notice of proposed rulemaking includes 63% of HVAC products that include furnace fans.

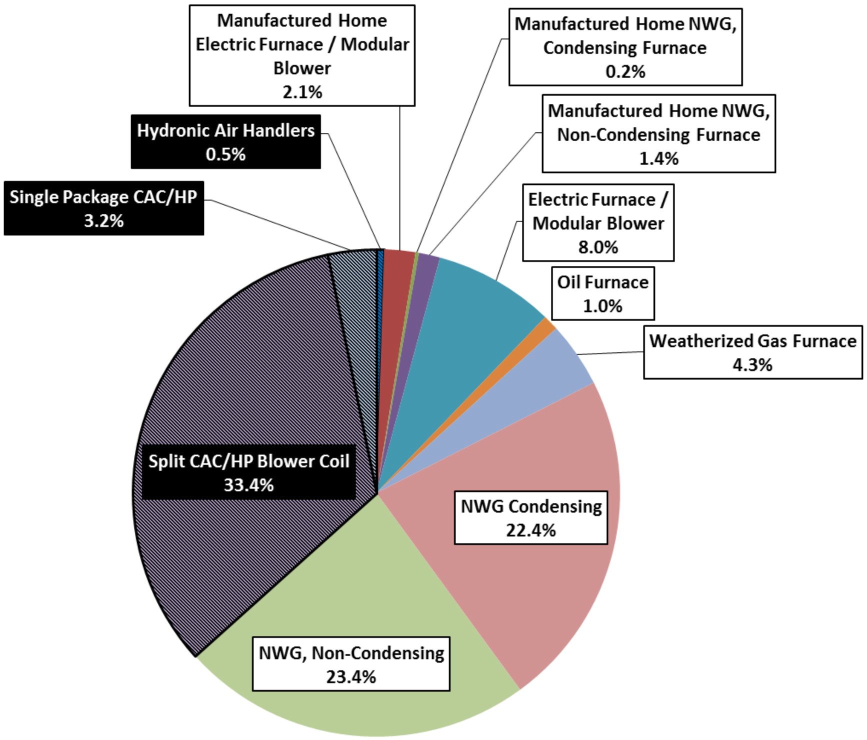

Figure 3.1.2: Market Share of Products Containing Furnace Fans (AHRI) [1]

According to Residential Energy Consumption Survey 2009 (RECS 2009) data, 60.8% (67.6 million) of U.S. homes have central warm-air furnaces.[2] Similar statistics are not available for modular blowers.[a] Electrical consumption attributable to residential furnace fans accounts for 0.13 quads/year in source energy, which is approximately 1 percent of total residential energy use.[3]

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[a] RECS 2009 provides data on the heating source but not the distribution system. Modular blowers generally are paired with a separate heating product such as an electric duct heater, or they may be installed in systems that do not provide heat.

3.1.2 Product Classes

DOE categorized furnace fans into product classes and intends to formulate a separate energy conservation standard for each in this rulemaking. EPCA specifies the criteria for product class separation, which include: (1) the type of energy consumed; (2) capacity; or (3) other performance-related features, such as those that provide utility to the consumer or other features deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 U.S.C. 6295(q)) DOE identified eight product classes differentiated by internal structure and application-specific design differences, presented in Table 3.1.1.

Table 3.1.1: Product Classes

Product Class
Non-weatherized, Non-condensing Gas Furnace Fan (NWG-NC)
Non-weatherized, Condensing Gas Furnace Fan (NWG-C)
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan (MH-NWG-NC)
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan (MH-NWG-C)
Manufactured Home Electric Furnace / Modular Blower Fan (MH-EF/MB)
Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC)
Weatherized Non-Condensing Gas Furnace Fan (WG-NC)
Electric Furnace / Modular Blower Fan (EF/MB)

Each product class title includes descriptors that indicate the internal structure and application-specific design changes of its included products. Weatherized and non-weatherized are descriptors that indicate whether the HVAC product is installed outdoors or indoors, respectively. Space and design constraints are different for products installed indoors compared to outdoors. These differing constraints will impact furnace fan performance differently because furnace fan energy consumption is dependent on clearances and airflow path. Weatherized products also include an internal evaporator coil, while non-weatherized products are not shipped with an evaporator coil but may be designed to be paired with one. The presence of an evaporator coil increases internal static pressure and impacts furnace fan performance and energy consumption.

Condensing refers to the presence of a secondary, condensing heat exchanger in addition to the primary combustion heat exchanger in certain furnaces. The presence of a secondary heat exchanger increases internal static pressure. As a result, DOE expects that furnace fans used in condensing units will consume more electrical energy than similar, non-condensing units.

Manufactured home products meet certain design requirements that allow them to be installed in manufactured homes. They require direct venting and are usually subject to more stringent space constraints. Manufactured home products are also typically installed without return air ducting. As a result, DOE expects that furnace fans used in manufactured home products will consume a different amount of electric energy than furnace fans installed in similar HVAC products that are designed for site-built applications.

Descriptors like gas, oil, or electric indicate the type of fuel that the HVAC product uses to produce heat, which determines the type and geometry of the primary heat exchanger used in the HVAC product. Each heat exchanger geometry could result in a unique internal static pressure and therefore, have differing impacts on furnace fan performance and energy consumption.

3.1.3 Test Procedures

Pursuant to EPCA, DOE must establish test procedures in order to allow for the development of energy conservation standards that will address the electrical consumption of furnace fan products. (42 U.S.C. 6295(o)(3)(A)) On May 15, 2012, DOE published a notice of proposed rulemaking for the test procedure in the Federal Register. 77 FR 28674 In this NOPR, DOE established methods to measure the performance of covered products and obtain a value of the proposed metric, referred to as the fan energy rating (FER). DOE held the test procedure NOPR public meeting on June 15, 2012 and the comment period closed on September 10, 2012. After receiving comments on the NOPR regarding the significant manufacturer burden associated with the proposed test procedure, DOE determined that an alternative test method should be developed. DOE published in the Federal Register a supplemental notice of proposed rulemaking (SNOPR) on April 2, 2013, which contained its revised test procedure proposal and an explanation of the changes intended to reduce burden. DOE proposed to adopt a modified version of the alternative test method recommended by AHRI and other furnace fan manufacturers to rate the electrical consumption of furnace fans. The AHRI-proposed method provides a framework for accurate and repeatable determinations of FER that is comparable to the test method previously proposed by DOE, but at a significantly reduced test burden.

To align the proposed furnace fan test procedure with the DOE test procedure for residential furnaces, DOE incorporated by reference specific provisions from American National Standards Institute (ANSI)/ American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 103 previously incorporated by reference in its furnace test procedure, which is codified in appendix N of subpart B of part 430 of the code of federal regulations (CFR). The specific provisions that DOE proposed to incorporate include definitions, test setup and equipment, and procedures for measuring combustion efficiency. In addition to these provisions, DOE proposed provisions for apparatuses and procedures for measuring throughput temperature, external static pressure, and electrical input power to the furnace fan. DOE also proposed calculations to derive FER based on the measured values. FER is the estimated annual electrical energy consumption of the furnace fan normalized by: (a) the estimated total number of annual fan operating hours (1,870), and (b) the airflow in the maximum airflow-control setting. The estimated annual electrical energy consumption, as proposed, is a weighted average of the fan electrical input power (in Watts) measured separately for multiple airflow-control settings at different external static pressures (ESPs). These ESPs are determined by a reference system that represents national average duct work system characteristics. The airflow-control settings contributing to the rating correspond to operation in the maximum setting (most often designated for cooling mode), heating mode, and constant-circulation mode. For the preliminary analysis, DOE divided the furnace fan heating operating hours used in the denominator by the heat capacity ratio for furnace fans paired with multi-stage heating controls. DOE finds that this overestimates the efficiency improvements attributable to multi-staging. For the NOPR, DOE used 1,870 furnace fan operating hours in the denominator for single-stage and multi-stage products to address this issue.

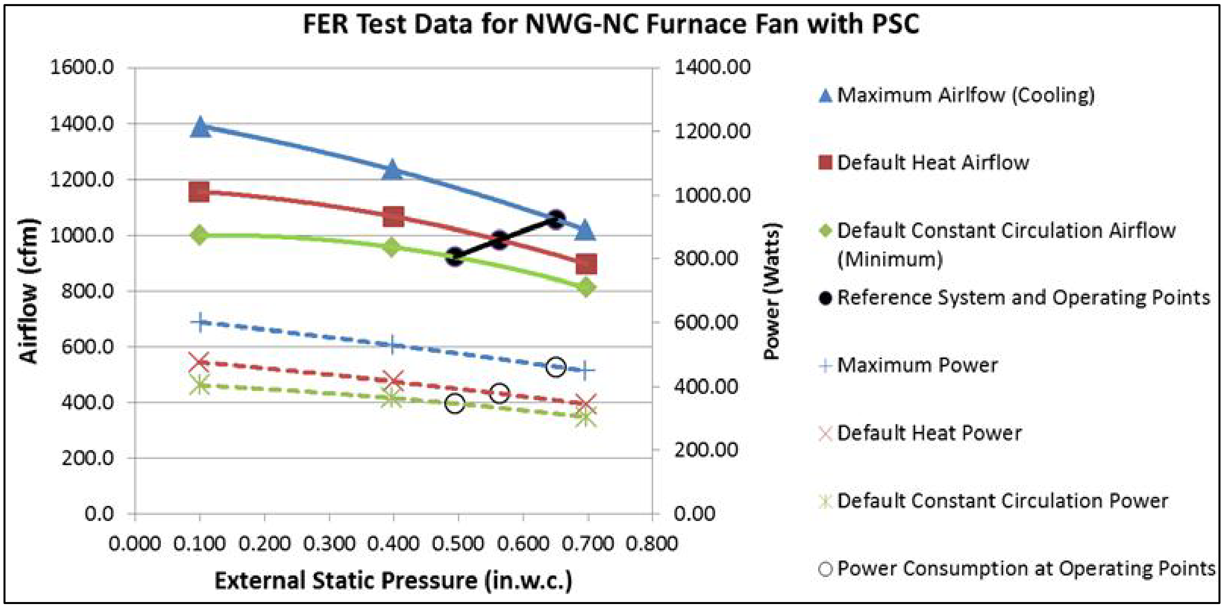

Figure 3.1.3: Example of Test Data Required to Derive FER for a 70KBtu/h, 3-ton, NWG-NC Furnace Fan with PSC Fan Motor

Table 3.1.2 presents the inputs that DOE proposes to use to calculate FER. These inputs include the power measured at the operating points identified in the example above and the proposed estimates for annual operating hours for each function, each of which is associated with an airflow-control setting (i.e. a furnace fan typically performs the cooling function in the maximum airflow-control setting). The example power measurements are multiplied by the estimated annual operating hours to calculate the estimated annual electrical energy consumption for each respective function. The sum of estimated annual consumption for each function represents the total estimated electrical energy consumption of the furnace fan.

Table 3.1.2: FER Inputs (Test Data from Above and Annual Operating Hour Assumptions)

Function	Power (W)	Annual Operating Hours	Annual Energy Consumption (Wh)
Cooling	450	640	288,000
Heating	375	830	311,250
Constant-Circulation	350	400	140,000
Standby	NA	NA	NA
Total		1,870	739,250

The equations that follow illustrate how DOE proposes that the inputs above be used to calculate the FER for the example furnace fan. As described previously, the estimated annual energy consumption is normalized by the total operating hours and airflow at the operating point in the maximum airflow-control setting.

$$FER = \frac{Annual\ Energy\ Consumption}{Airflow\ at\ Max\ Operating\ Point \times Total\ Annual\ Operating\ Hours} \times 1000$$

$$FER = \frac{739{,}250\ Wh}{1{,}050\ cfm \times 1{,}870\ hours} \times 1000 = \mathbf{376\ Watts\ per\ 1000\ cfm}$$

3.2 MARKET ASSESSMENT

The following market assessment identifies manufacturer trade associations, domestic and international manufacturers of residential furnace fans and their corresponding market shares, and regulatory and non-regulatory programs to incentivize or mandate improved efficiency. The market assessment also describes the cost structure for the residential furnace fan industry and summarizes relevant market performance data.

3.2.1 Trade Associations

DOE identified the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Air Movement and Control Association, Inc. (AMCA), Heating, Air-conditioning & Refrigeration Distributors International (HARDI), and Air Conditioning Contractors of America (ACCA) as the key trade groups that support, or have an interest in, the residential furnace fan industry.

AHRI is a national trade association of manufacturers of residential, commercial, and industrial appliances and equipment, components, and related products. AHRI was established in January of 2008 when the Air-Conditioning and Refrigeration Institute (ARI) merged with the Gas Appliance Manufacturers Association (GAMA). AHRI's member companies are responsible for over 90 percent of the residential and commercial air conditioning and space heating equipment sold in North America.[4] AHRI develops and publishes technical standards for residential and commercial equipment using rating criteria and procedures for measuring and certifying equipment performance. AHRI also participates in developing U.S. and international standards. AHRI administers the GAMA Certification program that tests and certifies the performance of gas- and oil-fired central furnaces that use single-phase electric current or DC and that have a heat input rate of less than 225,000 Btu/h. AHRI maintains the AHRI Directory of Certified Product Performance that lists all products that have been certified by the AHRI. AHRI also administers the ARI Performance Certified program that tests and certifies the performance of central air conditioners and heat pumps, as well as many other products manufactured by AHRI members. AHRI maintains the AHRI Directory of Certified Product Performance that lists all products that have been certified by the AHRI.[b] AHRI maintains

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[b] http://www.ahridirectory.org/ahridirectory/pages/home.aspx

certified performance directories for both air conditioners and heat pumps rated below 65,000 Btu/h. The AHRI directories subdivide these products based upon certain defining characteristics, such as single package or split system and coil only or coil and blower combinations.

AMCA is a not-for-profit international association of the world's manufacturers of related air system equipment - primarily, but not limited to: fans, louvers, dampers, air curtains, airflow measurement stations, acoustic attenuators, and other air system components for the industrial, commercial and residential markets. AMCA publications and standards are developed when sufficient interest has been expressed by AMCA members.

HARDI is an international trade organization that represents over 450 wholesale companies in the HVAC industry, including 17 international companies, plus over 300 manufacturing associates and nearly 140 manufacturer representatives. HARDI estimates that its members represent 80 percent of the dollar value of the HVACR products sold through distribution. In 2003, the organization was formed from the consolidation of the North American Heating, Refrigeration & Air Conditioning Wholesalers (NHRAW) and Air-conditioning & Refrigeration Wholesalers International (ARWI).[5]

ACCA is a nationwide trade organization that represents over 4,000 air conditioning contractors. ACCA supports the HVACR industry by bringing contractors together and providing technical, legal, and marketing resources. ACCA is "the only nationwide organization of, by and for the small businesses that design, install and maintain indoor environmental systems."[6]

3.2.2 Manufacturers and Market Share

DOE considers the manufacturer of the HVAC product in which the furnace fan is integrated to be the furnace fan manufacturer. DOE is aware that HVAC product manufacturers purchase many of the components in the furnace fan assembly, such as the motor and impeller, from separate component manufacturers. However, the HVAC product manufacturer determines the design requirements, selects the purchased components based on these requirements, and performs the final assembly and integration of the fan assembly into the HVAC product. For these reasons, DOE considers the HVAC product manufacturer to be the furnace fan manufacturer. As mentioned above, the majority of the furnace fans considered in this rulemaking are integrated in residential furnace fans. DOE focused its market assessment on furnace manufacturers as a result. Furnace fans integrated in modular blowers are also considered in this rulemaking. Modular blowers are typically manufactured by CAC and heat pump manufacturers. Consequently, DOE also gathered CAC/heat pump market information. DOE examined its database of residential furnaces, the AHRI directories for residential furnaces and CAC/heat pumps, HVAC product manufacturers' websites, and product catalogs to identify HVAC product manufacturers. All manufacturers listed in DOE's database for residential furnaces and CAC and heat pumps are shown in Table 3.2.1. HVAC product manufacturers may offer multiple brand names. DOE identified more than 50 brands under which HVAC products are manufactured and marketed.

Table 3.2.1: Manufacturers Whose Products are Included in DOE's Residential Furnaces and CAC/Heat Pumps Databases*

Manufacturer	Parent Company (if applicable)	NWG**	WG**	Oil	MH-NWG**	CAC & Heat Pumps
Aaon, Inc.	N/A		X			X
Adams Manufacturing Company***	N/A			X		
Airwell-Fedders North America, Inc.	Elco Holdings Ltd.	X				X
AllStyle Coil Company, L.P.***		X				X
Bard Manufacturing Company***	N/A		X	X		X
Boyertown Furnace Company***	N/A			X		
Carrier Corporation	United Technologies Corporation	X	X	X	X	X
Cold Point Corp.***	N/A					X
Crown Boiler Company***	Burnham Holdings, Inc.	X		X		
Dayton Electric Manufacturing Company	WW Grainger, Inc.					X
ECR International ***	N/A	X		X		
EFM Sales Company***	General Machine Corporation			X		
Espitech, LLC***	N/A					X
Friedrich Air Conditioning Co.	US Natural Resources, Inc.					X
Fujitsu General America, Inc.	Fujitsu General Group					X
GD Midea Commercial Air-Conditioning Equipment Co, Ltd.	N/A					X
Goodman Manufacturing Company	Goodman Global Group, Inc.	X	X			X
Haier America	Haier Group Company	X				X
Heat Controller, Inc. ***	N/A	X				X
Kerr Energy Systems***	Granby Industries Limited Partnership			X		
Lennox Industries, Inc.	Lennox International, Inc.	X	X	X		X
LG Electronics, Inc.	N/A					X
McQuay International	Daikin Industries, Ltd.					X
Mortex Manufactured Housing Products***	Mortex					X
Mitsubishi Electric and Electronics USA, Inc.	N/A					X
National Comfort Products***	N/A	X				X
Newmac Manufacturing, Inc.	William Newport Holdings Limited			X		

Manufacturer	Parent Company (if applicable)	NWG**	WG**	Oil	MH-NWG**	CAC & Heat Pumps
Nordyne, Inc.	Nortek, Inc.	X	X	X	X	X
Rheem Manufacturing Company	Paloma Group	X	X	X		X
Style Crest Products***	N/A					X
Thermo Products, LLC***	Burnham Holdings, Inc.	X		X	X	X
Trane Inc.	Ingersoll Rand	X	X	X	X	X
V-Aire	N/A					X
York International Corporation	Johnson Controls, Inc.	X	X	X	X	X
Weil-McLain	SPX Corporation	X				
Whirlpool Home Cooling and Heating	Whirlpool Corporation	X	X			X
Wolf Steel Ltd.	N/A	X				

* Airwell-Fedders North America, Inc., owned by Israeli parent company Elco Holdings Ltd., refers to Fedders, Eubank, and Airtemp products. Carrier Corporation is owned by United Technologies Corporation and refers to its subsidiaries: Carrier North America Home Comfort, Bryant Heating and Cooling Systems, International Comfort Products (ICP), Payne Heating and Cooling Systems, and Day & Night Heating and Cooling Products. Brands under ICP include: Heil, Tempstar, Arcoaire, Comfortmaker, Airquest, KeepRite, and Lincoln. ECR International includes Climate Energy, LLC and Oneida Royal. Goodman Manufacturing Company is a division of Goodman Global, Inc. and primarily markets its products under the Goodman and Amana brand names. Haier America is a subsidiary of the Haier Group Company. Heat Controller, Inc. manufactures and distributes the Comfort-Aire and Century brands. Lennox Industries, Inc., a subsidiary of Lennox International Inc., includes Lennox, Armstrong Air, AirEase, Concord, Ducane Air Conditioning and Heating, Allied Commercial, and Magic-Pak. Newmac Manufacturing, Inc. is a subsidiary of William Newport Holdings Limited. Nordyne, Inc. is a subsidiary of Nortek Incorporated and manufactures furnaces under the following brands: Broan, Elect-Aire, Frigidaire, Garrison, Gibson, Grandaire, Intertherm, Kelvinator, Maytag, Miller, Nutone, Philco, Tappan, Thermal Zone, and Westinghouse. Rheem Manufacturing Company refers to Rheem Manufacturing Company, Rheem Air Conditioning Division, Rheem Sales Company, Inc., and Ruud Air Conditioning Division. All Rheem and Ruud companies are subsidiaries of the Paloma Group. Crown Boiler Company and Thermo-Products, LLC are owned by Burnham Holdings, Inc. Trane Inc. manufactures products under the American Standard and Trane brand names. Ingersoll Rand owns Trane. York International Corporation refers to the following brands: Coleman, Evcon, Fraser-Johnston, Guardian, Luxaire, and York. York International Corp. is owned by Johnson Controls. Weil-McLain, which includes Williamson-Thermoflo, is a division of SPX Corporation. Whirlpool Home Cooling and Heating is a division of the Whirlpool Corporation. Wolf Steel Ltd. also does business as Napoleon Fireplaces.

** NWG is non-weatherized gas furnaces; WG is weatherized gas furnaces; and MH-NWG is mobile home, non-weatherized gas furnaces

*** Small businesses, according to http://www.sba.gov/

The domestic gas furnace market is almost entirely held by seven U.S. manufacturers: Carrier, Goodman, Lennox, Trane,[c] Rheem, York, and Nordyne.[7] Figure 3.2.1 shows the 2008

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[c] Prior to 2007, Trane was a subsidiary of American Standard Companies. On November 28, 2007 Trane separated from the two other branches of American Standard Companies. On June 5, 2008, Ingersoll Rand acquired Trane. For more information, visit www.trane.com/Corporate/About/history.asp.

market shares for residential furnace manufacturers as depicted in the September 2009 issue of *Appliance Magazine*.

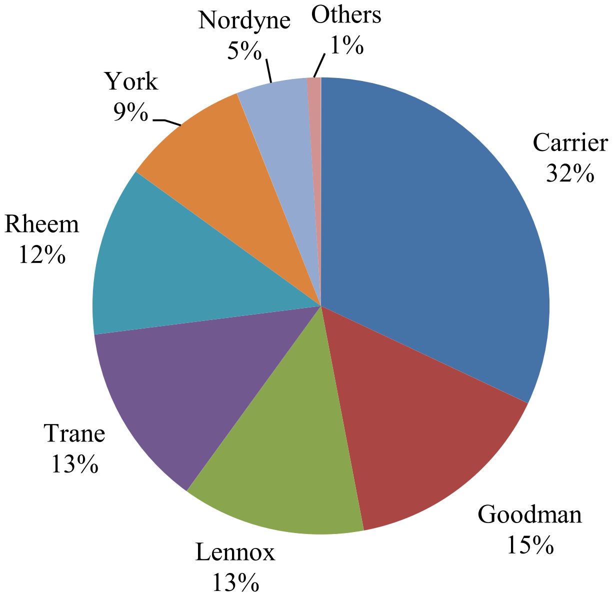

Figure 3.2.1: 2008 Market Shares for U.S. Manufacturers of Residential Gas Furnaces[8]

In contrast to the gas furnace market, the U.S. residential oil-fired furnace market is composed almost entirely of minor manufacturers. Minor manufacturers include Adams, Bard, Boyertown, Crown Boiler, ECR International, EFM, Kerr, and Newmac; major manufacturers include Thermo Pride and Lennox. Some of the major gas furnace manufacturers (including Carrier, Nordyne, Rheem, Trane, and York) also market oil-fired furnaces, although these furnaces are commonly rebranded units from another original equipment manufacturer (OEM). DOE estimated the market shares of oil-fired furnace manufacturers based on publicly available information and manufacturer feedback. Oil furnace manufacturers are shown in Table 3.2.1.

DOE examined AHRI's Directory of Certified Product Performance for residential central air conditioners to identify residential central air conditioner manufacturers that would integrate furnace fans in their products. Many of the previously identified furnace manufacturers fabricate central air conditioners as well. DOE identified 28 separate companies that manufacture and market air conditioner and coils. The manufacturers found in the AHRI Directories of Certified Product Performance for residential central air conditioners and heat pumps are listed in Table 3.2.1, along with their parent company in parentheses, if applicable.

Figure 3.2.2 displays the 2008 market shares for the residential central air conditioner market.

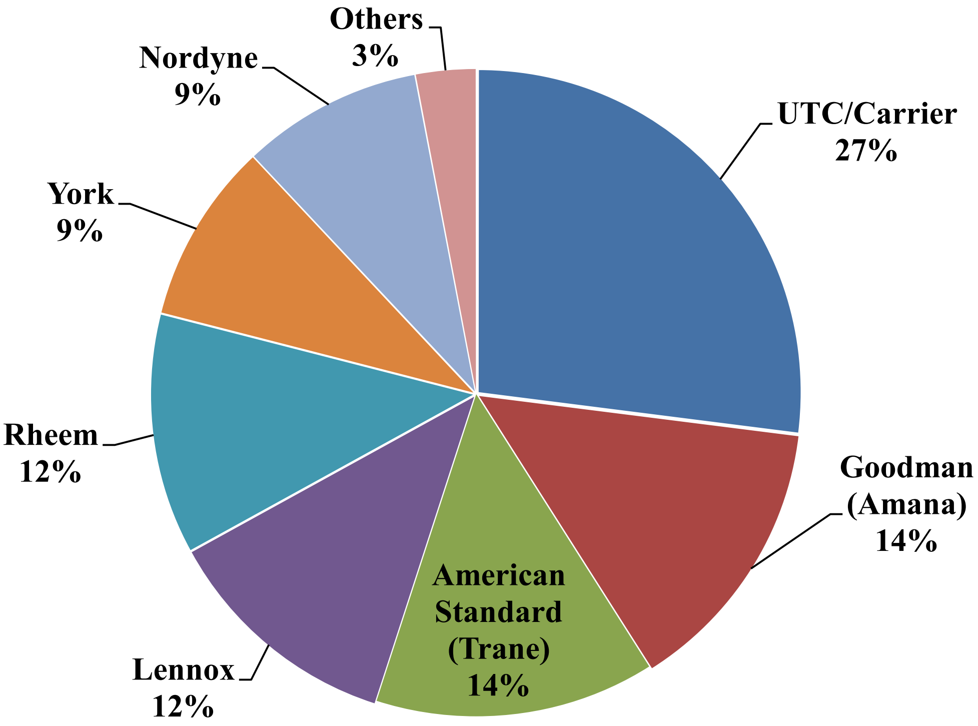

Figure 3.2.2: 2008 Market Shares for Unitary Air Conditioners[9]

Comparing Figure 3.2.1 to Figure 3.2.2, DOE recognizes that the seven largest residential gas furnace manufacturers control 97 percent of the central air conditioner market share (as of 2008). These seven manufacturers include Carrier, Goodman, Trane[d], Lennox, Rheem, York, and Nordyne.

3.2.2.1 Mergers and Acquisitions

A trend in the HVAC industry over the past decades has been the consolidation of major manufacturers. In the last ten years or so, the seven major manufacturers (*i.e.*, Goodman, Lennox, Carrier, York, Rheem, Nordyne, and Trane) have gone through various mergers and acquisitions, and have materialized as differentiated leaders in the HVAC industry. A brief summary of the recent history of each of the seven largest manufacturers is as follows:

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[d] Trane Inc. was acquired by American Standard Companies in 1984. On November 28, 2007 Trane separated from the two other branches of American Standard Companies. On June 5, 2008, Ingersoll Rand acquired Trane. For more information, visit www.trane.com/Corporate/About/history.asp.

- Goodman Global, Inc. was founded and purchased Janitrol in 1982. In 1997, Goodman acquired Amana, which was then sold to Maytag in 2001, and later acquired by Whirlpool when Whirlpool purchased Maytag in 2006. Goodman was acquired by Daikin Industries, Ltd. in 2012.
- Lennox Industries is a subsidiary of Lennox International, Inc., a holding company that was created in 1984. Lennox International acquired Armstrong Air Conditioning Inc. in 1988. In 1999, Lennox International completed an Initial Public Offering and became a public company.[10] Around this time, Lennox also acquired Service Experts and other equipment service companies.
- Carrier has been a wholly-owned subsidiary of United Technologies Corporation since 1979. In 1999, Carrier Corporation acquired International Comfort Products (ICP). [11]
- York Unitary Products Group and York International are subsidiaries of Johnson Controls, Inc, which purchased York in 2005. [12]
- Rheem is a privately held firm that was acquired by Paloma Industries of Japan in 1987. Paloma Industries also acquired Rheem Australia (Solahart) in 2002. [13]
- Nordyne is a subsidiary of the privately held Nortek, Inc. [14]

3.2.2.2 Small Businesses

DOE realizes that small businesses may be disproportionately affected by the promulgation of new energy conservation standards for residential furnace fans. The Small Business Administration (SBA) lists small business size standards for industries as they are described in the North American Industry Classification System (NAICS). The size standard for an industry establishes the largest size that a for-profit entity can be while still qualifying as a small business for Federal Government programs. These size standards are generally expressed in terms of the average annual receipts or the average employment of a firm. Residential furnace fan manufacturing is classified as a subset under NAICS 333415, "Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing." The size standard is 750 employees or fewer for this NAICS code.

DOE has identified small business residential furnace fan manufacturers, including small business parent companies, if applicable in Table 3.2.1. DOE is aware of 14 domestic small business manufacturers associated with the products anticipated to be affected by this rulemaking.

3.2.3 Distribution Channels

Two types of distribution channels describe how most furnace fan products pass from the manufacturer to the consumer. The first distribution channel applies to furnace fan products installed in replacement markets. In the replacement distribution channel, the manufacturer generally sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it and installs it for the consumer.[e] The second distribution channel applies to furnaces that are installed in new construction and, thus, includes an additional link in the chain—the general contractor. In the new construction distribution channel, the manufacturer sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it to a general contractor.

Figure 3.2.3 illustrates the two main distribution channels for most residential furnaces.

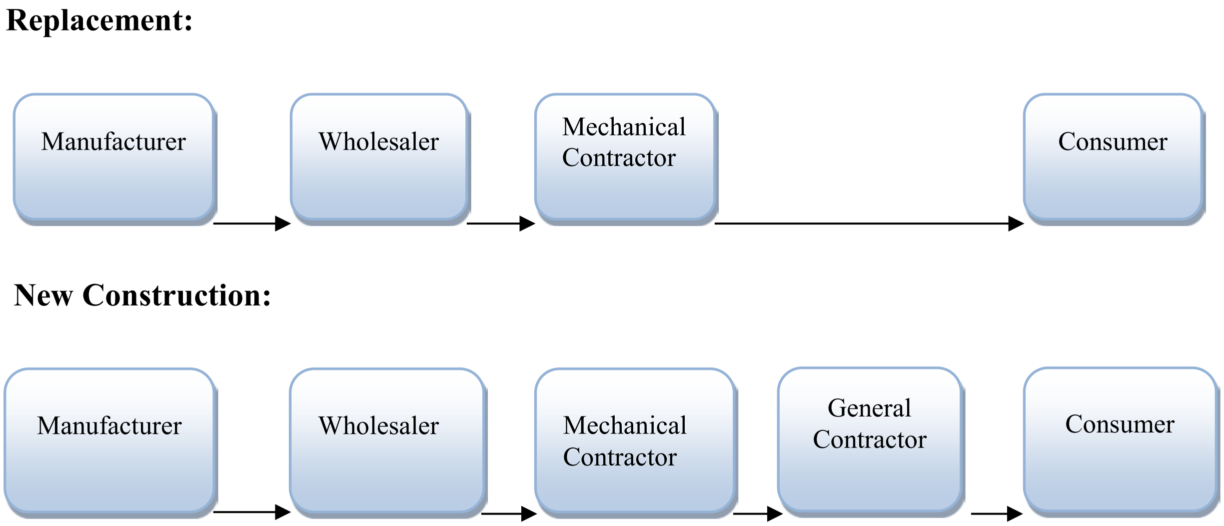

Figure 3.2.3: Distribution Channels for Residential Furnaces

The new construction market tends to be a low-cost, low-efficiency market, as the decision-makers are not the beneficiary of the system installed.

After installation, mechanical contractors typically perform additional lifecycle service on the system, including inspection, maintenance, and repair.

Manufactured home gas furnaces are sold as part of manufactured homes, so these furnaces have a specific distribution chain when purchased for the new construction market. The furnace manufacturer sells to the maker of the manufactured home, who installs the equipment in the home. The manufactured home manufacturer sells the home to a contractor, who in turns sells it to a homebuyer and provides installation services. The equipment manufacturer markup for manufactured home gas furnaces is identical to the manufacturer markup for other furnaces. For manufactured home furnaces purchased for the replacement market, the distribution channel should be the same as the replacement distribution channel for non-weatherized gas furnaces.

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[e] One major manufacturer uses one-step distribution (manufacturer to contractor) and is the only known exception. Several large retailers are trying to replace the wholesalers in the distribution chain, but most experts do not expect the trend to change the distribution chain significantly in the near term.

3.2.4 Regulatory Programs

The following section details current regulatory programs mandating energy conservation standards for residential furnace fans. Section 3.2.4.1 discusses other current Federal energy conservation standards that affect furnace fan products. Section 3.2.4.2 reviews standards in Canada that may impact the companies servicing the North American market.

3.2.4.1 Other Federal Energy Conservation Standards Affecting Furnace Fan Products

There are currently no Federal energy conservation standards for residential furnace fans, i.e. standards that specifically regulate energy use for circulating air through duct work. However, there are Federal energy conservation standards for other functions of the HVAC products that use furnace fans. Part A of Title III of EPCA addresses the energy conservation standards for consumer products other than automobiles, which include residential furnaces and residential central air conditioners and heat pumps. (42 U.S.C. 6291-6309) Federal energy conservation standards for residential furnaces are based on the annual fuel utilization efficiency (AFUE) metric, which measures the efficiency of the delivery of heat, but does not account for the electrical energy consumption of the furnace fans used in furnaces. Consequently, the electrical energy consumption of furnace fans used in furnaces is not subject to the current DOE standard for furnaces. (10 CFR part 430, subpart B, Appendix N) Federal energy conservation standards for CAC and heat pump products are based on the seasonal energy efficiency ratio (SEER) and heating seasonal performance factor (HSPF). Both of these metrics account for the electrical consumption of the furnace fan used in CAC products, some of which are included in the provisional scope of coverage of this rulemaking (modular blowers and weatherized furnaces). (10 CFR part 430, subpart B, Appendix M)

3.2.4.2 Canadian Energy Conservation Standards

In June 2010, the Office of Energy Efficiency (OEE) of Natural Resources Canada (NRCan) published a bulletin to announce that it would be proposing new electricity reporting requirements for air handlers used in central heating and cooling systems that are imported or shipped across provincial boundaries for sale or lease in Canada. NRCan proposed to base the new requirements on the test procedure and rating metric specified in Canadian Standard Association (CSA) C823-11 - Performance of air handlers in residential space conditioning systems. At the time of the June 2010 bulletin CSA C823 was still in development, but has since been finalized (2011). In the bulletin, NRCan identified HVAC products that would be subject to the proposed regulation: gas and oil furnaces, air handlers used in geothermal heat pumps and air-source heat pumps, and combination space and water heating (combo) air handlers.[f] NRCan announced in a more recent November 2011 bulletin that it intends initially to extend the proposed new electricity reporting requirements to air handlers used in residential gas furnaces

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[f] The June 2010 NRCan bulletin regarding proposed new electricity reporting requirements for air handlers used in central heating and cooling systems is accessible at the following website: http://oee.nrcan.gc.ca/regulations/bulletins/14551

only. NRCan added that it intends to expand the requirements to air handlers used in other heating and cooling systems in the future.[g]

3.2.5 Non-Regulatory Programs

DOE identified non-regulatory programs aimed at improving the energy efficiency of residential furnace fans. One such program is based on voluntary efficiency targets: the ENERGY STAR program. In addition, DOE identified rebate programs and Federal and State tax credits for residential purchasers of higher-efficiency central air conditioners and heat pumps, and reviewed Federal procurement specifications for these products as well.

3.2.5.1 ENERGY STAR

ENERGY STAR is a voluntary labeling program conducted by the U.S. Environmental Protection Agency (EPA) and DOE that identifies and promotes energy-efficient products. To qualify, a product must usually exceed federal minimum standards by a specified amount, or if no federal standard exists, it must meet minimum efficiency levels set by the program and/or exhibit selected energy saving features. ENERGY STAR creates minimum energy efficiency specifications for various products, including residential furnace fans used in residential furnaces and split system and single package air conditioners and heat pumps.

ENERGY STAR originally set specifications for residential gas and oil furnaces in 1995. ENERGY STAR specifications for furnaces did not include provisions for the electrical consumption of the furnace fan until the most recent revisions, Versions 3.0 and 4.0. In versions 3.0 and 4.0, the furnace fan electrical consumption must account for less than 2% of the total energy consumption (electrical and fuel) of the furnace. Version 3.0 took effect on February 1, 2012 and Version 4.0 took effect on February 1, 2013.[h] Furnace fan energy consumption for ENERGY STAR compliance is based on ENERGY STAR's "Interim Approach for Determining Furnace Fan Energy Use." This approach includes calculations based on measurements taken in accordance with ANSI/ASHRAE Standard 103–1993, which is incorporated by reference in the DOE furnace and boiler test procedure. (10 CFR part 430, subpart B, appendix N) ANSI/ASHRAE Standard 103–1993 specifies a steady state measurement of fan electrical consumption at an airflow at which a specified temperature rise and minimum ESP are achieved. The ESP specified by ENERGY STAR (from 0.18 in.w.c. to 0.33 in.w.c. in heating mode depending on input capacity) differs from the ESP proposed in the DOE furnace fan test procedure NOPR (0.3 in.w.c. to 0.65 in.w.c. in cooling mode depending on internal structure and application-specific design changes). Another important distinction between ENERGY STAR furnace fan specifications and the proposed DOE test procedure is that the "e" metric used to determine ENERGY STAR compliance is a function of Eae, which includes the electrical consumption of other furnace components besides the circulation fan (e.g. the inducer fan and gas valve).

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[g] The November 2011 NRCan bulletin regarding proposed new electricity reporting requirements for air handlers used in central heating and cooling systems is accessible at the following website: http://oee.nrcan.gc.ca/regulations/bulletins/17839#Air_Handlers

[h] ENERGY STAR specifications for residential furnaces are accessible at the following link: http://www.energystar.gov/index.cfm?c=revisions.furnace_spec

ENERGY STAR originally set specifications for central air conditioners and heat pumps in 1995, followed by revisions in 2002, 2006, and 2009. The current (2009) ENERGY STAR levels for CAC and heat pump products are shown in Table 3.2.2.

Table 3.2.2: ENERGY STAR Specifications for Central Air Conditioner Products (2009)

Product	ENERGY STAR Specification
Central Air Conditioners	>=14.5 SEER/ >=12 EER* for split systems >=14 SEER/ >=11 EER* for single package equipment including gas/electric package units

* Energy efficiency ratio (EER) means the ratio of the average rate of space cooling delivered to the average rate of electrical energy consumed by the air conditioner or heat pump. These rate quantities must be determined from a single test or, if derived via interpolation, must be tied to a single set of operating conditions. EER is expressed in units of Btu/h/W. (10 CFR part 430, subpart B, appendix M)

3.2.5.2 Consumer Rebate Programs

In addition to the Federal and State tax credits available for purchasers of residential furnaces, central air conditioners, and heat pumps many States and local utility companies offer rebates for higher efficiency products, typically for existing home retrofits only. DOE maintains a database of such rebates, called the Database of State Incentives for Renewables & Efficiency (DSIRE), in addition to information on other state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. For more information on individual rebate programs, please visit the DSIRE website at www.dsireusa.org.

3.2.5.3 Federal Tax Credits

A Federal tax credit provides consumers a credit towards their Federal income tax if they purchased a furnace that uses a qualifying main circulating fan. This tax credit applies only to products being installed in existing homes, not new housing construction. Consumers that purchase a furnace with an "advanced main air circulating fan", which consumes less than 2% of the furnace's total energy consumption (electrical and fuel, based on the same measurement for the ENERGY STAR specification), are eligible to receive a $50 tax credit.[i]

Manufacturers stated that residential tax credits, weatherization programs, utility rebates, and manufacturer consumer rebates all drive the consumer towards purchasing high efficiency equipment. Manufacturers stated that they are selling more high efficiency products such as air handlers and BPM motors to meet these tax credits and rebate programs.

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[i] Details regarding the 2013 Federal tax credit for furnace fans is available at the following link: http://www.energystar.gov/index.cfm?c=tax_credits.tx_index

3.2.5.4 State Tax Credits

DOE also identified two states that have tax credits for furnace fans used in residential furnaces: Oregon and Kentucky.

Table 3.2.3: State Tax Credits for Residential Gas Furnaces[15]

State	Furnace Fan Requirement*	Available Tax Credit
Kentucky	< 2% total furnace energy consumption	$250

*Fraction of total furnace energy consumption calculated according to the DOE test procedure for furnaces codified in 10 CFR part 430, subpart B, Appendix N.

Kentucky offers a 30 percent state income tax credit beginning in 2009 for taxpayers who install certain energy efficiency measures on their principal residence or residential rental property. These energy efficiency measures include “Qualified Energy Property Installation,” which includes advanced main air circulating fans. Equipment must meet the efficiency guidelines specified in the Federal tax credit for residential energy property (see section 3.2.5.3). The total annual tax credit for this equipment may not exceed $250. These credits apply to equipment purchased in taxable years 2009 to 2015 and may be carried forward for one year.[16]

3.2.5.5 FEMP Procurement Guidelines

DOE reviewed the Federal Energy Management Program (FEMP) procurement guidelines for Federal government equipment purchasing. The mission of DOE’s FEMP[j] is “to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites.”[17] FEMP helps Federal buyers identify and purchase energy-efficient equipment.

FEMP designates standards for residential gas furnaces purchased by the Federal government. The designated FEMP gas furnace standard level is the ENERGY STAR level, which includes requirements for the main circulating air fan (i.e., furnace fan).[18]

3.2.6 Industry Cost Structure

DOE is unaware of any publicly available industry-wide cost data specific to only manufacturers of residential furnace fans. DOE examined the North American Industry Classification System (NAICS) codes for small business sizes and determined that furnace fan manufacturing is classified as a subset under NAICS code 333415, Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing.[19] Therefore, DOE presents the data below as a broader industry proxy for the furnace fan industry, which, in combination with information gained in interviews, inform DOE’s analysis of the industry cost structure.

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[j] For more information, please visit www.eere.energy.gov/femp.

DOE obtained the below data from the U.S. Census Bureau's Annual Survey of Manufacturers, Statistics for Industry Groups and Industries from 2002 to 2011.[20]

Table 3.2.4 presents the industry employment levels and earnings from 2002 to 2011. The statistics illustrate approximately a 22.9% decrease in production workers and a 22.4% percent decrease in overall number of employees from 2002 to 2011. This may be due to the decrease in shipments from 2005 to 2011, as seen in Figure 3.2.4.

Table 3.2.4: Employment and Earnings for the Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing

Industry Year	**Production Workers**	**All Employees**	**Annual Payroll *$1000s***
2002	80,417	108,274	3,815,747
2003	77,488	104,668	3,776,417
2004	73,106	99,035	3,691,029
2005	76,011	102,354	3,942,808
2006	74,909	98,097	4,019,813
2007	74,728	101,485	4,034,043
2008	70,787	96,610	4,020,656
2009	60,041	86,454	3,666,278
2010	61,380	83,054	3,773,498
2011	62,009	83,969	3,763,853

Source: U.S. Census Bureau. *Annual Survey of Manufacturers*, 2002-2011.

Table 3.2.5 presents the costs of materials and industry payroll as a percentage of shipment value of the entire HVAC product from 2002 to 2011.[k] Note that the shipment values presented later in Table 3.2.7 are only attributable to the furnace fan components of the HVAC products (i.e., 10% of the total). From 2002 to 2011, the cost of materials as a percentage of shipment value has increased 11.6%, the cost of payroll for production workers as a percentage of shipment value has decreased 23.4%, and the cost of total payroll as a percentage of shipment value has decreased 19.5%.

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[k] Includes just manufacturing cost, and not distribution.

Table 3.2.5: Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing Industry Material and Payroll Costs

Year	Cost of Materials *% of shipment value*	Cost of Payroll for Production Workers *% of shipment value*	Cost of Total Payroll *% of shipment value*
2002	49.36	9.83	15.85
2003	50.59	9.53	15.39
2004	51.14	8.80	14.22
2005	53.74	8.45	13.66
2006	53.17	8.87	13.80
2007	55.59	8.17	13.43
2008	54.56	8.10	13.46
2009	54.14	7.89	14.05
2010	52.59	7.79	13.44
2011	55.11	7.53	12.76

Source: U.S. Census Bureau. *Annual Survey of Manufacturers*, 2002-2011.

3.2.7 Product Lifetime

The lifetime of residential furnace fans can vary greatly depending on how often the system is used, which is dependent upon the climate of the region, where the product is installed, and the personal preferences of the consumer. The lifetime is also dependent on how regularly the HVAC product is maintained and serviced. DOE expects that the lifetime of the furnace fan is equivalent to the lifetime of the HVAC product in which it is incorporated. DOE modeled furnace fan lifetime based on the distribution of furnace lifetimes developed for the recent HVAC rulemaking. DOE assumed that the lifetime is the same for fans at different efficiency levels. Generally, most sources estimate the lifetime of furnaces to be between 10 and 30 years. Appliance Magazine publishes an Annual Portrait of the U.S. Appliance Industry, [21] in which it estimates low, high, and average lifetimes for a range of home appliances, including gas and oil furnaces, based on input from appliance experts and many additional sources. Table 3.2.6 shows the average lifetime for each product class. Additional information about furnace lifetimes is contained in the Life-Cycle Cost and Payback Period Analysis chapter (Chapter 8) of this TSD.

Table 3.2.6: Average Lifetime for Furnace Fans

Product Class	Average *years*

Non-weatherized, Non-condensing Gas Furnace Fan (NWG-NC)	26.7
Non-weatherized, Condensing Gas Furnace Fan (NWG-C)	26.7
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan (MH-NWG-NC)	26.7
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan (MH-NWG-C)	26.7
Manufactured Home Electric Furnace / Modular Blower Fan (MH-EF/MB)	26.7
Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC)	29.7
Weatherized Non-Condensing Gas Furnace Fan (WG-NC)	26.7
Electric Furnace / Modular Blower Fan (EF/MB)	26.7

3.2.8 Historical Shipments and Efficiencies

3.2.8.1 Historical Shipments

Information about annual furnace fan shipment trends allows DOE to estimate the impacts of energy conservation standards on the residential furnace fan industry. DOE has examined unit shipments and value of shipments using publicly available data from the U.S. Census Bureau's Annual Survey of Manufacturers (ASM) and Current Industrial Reports (CIR) and estimates from AHRI and *Appliance Magazine*.

AHRI provides estimates of annual unit shipments for various appliances. The data, however, do not distinguish between shipments for new construction and replacement. Figure 3.2.4 presents annual shipments of furnaces from 1990 to 2012 reported by AHRI.[22]

From the data, it is apparent that gas furnaces comprise the vast majority of the residential furnace fan product industry. Shipments of gas furnaces grew steadily until 2005, then plunged in the subsequent four years to 30 percent below the unit shipments at the beginning of the decade. This trend mirrors that of new housing starts over the same time period, indicating that gas furnace shipments may be driven, in part, by the new construction market. Shipments of oil-fired furnaces remained relatively steady over the first part of the decade, before dropping by more than half between 2005 and 2009.

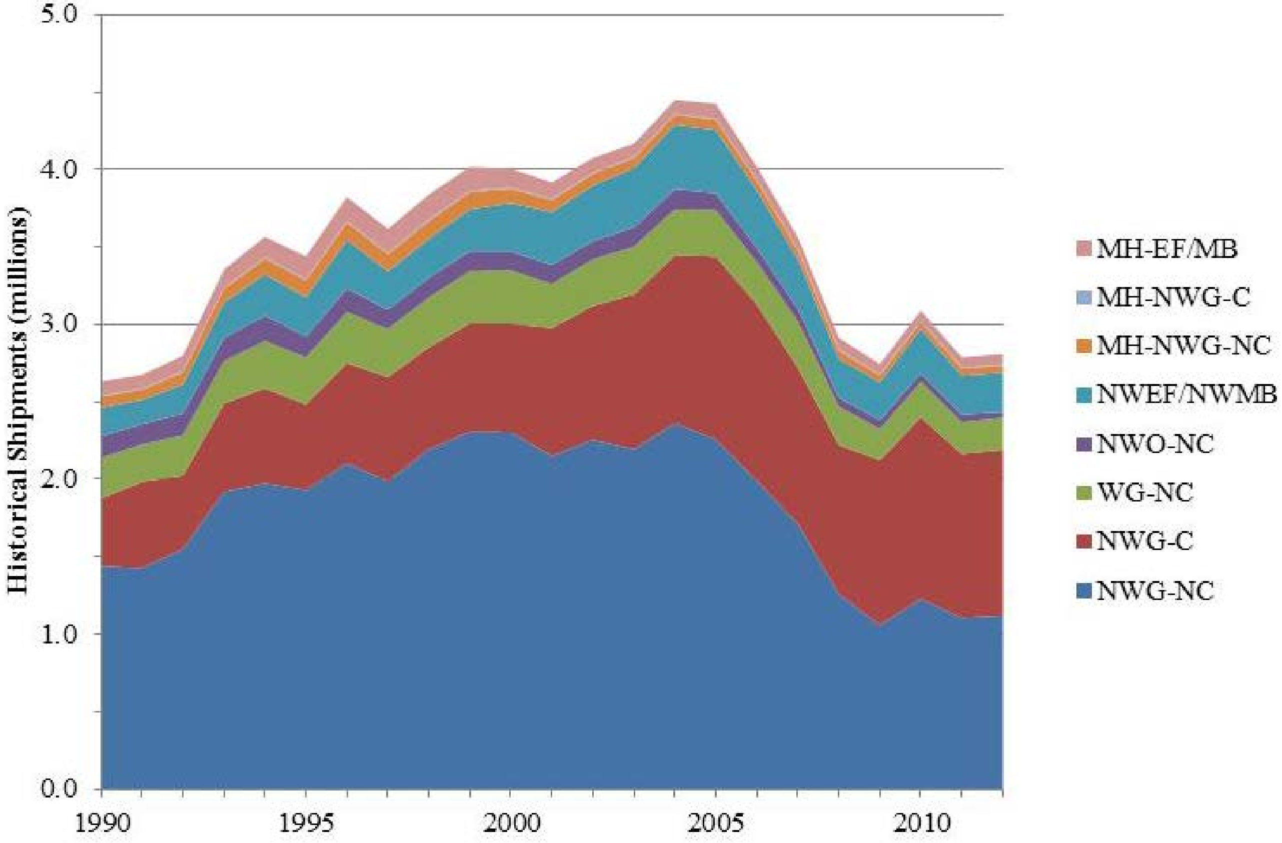

Figure 3.2.4: Residential Furnace Fan Industry Shipments (Domestic and Imported)

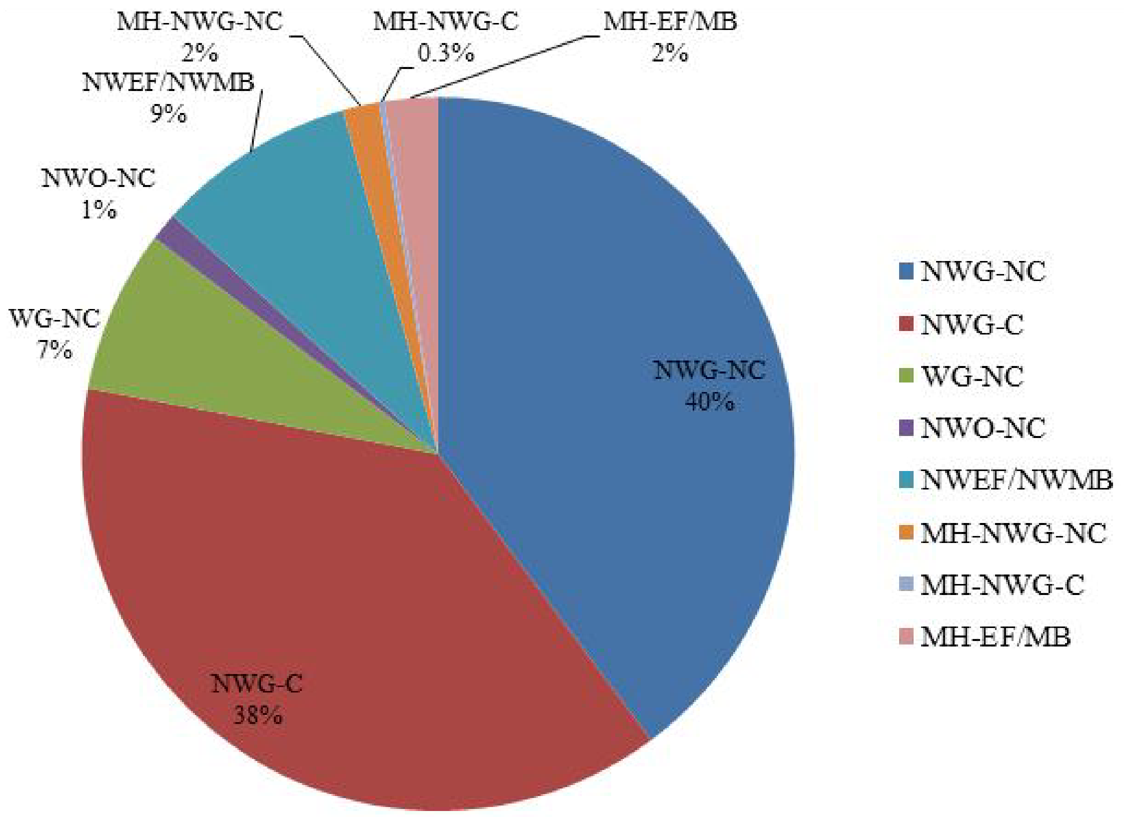

Figure 3.2.5: Residential Furnace Fan Industry Share 2012 (Domestic and Imported)

3.2.8.2 Value of Shipments

Table 3.2.7 provides the value of shipments attributable to the furnace fan components of HVAC products for the residential furnace fan industry from 2006 to 2010 using the U.S. Census Bureau CIR.[23] The product description in the CIR is “warm air furnaces, including duct furnaces and humidifiers, and electric comfort heating.” The values of shipments reported in the CIR represent the total value of the HVAC products in which the furnace fans are incorporated. Based on its manufacturing cost modeling, DOE estimated that furnace fans account for 5-15% of the total furnace cost, depending on the type of motor and the type of furnace. Accordingly, DOE estimates that furnace fan shipment values represent 10% of the total furnace shipment values reported in the CIR. The CIR expresses all dollar values in current dollars (*e.g.*, 2006 data are expressed in 2006$). Using the gross domestic product (GDP) deflator, DOE converted each year’s shipment values to 2012$; 2010 was the last year included in the CIR data set.

Table 3.2.7: Value of Residential Furnace Fan Shipments by Year[24]

Year	**Value of Shipments** ***$, millions***	**Value of Shipments in 2012$** ***$, millions***
2010	200	209
2009	183	189
2008	183	196
2007	209	242
2006	221	263

3.2.8.3 Saturation in U.S. Households

Stock saturation refers to the percentage of the housing stock equipped with a given product or exhibiting a certain feature. According to RECS 2009 data, 60.8% (67.6 million) of U.S. homes have central warm-air furnaces.[25] Of these furnaces, 44.7 million are gas furnaces, 16.0 are electric furnaces, 2.8 million are oil-fired furnaces, and 4.1 million are liquid petroleum gas (LPG) furnaces. Similar statistics for modular blowers is not available.

3.2.9 Market Performance Data

DOE examined the AHRI,[26] the CEC,[27] and ENERGY STAR[28] directories and other publicly available data from furnace and CAC manufacturers’ catalogs and websites to develop an understanding of the industry and its market. These databases contain information such as manufacturer name, model number, input rating, and efficiency. DOE’s goal in researching HVAC products was to better understand the furnace fan market and product distribution. DOE excluded from its analysis any products that were manufactured for Canada or export only and any products in the AHRI Directory of Certified Product Performance that were not labeled as “active”.

3.2.9.1 Airflow Data

DOE recognizes that HVAC products with a given heat input capacity can have varying cooling capacities. DOE also recognizes that cooling capacity determines the nominal maximum airflow capacity of the HVAC product. Typically, HVAC products are designed to provide between 350 and 450 cfm/ton. An HVAC product with a cooling capacity of 3 tons will have a nominal maximum airflow capacity of approximately 1200 cfm, for example. The marked cells in Table 3.2.8 reflect the input capacity and nominal maximum airflow for the most common input and nominal maximum airflow capacities of furnace models in the June 2010 AHRI Directory.[25]

Table 3.2.8: Common Furnace Input Capacity and Airflow Combinations

Airflow Sizing in cfm *tons*	**Input Capacity** *kBtu/h*											
	45	50	60	70	75	80	90	100	115	120	125	140
800 cfm (2 tons)	x	x	x									
1,200 cfm (3 tons)	x	x	x	x	x	x	x	x				
1,600 cfm (4 tons)				x	x	x	x	x	x	x	x	
2,000 cfm (5 tons)							x	x	x	x	x	x

Based on historical shipment information of residential central air conditioners by capacity, DOE constructed the airflow capacity percentiles table for air conditioners. (See Table 3.2.9). The Department restricted the airflow sizes to two, three, four, or five tons—the equivalent of 800, 1,200, 1,600, or 2,000 cfm at 0.5 in. w.c. static pressure. Since there are no available shipment data on the airflow capacity of furnaces, the Department used the airflow capacity of residential central air conditioners as a proxy.

Table 3.2.9: Expected Distribution of Airflow for Furnace Fans

Airflow Rating *cfm*	**2010 AHRI Shipments** *%*	**Cumulative Fraction** *%*
800	37.3	37.3
1200	35.0	72.3
1600	16.8	89.0
2000	11.0	100.0

DOE performed capacity-weighted calculations in the Engineering Analysis (chapter 5) using the shipment percentages presented in Table 3.2.9.

3.2.9.2 Energy Metric

DOE does not have an existing standard for residential furnace fans. Consequently, values of the proposed rating metric, FER, are unavailable for evaluating market-wide trends in energy performance. A related energy metric, the average annual auxiliary electrical energy consumption (Eae), is widely available for residential furnace models, however. Eae includes the electrical energy consumption of the circulation fan, but also includes the electrical consumption of other components of the furnace, such as the induced draft blower. (10 CFR part 430, subpart B, Appendix N) DOE used Eae as a proxy for FER to evaluate market-wide energy performance of furnace fans. DOE characterized the distribution of Eae for commercially-available furnaces by dividing the products listed in the AHRI database into bins based on their Eae. DOE determined bin sizes based on the range of Eae within each key product class. The bin labels represent the bin ranges' upper bounds (i.e., the 500 kWh Eae bin includes products with Eae values from 401 kWh to 500 kWh). As shown in Table 3.2.8 and Table 3.2.9, a large number of furnace fan basic models fall in the 70-80 kBtu/hr input capacity range. Thus, DOE used the Eae of models in this range to evaluate market-wide furnace fan energy performance. DOE recognizes that furnace fan energy consumption is proportional to capacity. DOE accounts for this relationship in its analysis, as described in detail in Chapter 5 of this TSD. Figure 3.2.6 shows a histogram of the energy data for products having 70-80 kBtu/hr input capacity..

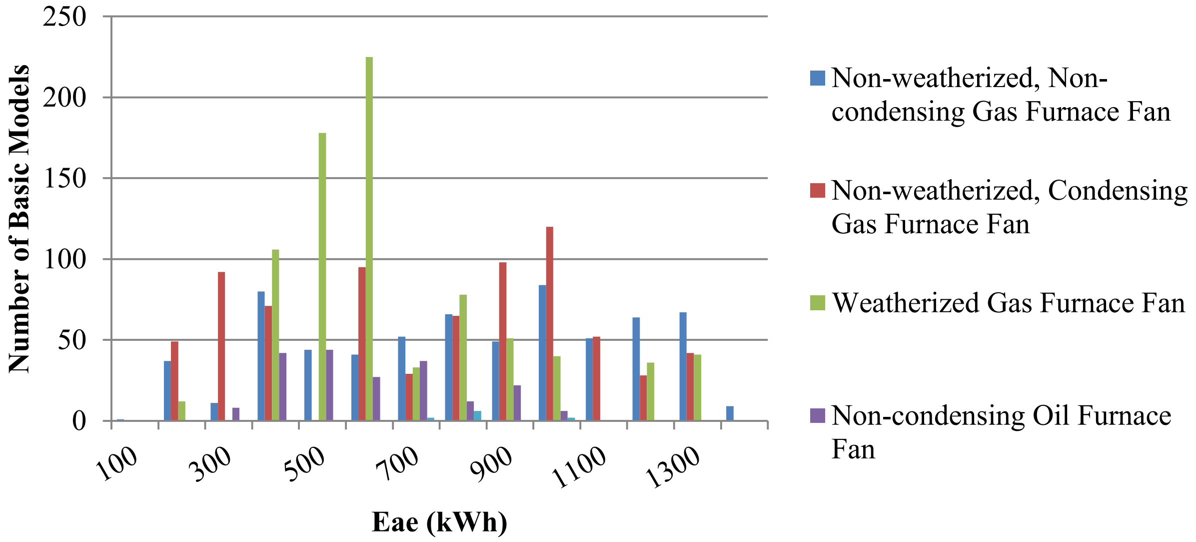

Figure 3.2.6: Distribution of 70-80 kBtu/hr Input Capacity Furnace Models by Eae[l]

As Figure 3.2.6 shows, energy performance differs across the major product classes at similar capacities. DOE did not include modular blowers and hydronic air handlers in these assessments because Eae values are not generated for these products. DOE expects that the energy consumption of these products will also be different at a given capacity due to differences in application and internal structure.

3.2.9.3 Motor Data

DOE also examined the distribution of motor types in residential furnaces. The two motor types are PSC and brushless permanent magnet (BPM).[m] DOE further divided BPM motors into

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[l] Source: AHRI database

[m] See Section 3.3.2.4 for motor type descriptions

constant-torque BPMs (commonly referred to as X13) and constant-airflow BPMs (commonly referred to as ECM). DOE used the AHRI database to develop motor distributions, when motor information was available. Figure 3.2.7 through Figure 3.2.10 show these distributions for a subset of key product classes covered in this rulemaking.

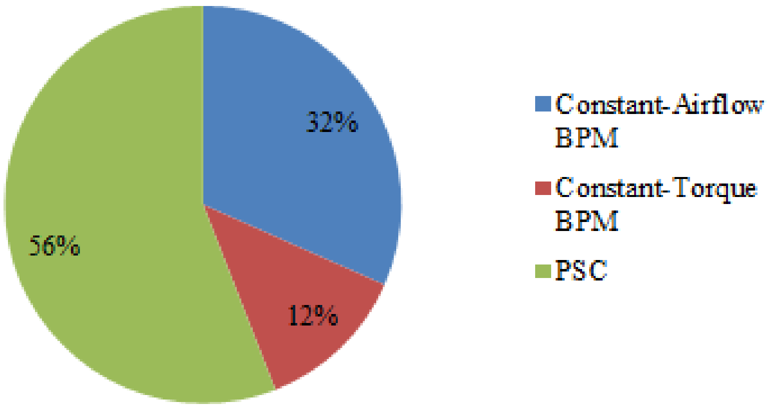

Figure 3.2.7: Motor Distribution for Non-Weatherized Gas Furnaces

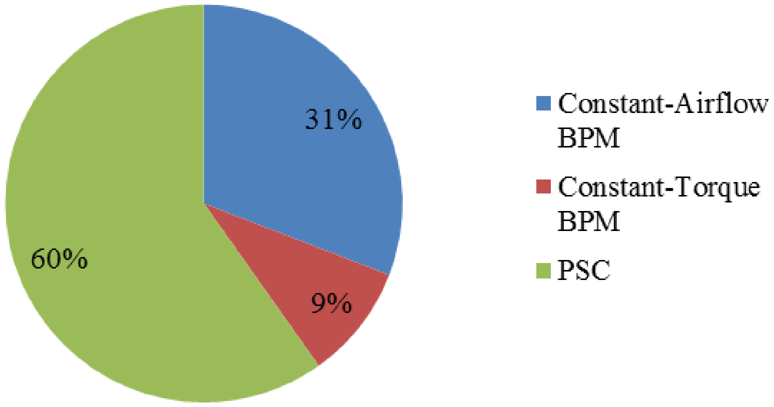

Figure 3.2.8: Motor Distribution for Weatherized Gas Furnaces

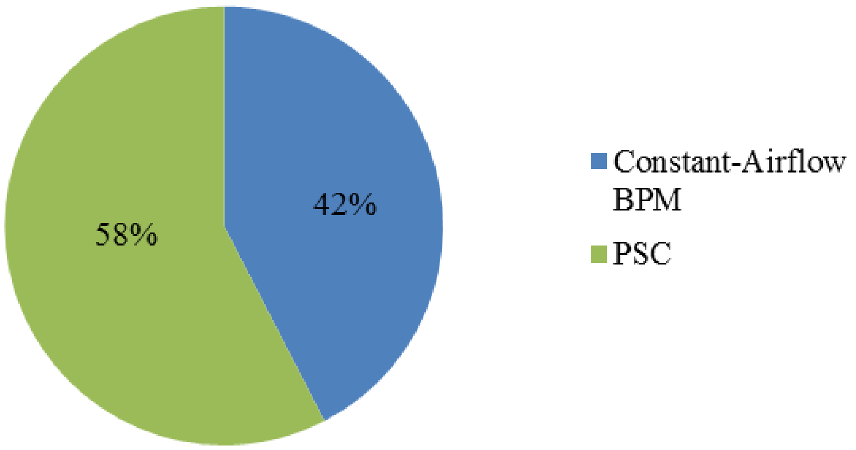

Figure 3.2.9: Motor Distribution for Oil Furnaces

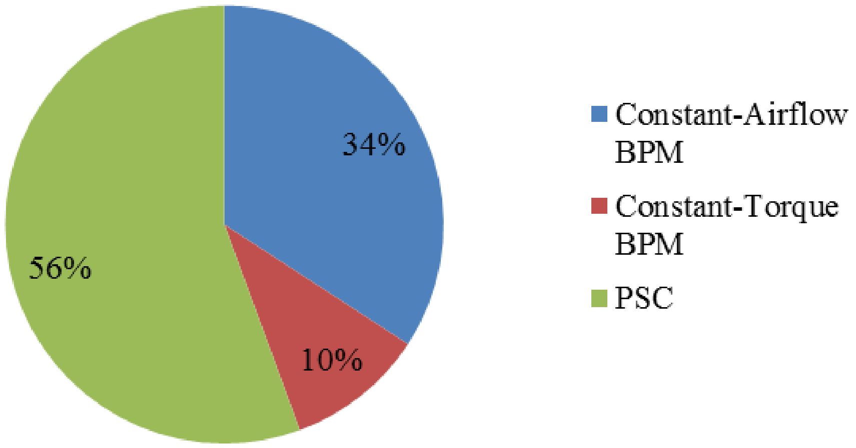

Figure 3.2.10: Motor Distribution for All Furnace Types

As shown above, the PSC motor dominates the furnace fan market at 56 percent market share, followed by constant-airflow BPM at 34 percent market share, and constant-torque BPM with 10 percent.

Figure 3.2.11 and Figure 3.2.12 show the distribution of motor type by Eae for all input capacities for the two major product classes (non-weatherized, non-condensing gas furnaces and non-weatherized, condensing gas furnaces). As shown below, constant-airflow BPM motors have a lower Eae (used as a proxy for FER) than PSC motors for both types of non-weatherized gas furnaces.

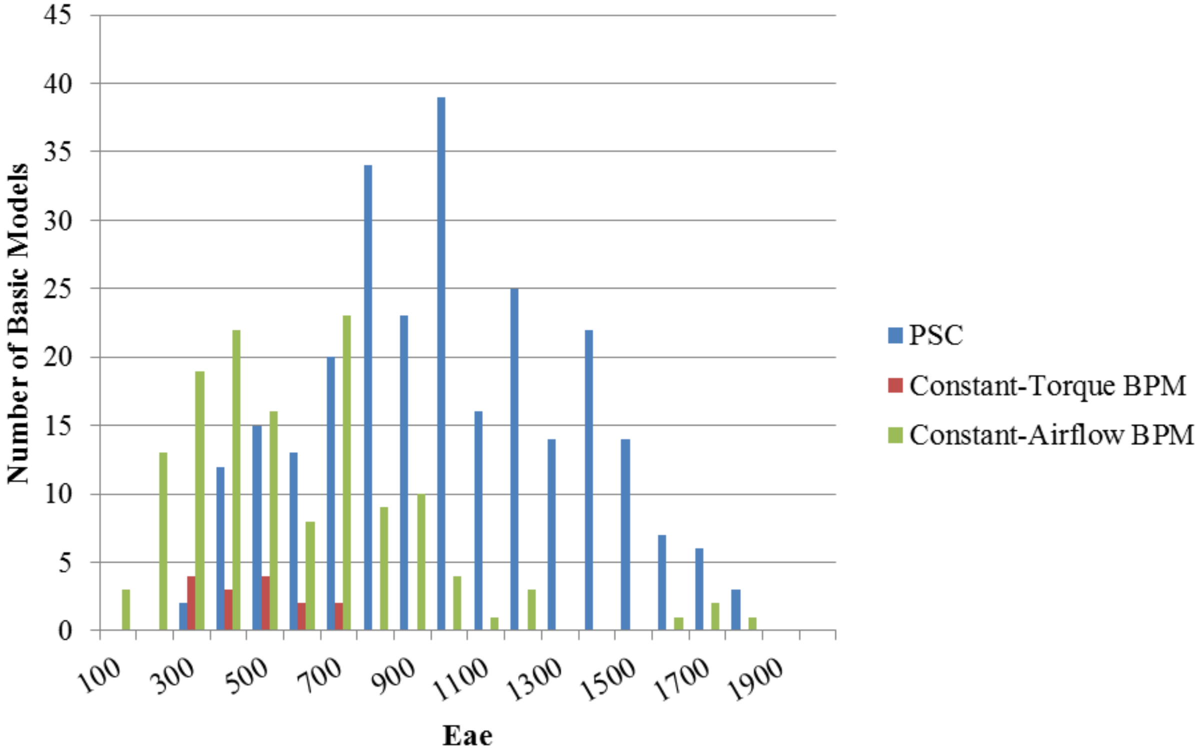

Figure 3.2.11: Motor Distribution by Eae for Non-weatherized, Non-condensing Gas Furnaces

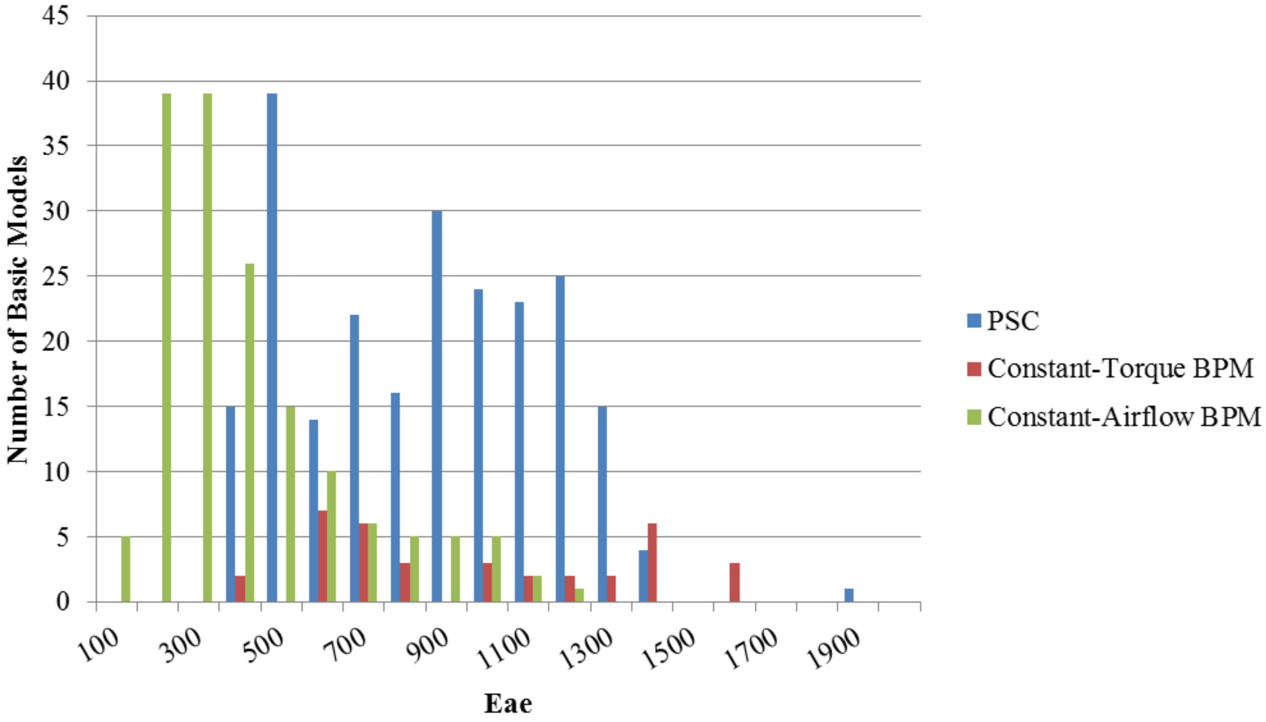

Figure 3.2.12: Motor Distribution by Eae for Non-weatherized, Condensing Gas Furnaces

3.3 TECHNOLOGY ASSESSMENT

This section provides a technology assessment for residential furnace fans. Contained in this technology assessment are details about product characteristics and operation (section 3.15.1), an examination of possible technological improvements for each product (section 3.15.2) and a characterization of the product efficiency levels currently commercially available (section 3.15.3).

3.3.1 Furnace Fan Operation

In preparation for the screening and engineering analyses, DOE prepared a brief description of the characteristics and operation of the furnace fans covered by this rulemaking. These descriptions provide a basis for understanding the technologies used to improve product efficiency.

DOE considered a typical furnace fan as consisting of a fan motor and its controls, an impeller, and a housing, all of which are components of an HVAC product that includes additional components, including the cabinet. To circulate air through duct work, the furnace fan motor rotates the impeller, which increases the velocity of an airstream. As a result, the airstream gains kinetic energy. This kinetic energy is converted to a static pressure increase when the air slows downstream of the impeller blades. This static pressure created by the fan must be enough to overcome the pressure losses the airstream will experience throughout the duct work, and to a smaller degree, within the HVAC product itself, to provide sufficient delivery of conditioned air to the residence. Pressure losses are the result of directional changes in the duct work, friction between the moving air and surfaces of the duct work, and possible appurtenances in the airflow path. (In layman's terms, the conditioned air slows and eventually would stop the further it travels from the fan. However, in effective systems, continued action of the furnace fan overcomes such resistance and provides conditioned air to the intended space.) Therefore, the geometry of any HVAC component that obstructs the airflow path, the length of the duct work path, and number and nature of direction changes in the duct work of a given system contribute to the pressure losses of the system. In most duct systems, the static pressure required to move the air is approximately equal to the square of the airflow rate.

Installed furnace fans can have as many as five or more airflow-control settings. In a given HVAC system, energy consumption of the furnace fan increases as airflow increases. Therefore, power input is higher for higher airflow-control settings. As mentioned, DOE finds that each airflow-control setting is often designated for a specific function, such as cooling, heating, or constant circulation. DOE understands that higher airflow-control settings are almost always factory set for cooling operation. Therefore, DOE expects that the electrical energy consumption of a furnace fan is higher while performing the cooling function. Median airflow-control settings are designated for heating operation. DOE further recognizes that the potential for significant power reduction occurs when the fan is operating in its lowest airflow-control setting, which DOE finds is typically factory set for constant-circulation. Constant circulation is the mode in which the furnace fan circulates air continuously but the HVAC product does not condition (heat or cool) the air. The significant power reduction in constant circulation mode is consistent with the theory that fan input power is proportional to the cube of the airflow.

The relative efficiency of certain furnace fan technologies is dependent on operating conditions (i.e. airflow-control setting and ESP). For instance, DOE is aware that some furnace fan technologies, such as improved impeller designs, may improve efficiency in some, but not all, of the expected range of operation. Therefore, DOE anticipates that evaluating energy performance of furnace fans across the entire range of expected field operation is necessary to meaningfully compare technology options.

3.3.2 Technology Options

The purpose of the technology assessment is to develop a list of technology options that manufacturers can use to improve product efficiency. The following assessment provides descriptions of technology options for furnace fans. DOE considered technologies incorporated in commercially-available products or in working prototypes to be technologically feasible.

3.3.2.1 Housing Design Modifications

The housing of a furnace fan is typically made of sheet metal. The design of the housing may impact fan efficiency. According to some manufacturers, the following housing design improvements can improve fan efficiency:

- Optimizing the shape of the inlet cone.
- Optimizing the fan housing shape.
- Optimizing the motor mount and the motor location.
- Increasing the distance between the impeller and the fan housing.
- Minimizing the gaps between the impeller and the inlet cone.
- Optimizing cut off location and the manufacturing tolerances.[n]

However, many manufacturers estimate these impacts to be minimal, and DOE has little quantitative data correlating specific housing design modifications with efficiency improvements. Additionally, housing design modifications result in a larger furnace cabinet.

3.3.2.2 Airflow Path Design

The internal structure (i.e., geometry and configuration of components in the airflow path) determines the internal static pressure. For example, the geometry of a tubular heat exchanger is different than the geometry of a clamshell heat exchanger, a furnace heat exchanger design typically found in non-weatherized gas furnaces. This difference results in different internal static pressure levels that in turn, impact furnace fan energy performance differently Manufacturers could modify the design and configuration of elements in the airflow path, such as the heat exchanger, to reduce internal static pressure. Reduced internal static pressure levels result in lower expected energy consumption levels. Airflow path design improvements may also involve an increase in package size.

3.3.2.3 High-Efficiency Fan Motors

Furnace fan manufacturers typically use either a permanent split capacitor (PSC) motor or a more-efficient, brushless permanent magnet (BPM) motor. DOE divided both PSC motors and BPMs into two further categories each. In all, DOE considered four motor types: baseline PSC motors; improved PSC motors; constant-torque BPM motors (often referred to as X13); and constant-airflow BPM motors (often referred to as ECM). The specific design and energy performance differences between these motor types are described in the following paragraphs. Each of these motor types operates based on the interaction of the magnetic fields produced by the stator (the stationary portion of the motor) and the rotor (the rotating portion of the motor). These magnetic fields can be produced by electromagnets or permanent magnets.

PSC motors are a type of induction motor. In induction motors, the stator is an electromagnet that consists of electrical wire windings. Current is driven through the windings to produce a magnetic field. Through electromagnetic induction, this magnetic field induces current in the conductor bars of the rotor. The conductor bars of the rotor, often made of copper or aluminum, are arranged in such a manner that they produce another magnetic field once current is induced. The interaction of the two magnetic fields results in rotation of the rotor. In a PSC motor, a smaller, start-up winding is present in addition to the main winding in the stator. The start-up winding is electrically connected in parallel with the main winding and in series with a

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[n] The cut-off partially blocks the fan discharge opening at the side of the opening closest to the impellor axis.

capacitor. At startup, the interactions between the magnetic fields generated by the start-up winding and the main winding initiate rotation in the correct direction. Because of the capacitor, however, the current to the start-up winding is cut off as the motor reaches steady state.

DOE considered PSC motors with 3 or less airflow-control settings to be baseline PSC motors, and PSC motors with more than 3 airflow-control settings to be improved PSC motors. PSC motors with more airflow-control settings provide more flexibility for designating which setting will be used for which HVAC product function (i.e. cooling, heating, or constant circulation). In addition, DOE expects that improved PSC motors have a higher turndown ratio, allowing them to increase fan efficiency by taking advantage of the cube law relationship between fan shaft power and airflow for operation with a given duct work system.

Manufacturers integrate an autotransformer in PSC motors to create distinct, selectable airflow-control settings (speed taps). The autotransformer is a single-winding electrical transformer that is wound to the stator assembly and connected to the main and auxiliary motor windings. The autotransformer is tapped at various points along the winding. The location of each tap determines the number of winding turns that are powered and in turn, the voltage applied to the stator windings when the tap is selected. Taps are powered through a selector switch, which allows only one lead to be connected at a time. Each tap corresponds to an airflow-control setting.

BPM motors are three-phase permanent magnet motors. Like a PSC motor, the stator of a BPM motor is an electromagnet used to produce a magnetic field. Unlike the PSC motor, the rotor of a BPM motor consists of a permanent magnet. The interaction of the magnetic field of the electromagnet and the magnetic field of the permanent magnet rotor result in rotation of the rotor. BPM type motors can be divided into two categories: constant-torque BPM motors and constant-airflow BPM motors. Constant-torque BPM motors, maintain a predetermined torque in each airflow-control setting as operating conditions change. Constant-airflow BPM motors maintain a constant airflow in each airflow-control setting as operating conditions change. Another difference between constant-torque BPM motors and constant-airflow BPM motors is that manufacturers design constant-torque BPM motor controls to mimic the speed tap interface of PSCs to facilitate integration. Constant-airflow BPM motors on the other hand, have variable speed controls. Theoretically variable speed controls allow a furnace fan to operate at any airflow rate between its minimum and maximum. Both constant-torque and constant-airflow BPM motors operate more efficiently than PSC motors by:

- operating more efficiently at a given operating condition;
- maintaining efficiency throughout the expected operating range; and
- achieving a lower turndown ratio (i.e., ratio of airflow in lowest setting to airflow in highest setting).

Constant-torque BPM motors are less efficient than constant-airflow BPM motors because they are designed to have a narrower speed range and higher turndown ratio, as a result. DOE used airflow data from publicly-available product literature to calculate average turndown ratios for typical motor type/speed control combinations. Table 3.3.1 presents DOE’s turndown ratio investigation results.

Table 3.3.1: Average Turndown Ratio by Motor Type

Motor Type	Speeds/Controls	Average Turndown Ratio
PSC	2-Speed	82%
	3-Speed	78%
	4-Speed	64%
	5-Speed	55%
	Inverter	48%
Constant-Torque BPM	5-Speed	68%
Constant-Airflow BPM	Variable	53%

3.3.2.4 Inverter Controls for PSC Motors

DOE is aware of an inverter-driven PSC furnace fan motor that was once commercially available in a furnace product that is no longer for sale. Inverter technology can improve PSC-driven furnace fan efficiency through more efficient control of the motor. Using an inverter, the incoming AC current is converted to DC current by a rectifier and then back to AC current at a specific frequency. The output AC current is used to drive the motor, the operating speed of which depends on the frequency of the AC current. Though there are other ways to change motor speed, inverter technology allows for more intermediate speeds within the same range of speeds from the voltage steps associated with the autotransformer approach used for conventional PSC motors. This allows PSC motors with inverter controls to better match demand. DOE finds that an inverter-driven PSC motor is more efficient than the other PSC motor types, but less efficient than both constant-torque BPM motors and constant-airflow BPMs.

3.3.2.5 Multi-Stage or Modulating Heating Controls

DOE identified two-stage and modulating heating controls, hereinafter collectively referred to as “multi-stage”, as a method of reducing furnace fan energy consumption. Single-stage furnaces only have one heat input rate, but multi-stage furnaces can provide heat at two or more different rates. When less heat is required in a residence, the multi-stage furnace can run at a low output rather than cycling repeatedly between a single heat input rate (often designed to be high enough to meet worst-case heating scenarios). Multi-stage furnaces are able to better match typical demand by operating at lower heat input rates to heat a residence and, in turn, a lower airflow-control setting for extended periods of time compared to single-stage furnaces. Due to the cubic relationship between fan input power and airflow, operating at the reduced airflow-control setting reduces overall fan electrical energy consumption for heating despite the extended hours. Multi-staging can be used for both PSC and BPM motors.

3.3.2.6 Backward-Inclined Impellers

Furnace fans use an impeller to move air across the heat exchanger and through duct work. Impellers are composed of a number of fan blades, or ribs, mounted around a hub. The air enters from the side of the impeller parallel to the axis of rotation, turns 90 degrees and accelerates due to centrifugal force as it flows over the fan blades and exits the fan housing. (AMCA News Spring 2010). DOE finds that centrifugal, forward-curved impellers are ubiquitous in commercially-available furnace fans. The forward-curved blades are made of thin, stamped sheet metal. These impellers are compact, inexpensive, easy to manufacture, and provide acceptable performance over a wide range of field operating conditions.

Energy savings may be possible by using backward-inclined impellers. These impellers incorporate backward facing inclined blades that are generally wider in the air flow direction across the blade as compared with forward-curved impellers. Unlike forward-curved designs, backward-inclined impellers are more efficient because the airflow direction change is less as the air flows over the blade, thus reducing losses associated with turbulence and separation. However, because the blades are inclined backwards as compared with the direction of the impeller rotation, backward-inclined impellers must have significantly higher tip speed to accelerate air to the same rotational velocity as the air leaves the blades. The higher tip speed requires either larger impeller diameter or higher rotational speed.

DOE is aware of one manufacturer that offers backward-inclined impellers for residential HVAC applications. DOE is also aware of research performed by General Electric and testing performed at national laboratories that include evaluation of a series of prototype residential furnaces that include backward-inclined impellers.[29] Figure 3.3.1 shows the results of these tests.

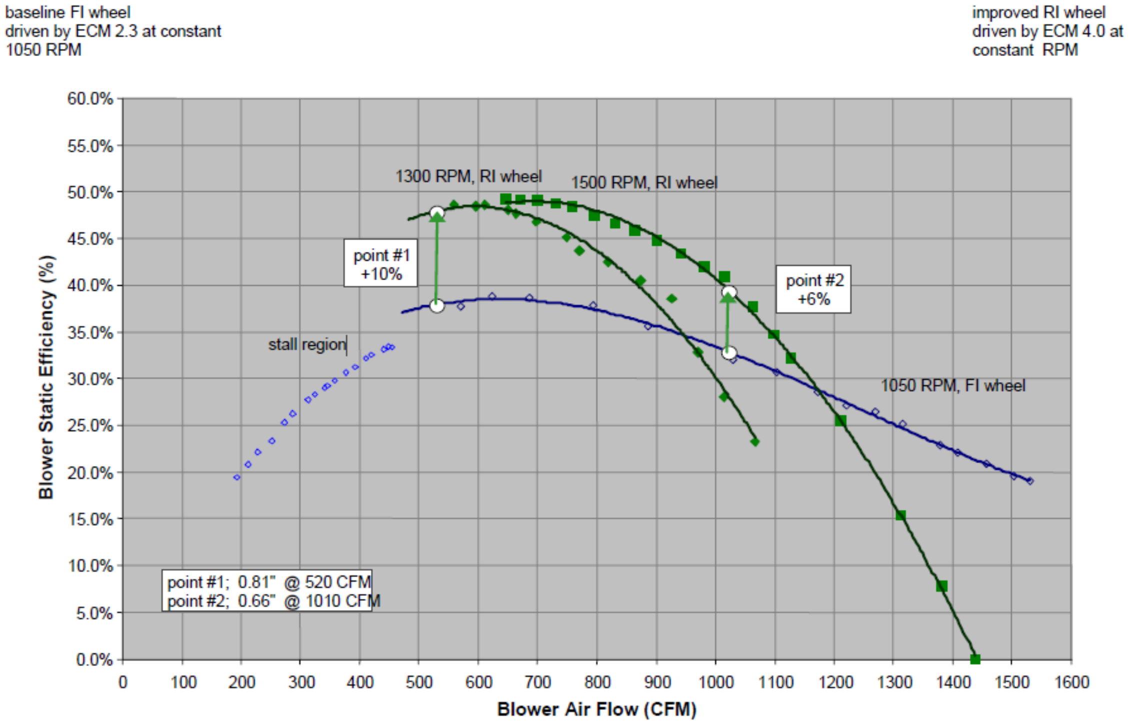

Figure 3.3.1: Performance Curves for Both Forward- and Backward-Inclined Impellers

The results of these tests show that backward-inclined impellers can improve furnace fan efficiency considerably, depending on the operating conditions. Notably, the efficiency of the backward-inclined design appears to be more sensitive to operating conditions than that of forward-curved designs. A backward-inclined impeller design may not perform more efficiently across the entire range of expected operation, as a result. Furthermore, Ebm-papst, a company that provides custom air-movement products, tested several HVAC products that they retrofitted with furnace fan assemblies that incorporated backward-inclined impellers without increasing cabinet size. Depending on the application and the external static pressure load (typically 0.5 in. w.c. to 1 in. w.c.), ebm-papst found that the backward-inclined impeller achieved input power reductions from 15-30% at peak speeds. DOE investigated the impacts on FER of a reduction in power in the range sited by ebm-papst. For a subset of ECM models for which DOE has sufficient performance data to calculate FER, DOE reduced the electrical energy consumption in the maximum airflow-controls setting (which is analogous to the peak speed at the ESP referenced by ebm-papst) by 15% and 30%. DOE then recalculated FER for those models using the reduced electrical power input estimates. The reductions in electrical input power in the maximum airflow-control setting resulted in a 10-10% reduction in FER. These results validate DOE's estimated 10% reduction in FER to represent the improvement associated with using a backward-inclined impeller used in the preliminary analysis. For this reason, DOE used a 10% reduction in FER for the backward-inclined design option in its NOPR analysis.

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CHAPTER 4. SCREENING ANALYSIS

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4.1 INTRODUCTION

This chapter details the screening analysis that the U.S. Department of Energy (DOE) conducted in support of the notice of proposed rulemaking (NOPR) for energy conservation standards for residential furnace fans.

In the market and technology assessment (MTA; chapter 3), DOE presents a list of technologies that manufacturers can use to improve the energy efficiency of residential furnace fans. DOE consulted a range of parties, including industry and technical experts and others, to develop this list of technology options. The purpose of the screening analysis is to evaluate each technology according to the screening criteria in the Energy Policy and Conservation Act (EPCA), as amended. (42 U.S.C. 6311-6317)Section 325(o) of EPCA establishes criteria for prescribing new or amended standards designed to achieve the maximum improvement in energy efficiency. Furthermore, EPCA directs the Secretary of Energy to determine whether a standard is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)(B)) In view of this requirement, 10 CFR Part 430 Subpart C, Appendix A, *Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products* (the Process Rule), guides DOE in its consideration and promulgation of new or revised product efficiency standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular, DOE determines whether to eliminate from consideration any technology that presents unacceptable problems with respect to the following criteria:

Technological feasibility. Technologies that are not incorporated in commercial products or in working prototypes will not be considered further.

Practicability to manufacture, install, and service. If it is determined that mass production of a technology in commercial products and reliable installation and servicing of the technology could not be achieved on the scale necessary to serve the relevant market at the time of the effective date of the standard, then that technology will not be considered further.

Impacts on product utility to consumers. If a technology is determined to have significant adverse impact on the utility of the product to significant subgroups of consumers or results in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the U.S. at the time, it will not be considered further.

Safety of technologies. If it is determined that a technology will have significant adverse impacts on health or safety, it will not be considered further. In sum, if DOE determines that a technology, or a combination of technologies, has unacceptable impacts on the policies stated in section 5(b) of the Process Rule, it will be eliminated from consideration. If a particular technology fails to meet one or more of the four criteria, it will be screened out from further consideration in the engineering analysis. 61 FR 36974-36987; 10 CFR part 430, subpart C, appendix A, section (5)(b). The reasons for eliminating any technology are documented in section 4.2.

4.2 SCREENED-OUT TECHNOLOGIES

This section describes the technologies that DOE eliminated based on consideration of the following four factors: 1) technological feasibility; 2) practicability to manufacture, install, and service; 3) adverse impacts on product utility or product availability; and 4) adverse impacts on health or safety. DOE eliminated the following technology options for residential furnace fans from further consideration: housing design modifications and airflow path design.

4.2.1 Housing Design Modifications

DOE investigated housing design modifications during its teardown analysis. DOE found that housing designs did not vary dramatically between baseline and higher-efficiency models or across manufacturers. In addition, DOE found no quantitative data correlating specific housing design modifications with efficiency improvements. Manufacturers also estimated that housing improvements would have very little effect on fan efficiency during manufacturer interviews. Additionally, many of the housing design modifications listed by manufacturers would increase HVAC product size. Any increase in product size would cause adverse impacts on practicability to install and consumer utility because the furnace fan market is predominantly a replacement market. Installing HVAC products that are larger in size compared to the products they are purchased to replace would likely present issues, mainly significant increases in installation costs or minimizing product availability to consumers. Manufacturers were not able to identify a case where fan housing modifications could lead to potential fan energy savings without increasing the size of the HVAC product in which the furnace fan is used. For these reasons, DOE is not including improved housing designs as a technology option.

4.2.2 Airflow Path Design

DOE recognizes that the airflow path design of the HVAC product in which the furnace fan is integrated impacts efficiency. DOE anticipates that modifying the size of the cabinet and the geometry of the heat exchanger(s) would be the primary considerations for improving airflow path design. Alterations to the design and configuration of internal components, such as the heat exchanger, could impact the thermal performance of the HVAC product. During conversations with manufacturers, it was noted that 13 SEER, 14 SEER requirements call for increased central air-conditioner or heat pump indoor coil size, leaving reduced space for other HVAC system components. Having to decrease the size of the fan due to these additional regulations could make the furnace fan less efficient. HVAC products that use furnace fans have space constraints. Any increase in overall size of the product could reduce utility to the consumer by potentially reducing or eliminating product availability for certain applications. While DOE did account for the impacts of airflow path design in the proposed test procedure and other aspects of the NOPR (e.g., product class selection), DOE did not consider airflow path design as a technology option for these reasons.

4.3 REMAINING TECHNOLOGIES

After screening out those technologies that that do not meet the requirements of sections 4(a)(4) and 5(b) of the Process Rule, DOE considered the technologies in the following sections.

4.3.1 Furnace Fan Energy Efficiency Standards

For its FER standards rulemaking analysis, DOE considered the following technology options:

- Higher-efficiency fan motors
- Higher-efficiency fan blades (backward-inclined impellers)
- Inverter motor drive technology
- Multi-stage heating components and controls

CHAPTER 5. ENGINEERING ANALYSIS

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy efficiency or consumption for the products covered in this rulemaking. For the purposes of the engineering analysis, the energy consumption of furnace fans is represented by the proposed rating metric, fan energy rating (FER). The cost-efficiency relationship serves as the basis for subsequent cost/benefit calculations for individual customers, manufacturers, and the Nation. In determining this relationship, the U.S. Department of Energy (DOE) estimates the increase in the manufacturer selling price (MSP) associated with technological changes that reduce the energy consumption of the baseline models.

The primary inputs to the engineering analysis are data from the market and technology assessment (chapter 3 in the TSD), energy performance data from testing and publicly available product literature and research reports, input from manufacturers, baseline specifications, and production cost estimates developed using a cost model. The primary output of the engineering analysis is a set of cost-efficiency relationships that represent the average incremental cost of increasing product efficiency above the baseline levels. In the subsequent markups analysis (chapter 6 in the TSD), DOE determines customer prices by applying distribution markups, sales tax, and contractor markups to the manufacturer sales prices (MSPs) developed in the engineering analysis. After applying these markups, the data serve as inputs to the energy use characterization (chapter 7 in the TSD) and the life-cycle cost and payback period analyses (chapter 8 in the TSD).

In this chapter, DOE discusses: (1) the identification of representative baseline units for each product class, (2) the methodology used to develop bills of materials (BOMs) and MSPs, (3) the process for constructing the industry cost-efficiency relationships, and (4) the cost-efficiency relationship outputs.

5.2 METHODOLOGY OVERVIEW

This section describes the analytical methodology used in the engineering analysis. In this rulemaking, DOE used an efficiency-level approach in conjunction with a design option approach to identify incremental improvements in efficiency for each product class. An efficiency level approach enabled DOE to identify incremental improvements in efficiency for efficiency-improving technologies that furnace fan manufactures already incorporate in commercially-available models. A design option approach enabled DOE to model incremental improvements in efficiency for technologies that are not commercially available in residential furnace fan applications. In combination with these approaches, DOE used a cost-assessment approach to determine the manufacturing production cost (MPC) at each efficiency level identified for analysis. This methodology estimates the incremental cost of increasing product efficiency.

The cost-assessment is based on reverse engineering data and was validated by manufacturer input. First, DOE used information gathered from manufacturers and/or data from the market and technology assessment to identify baseline units and representative models. DOE selected a set of units at the baseline and higher efficiencies for teardown analysis based on this information. The baseline unit serves as a starting point for the analysis, and the units selected for teardown analysis span a range of manufacturers, functionality, and efficiencies for commercially available products. DOE developed estimates of MPC for the each of the units selected for teardown by disassembling each unit, developing a bill of materials, and using this information as input for a manufacturing cost model.

To determine the MSP of a unit at each efficiency level, DOE applied manufacturer markups to the MPC. DOE derived the manufacturer markup for that rulemaking by evaluating publicly available industry financial data and through manufacturer feedback. The results of the engineering analysis are a set of cost-efficiency relationships, in the form of MSP as a function of FER, for each product class. The methodology for the engineering analysis is a logical, concise, and reproducible process, as illustrated in Figure 5.2.1.

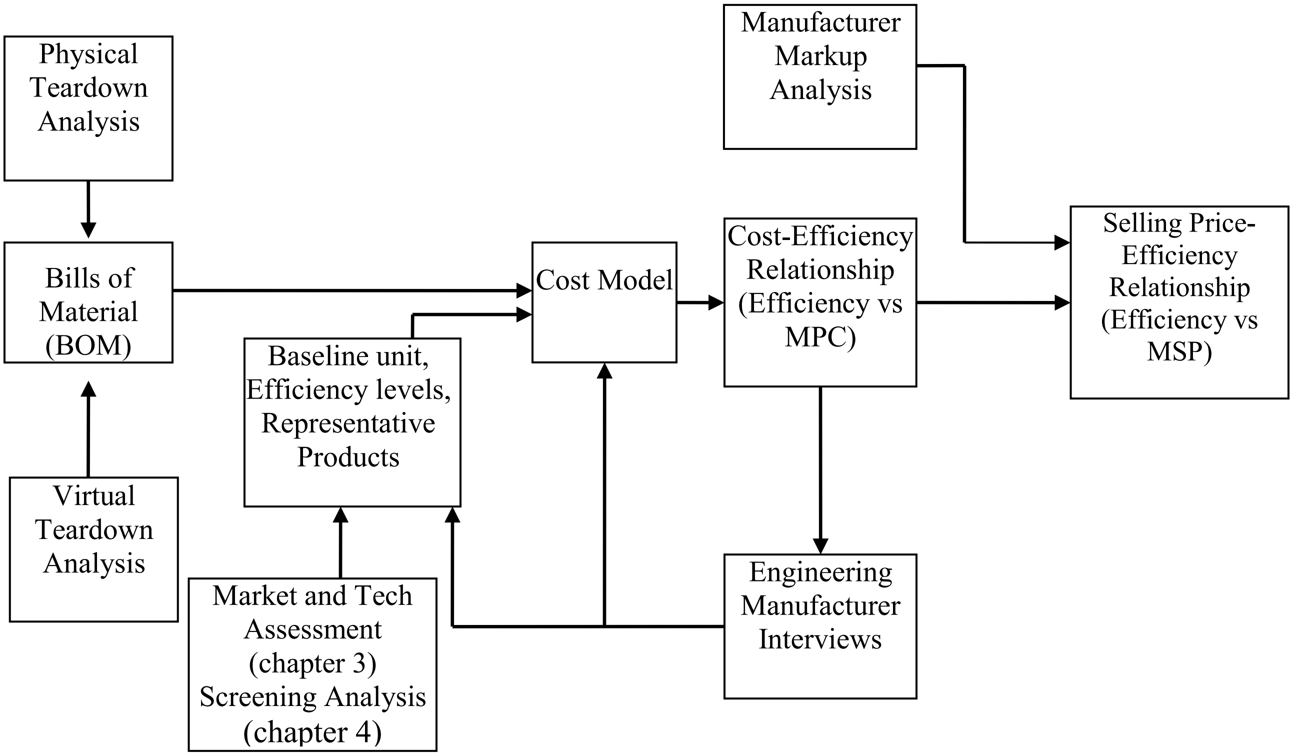

Figure 5.2.1: Engineering Analysis Methodology

5.3 PRODUCT CLASSES

DOE identified eight product classes that DOE differentiated by internal structure and application-specific design changes. Table 5.3.1 lists these product classes.

Table 5.3.1: Product Classes

Product Class
Non-Weatherized, Non-Condensing Gas Furnace Fan (NWG-NC)
Non-Weatherized, Condensing Gas Furnace Fan (NWG-C)
Weatherized Non-Condensing Gas Furnace Fan (WG-NC)
Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC)
Non-Weatherized Electric Furnace / Modular Blower Fan (NWEF/NWMB)
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan (MH-NWG-NC)
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan (MH-NWG-C)
Manufactured Home Electric Furnace / Modular Blower Fan (MH-EF/MB)

DOE developed trial standard levels for the product classes based on FER. FER represents normalized annual energy use. FER only accounts for active-mode energy use because standby and off mode energy use for furnace fans integrated in the products considered in this rulemaking is accounted for in other DOE rulemaking activities. Chapter 3 of this TSD describes the rating metric in greater detail.

5.4 EFFICIENCY LEVELS ANALYZED

DOE analyzed multiple efficiency levels for each product class (presented in section 5.3) and estimated the manufacturer production cost (MPC) at those levels. The following subsections discuss efficiency levels from the baseline to maximum technologically feasible ("max-tech") efficiency for each product class. DOE identified the max-tech efficiency level by reviewing product literature for commercially available products and research reports that included energy performance data of prototype furnace fans.

5.4.1 FER as a Function of Airflow Capacity

DOE is aware that manufacturers use the same size cabinet for HVAC products that vary in capacity. Some internal components of HVAC products (e.g. fan housing, impeller, and heat exchanger) typically increase in size as capacity increases. Consequently, for a higher capacity HVAC product that uses the same size cabinet as a lower capacity model, clearances become smaller and the airflow path is more restrictive, even though airflow itself would be higher, and hence, furnace fan energy consumption can increase more rapidly than the airflow. New data received after the preliminary analysis enabled DOE to conduct a quantitative investigation of the relationship between FER and airflow capacity.[a] DOE did this by evaluating the trends in these metrics for multiple series of models of NWG-NC and NWG-C furnaces.[b] The data represent a significant share of the furnace fan market because these product classes account for a large percentage of furnace fan shipments and the models are from manufacturers with significant market share. The results confirmed that FER increases with airflow capacity. In light of the new data and results, DOE proposes to represent the baseline and efficiency levels using FER equations that are a function of airflow capacity instead of using single FER values, as had been done for the preliminary analysis. DOE also finds that the slopes of the trend lines fit to the FER values for each series of furnace fan models are similar at a given efficiency, regardless of manufacturer or product class. Consequently, DOE also proposes to characterize the relationship between FER and airflow capacity using the same slope at a given efficiency level across all product classes. The subsequent sections provide a detailed description of the methodology that DOE used to generate FER equations that are a function of airflow capacity to represent the baseline and each efficiency level.

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[a] For the purposes of this rule, DOE is using the airflow measured at the maximum airflow-control setting according to the proposed DOE test procedure (Q_{Max}) to represent airflow capacity.

[b] Each series comprises product models of different capacity but similar nominal efficiency (e.g. AFUE) offered by a single manufacturer.

5.4.2 Baseline

DOE selected baseline units as reference points for each product class, against which changes resulting from potential new energy conservation standards could be measured. The baseline unit in each product class possesses the basic characteristics of products in that class. Typically, a baseline unit is a unit that just meets, but does not exceed current Federal energy conservation standards and provides basic consumer utility. However, federal energy conservation standards for furnace fans do not exist. As a result, DOE selected baseline models typical of the least-efficient furnace fans integrated in commercially available residential HVAC models that have significant shipments.

DOE used the baseline units for comparison to higher-efficiency products in several analyses, including the engineering analysis, life-cycle cost (LCC) analysis, payback period (PBP) analysis, and national impacts analysis (NIA). For example, energy savings that will result from a new energy conservation standard are equal to energy consumption for the baseline unit minus the energy consumption for a higher energy efficiency level that is being considered. Similarly, consumer price increases that will result from a new energy conservation standard are equal to the price of a unit of a higher-efficiency level that is under consideration minus the price of a baseline unit.

DOE performed a market- and capacity-weighted least-squares regression analysis to characterize the relationship between FER and airflow capacity at the baseline. This analysis included the following steps.

1. DOE reviewed FER values that it calculated using test data and performance information from publicly-available product literature to determine baseline FER ratings.
2. DOE plotted FER versus airflow measured at the maximum airflow control setting (in cfm) for multiple series of baseline models of NWG-C and NWG-NC furnaces and fit a linear trend line to each series.
3. DOE found that the average slope for these linear trend lines for baseline FER vs. airflow capacity is 5.7 in FER (W per 1,000 cfm) per 1,000 cfm of airflow capacity.
4. Separately for all of the NWG-NC baseline models and for all of the NWG-C baseline models for which sufficient data is available, DOE determined the least-squares best-fit line for FER that has a 5.7 FER/1,000cfm slope. In conducting this calculation, DOE weighted the error associated with the FER of each model in the database to account for distribution of shipments by capacity and manufacturer market share. DOE used the distribution of shipments by capacity and manufacturer market shares as described in Chapter 3 of this TSD. The

baseline y-intercepts determined with this analysis are 362 for NWG-NC furnace fans and 395 for NWG-C furnace fans.[c]

DOE does not have enough FER data for the other product classes to conduct a similar regression analysis. Instead, DOE developed baseline FER equations for the other classes using the same 5.7 slope found for the NWG-NC and NWG-C classes. DOE set the intercepts (constant terms) of these equations to reflect the differences in average FER values (taking capacity distribution and manufacturer market share of the data into account) for the classes. This was done as follows. DOE divided the capacity and market-weighted average baseline FER considering all of the FER data for each product class by the capacity and market-weighted baseline FER for NWG-NC furnace fans to create class-specific conversion factors. The capacity and market-weighted average FER for NWG-NC is 431. The conversion factor for weatherized gas furnace fans, for example, is the capacity and market-weighted average FER for weatherized gas furnace fans, 322, divided by 431, resulting in a conversion factor of 0.75. DOE then multiplied the y-intercept for NWG-NC furnace fans (362) by these conversion factors to get the baseline y-intercept for the remaining product classes.

Table 5.4.1 presents the baseline FER equation for each product class.

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[c] For example, using the slope and y-intercepts presented, the baseline FER equation for NWG-NC, is $0.057*Q_{Max}+362$.

Table 5.4.1: Baseline Unit FER for Residential Furnace Fans

Product Class	FER (W/1000 cfm)
Non-Weatherized, Non-Condensing Gas Furnace Fan (NWG-NC)	$0.057*Q_{Max}^{*}+362$
Non-Weatherized, Condensing Gas Furnace Fan (NWG-C)	$0.057*Q_{Max}+395$
Weatherized Non-Condensing Gas Furnace Fan (WG-NC)	$0.057*Q_{Max}+271$
Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC)	$0.057*Q_{Max}+336$
Non-Weatherized Electric Furnace / Modular Blower Fan (NWEF/NWMB)	$0.057*Q_{Max}+331$
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan (MH-NWG-NC)	$0.057*Q_{Max}+271$
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan (MH-NWG-C)	$0.057*Q_{Max}+293$
Manufactured Home Electric Furnace / Modular Blower Fan (MH-EF/MB)	$0.057*Q_{Max}+211$

$^{*}Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

5.4.3 Intermediate Efficiency Levels

For all product classes, DOE analyzed five intermediate efficiency levels in addition to the baseline and the max-tech. The intermediate efficiency levels are all defined by specific design options that manufacturers can use to achieve them.[d] DOE determined FER values representing the intermediate efficiency levels based on tests conducted for selected products and on information obtained in AHRI's product certification directories,[1] manufacturer catalogs, and other publicly available literature. DOE used a combination of an efficiency level approach and a design option approach to determine MPCs for intermediate efficiency levels for each product class. DOE used the efficiency level approach for intermediate efficiency levels that products can achieve by using commercially available technologies. MPCs were determined based on reverse engineering of purchased products representing these efficiency levels. However, some of the efficiency levels, particularly the higher efficiency levels, are based on use of prototype technologies that are not commercially available, technologies that are just entering the market, or technologies that are commercially available but not in residential furnace fan applications. For assessment of these efficiency levels, DOE used the design option approach, determining the

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[d] DOE policy is to not use proprietary technology that is a unique pathway to achieving a certain efficiency level as design option. DOE believes that all design options proposed at each efficiency level include non-proprietary technology.

additional cost and the additional energy savings associated with adoption of the particular technologies. Table 5.4.2 lists the efficiency levels DOE considered, showing the technologies and analysis approach used for each. Chapter 3 of this TSD includes a detailed discussion of each technology option.

Table 5.4.2: Intermediate Efficiency Level Correlation between Technologies, Technology Status, and Analysis Approach

Efficiency Level	Design Option	Technology Status	Analysis Approach
1	Improved PSC	Commercialized	Efficiency Level
2	Inverter-Driven PSC	Prototype*	Design Option
3	Constant-Torque BPM Motor	Commercialized	Efficiency Level
4	Constant-Torque BPM Motor and Multi-Staging	Commercialized	Efficiency Level
5	Constant-Airflow BPM Motor and Multi-Staging	Commercialized	Efficiency Level
6	Premium Constant-Airflow BPM Motor and Multi-Staging + Backward-Curved Impeller	Prototype	Design Option

*DOE is aware that a furnace model using an inverter-driven PSC motor was once commercially available, but no longer.

DOE finds from manufacturer feedback and its review of publically available product literature that manufacturers use similar furnace fan components and follow a similar technology path to improving efficiency across all product classes. DOE does not expect the percent reduction in FER associated with each design option, whether commercially available or prototype, to differ across product classes as a result. Therefore, DOE determined average FER reductions for each efficiency level for a subset of product classes and applied these reductions to all product classes. DOE based the reductions in FER associated with commercialized technologies on measurements or publicly available performance information. DOE based the FER reductions associated with prototype technologies on research reports that included performance data. Table 5.4.3 presents the percent FER reductions that DOE determined each design option and efficiency level. The FER reductions for efficiency levels 1 through 6 are expressed in relation to the baseline. DOE determined these percent reductions based on averaging the calculated reductions associated with all products for which information was available, including both tested products and products for which sufficient information was available in public literature.

Table 5.4.3: Reduction in FER for Each Efficiency Level

Efficiency Level (EL)	Design Option	Percent Reduction in FER from Baseline
1	Improved PSC	10%
2	Inverter-Driven PSC	25%
3	Constant-Torque BPM Motor	42%
4	Constant-Torque BPM Motor and Multi-Staging	50%
5	Constant-Airflow BPM Motor and Multi-Staging	53%
6	Premium Constant-Airflow BPM Motor and Multi-Staging + Backward-Curved Impeller	57%*

* DOE estimates that implementing a backward-inclined impeller at EL6 results in a 10% reduction in FER from EL5. This is equivalent to a 4% percent reduction in FER from baseline. The total percent reduction in FER from baseline for EL6 includes the 53% reduction from EL5 and the 4% net reduction from the backward-inclined impeller for a total percent reduction of 57% from baseline.

DOE generated the intermediate efficiency level FER equations that are a function of airflow capacity for each product class by multiplying the slope and y-intercept of the baseline FER equation for that product class (presented in section 5.4.2). Table 5.4.4, Table 5.4.5, and Table 5.4.6 show the FER equation for each efficiency level within each product class.

Table 5.4.4: Efficiency Levels for Non-Weatherized Gas Furnace Fan Product Classes

Efficiency Level	NWG-NC	NWG-C
Baseline	$0.057*Q_{Max}+362$	$0.057*Q_{Max}+395$
1	$0.051*Q_{Max}+323$	$0.051*Q_{Max}+354$
2	$0.043*Q_{Max}+271$	$0.043*Q_{Max}+296$
3	$0.033*Q_{Max}+212$	$0.033*Q_{Max}+231$
4	$0.029*Q_{Max}+180$	$0.029*Q_{Max}+196$
5	$0.027*Q_{Max}+172$	$0.027*Q_{Max}+188$
6	$0.025*Q_{Max}+155$	$0.025*Q_{Max}+169$

$^*Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

Table 5.4.5: Efficiency Levels for Non-Weatherized Electric Furnace/Modular Blower Fans, Weatherized Gas Fans, and Non-Weatherized Oil Furnace Fans

Efficiency Level	NWEF/ NWMB	WG-NC	NWO-NC
Baseline	$0.057*Q_{Max}+331$	$0.057*Q_{Max}+271$	$0.057*Q_{Max}+336$
1	$0.051*Q_{Max}+297$	$0.051*Q_{Max}+242$	$0.051*Q_{Max}+301$
2	$0.043*Q_{Max}+248$	$0.043*Q_{Max}+203$	$0.043*Q_{Max}+252$
3	$0.033*Q_{Max}+194$	$0.033*Q_{Max}+158$	$0.033*Q_{Max}+196$
4	$0.029*Q_{Max}+165$	$0.029*Q_{Max}+135$	$0.029*Q_{Max}+167$
5	$0.027*Q_{Max}+157$	$0.027*Q_{Max}+129$	$0.027*Q_{Max}+159$
6	$0.025*Q_{Max}+142$	$0.025*Q_{Max}+116$	$0.025*Q_{Max}+144$

$^*Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

Table 5.4.6: Efficiency Levels for Manufactured Home Furnace Fan Product Classes

Efficiency Level	MH-NWG-NC	MH-NWG-C	MH-EF/MB
Baseline	$0.057*Q_{Max}+271$	$0.057*Q_{Max}+293$	$0.057*Q_{Max}+211$
1	$0.051*Q_{Max}+242$	$0.051*Q_{Max}+262$	$0.051*Q_{Max}+189$
2	$0.043*Q_{Max}+203$	$0.043*Q_{Max}+220$	$0.043*Q_{Max}+158$
3	$0.033*Q_{Max}+158$	$0.033*Q_{Max}+171$	$0.033*Q_{Max}+123$
4	$0.029*Q_{Max}+134$	$0.029*Q_{Max}+146$	$0.029*Q_{Max}+105$
5	$0.027*Q_{Max}+128$	$0.027*Q_{Max}+139$	$0.027*Q_{Max}+100$
6	$0.025*Q_{Max}+116$	$0.025*Q_{Max}+125$	$0.025*Q_{Max}+90$

[*] Q_{Max} is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

5.4.4 Max-tech Efficiency Levels

As part of the engineering analysis, DOE determined the maximum technologically feasible improvement in energy efficiency for the covered products, as required by section 325(o) of EPCA. (42 U.S.C. 6295(o)) In the market and technology assessment (chapter 3 of this TSD), DOE conducted a survey of the markets for the covered products and their supporting research areas. The max-tech efficiency level in each product class is based on a combination of design options that is not used in any known product on the market.

The max-tech levels identified for the furnace fan product classes are shown in Table 5.4.7. The max tech efficiency level for all product classes can be achieved using a backward-inclined impeller assembly. DOE modeled the backward-inclined impeller assembly based on the prototype used in research performed by General Electric and testing performed at national laboratories.[2] The backward-inclined impeller assembly included a premium constant-airflow BPM motor that operates at a higher RPM than a typical constant-airflow BPM motor, which is required to deliver the same airflow as a forward-curved impeller when using a backward-inclined impeller that is the same diameter of the forward-curved impeller it replaces. In addition, the premium constant-airflow BPM motor was a smaller diameter, resulting in a less-restricted furnace fan inlet and improved efficiency. Chapter 3 provides a detailed discussion of the backward-inclined impeller technology option. The max-tech equations below are derived by multiplying the slope and y-intercept of the baseline FER equation for each product class (see Table 5.4.1) by the percent reduction for EL6 (see Table 5.4.3).

Table 5.4.7: Max-Tech Efficiency Levels for Furnace Fans

Product Class	Max-Tech Efficiency Level FER (W/1000 cfm)
Non-Weatherized, Non-Condensing Gas Furnace Fan (NWG-NC)	$0.025*Q_{Max}+155$
Non-Weatherized, Condensing Gas Furnace Fan (NWG-C)	$0.025*Q_{Max}+169$
Weatherized Non-Condensing Gas Furnace Fan (WG-NC)	$0.025*Q_{Max}+116$
Non-Weatherized, Non-Condensing Oil Furnace Fan (NWO-NC)	$0.025*Q_{Max}+144$
Non-Weatherized Electric Furnace / Modular Blower Fan (NWEF/NWMB)	$0.025*Q_{Max}+142$
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan (MH-NWG-NC)	$0.025*Q_{Max}+116$
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan (MH-NWG-C)	$0.025*Q_{Max}+125$
Manufactured Home Electric Furnace / Modular Blower Fan (MH-EF/MB)	$0.025*Q_{Max}+90$

$^*Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure

5.5 TEARDOWN ANALYSIS

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a product is to disassemble it piece-by-piece, compile a bill of materials (BOM), and estimate the material and labor cost of each component. DOE refers to this practice as a physical teardown. A supplementary method, called a catalog teardown (or "virtual teardown"), uses published manufacturer product literature and supplementary component data to estimate the major physical differences between the catalog teardown unit and a similar physical teardown unit. One alternative to the teardown method is to conduct price surveys to determine the production cost, but this approach only provides insight into total MPC under current market conditions. The teardown approach provides insight into MPC by component and cost category, which enables DOE to estimate product costs and prices as new energy conservation standards change the affected market.

Units selected for physical teardowns were dismantled, and each part was characterized according to weight, manufacturing processes, dimensions, material, and quantity, in order to facilitate the creation of a complete BOM and manufacturing cost estimate for the product. BOMs for catalog teardowns leverage existing BOMs from teardowns by substituting components that are different between models based on product literature. These modifications are based on data taken from manufacturer specification sheets and supplementary component data.

5.5.1 Selection of Units

For the teardown analysis of furnace fans, DOE included 26 physical teardowns and two additional virtual teardowns. DOE identified and selected representative units across the entire range of efficiencies that are currently available to consumers. To the extent possible, all major efficiency levels and technologies were captured in the selection of models for teardown analysis. Each product class was considered separately.

Teardown units must be representative of their product class; hence their characteristics should be representative of typical characteristics of the products sold in the market. The characteristics of the product classes are shown in Table 5.5.1. DOE also required that teardown units be manufactured in considerable volume, be commonly available, and have the most popular features.

Table 5.5.1: Characteristics of Representative Residential Furnaces

Product Class	**Input Heat Capacity *kBtu/h***	**Airflow Capacity cfm**	**Heat Exchanger Type**	**Number of Heat Exchangers**
Non-Weatherized, Non-Condensing Gas Furnace Fan	70	1200	Clamshell/ Tubular	1
Non-Weatherized, Condensing Gas Furnace Fan	70	1200	Clamshell/ Tubular	2
Weatherized Non-Condensing Gas Furnace Fan	70	1200	Clamshell/ Tubular	1
Non-Weatherized, Non-Condensing Oil Furnace Fan	120	1200	Drum	1
Non-Weatherized Electric Furnace / Modular Blower Fan	70	1200	Electrical Resistance Heat Elements	1
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan)	70	1200	Clamshell/ Tubular	1
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	70	1200	Clamshell/ Tubular	2
Manufactured Home Electric Furnace / Modular Blower Fan	70	1200	Electrical Resistance Heat Elements	1

DOE also adopted more specific criteria to guide the selection process. In order to understand incremental manufacturing costs associated with design options that improve efficiency, products chosen for teardowns included models of various efficiency levels taken from the same manufacturer and product series to the extent possible. This approach minimized the cost effects of non-efficiency-related design differences between models. The manufacturers that were chosen have large market shares of the particular product class. DOE made an exception to this criterion for the highest efficiency product (or max-tech product) in each product class; as such, the max-tech products for teardown were chosen irrespective of manufacturer. DOE selected products to represent max-tech efficiency that include design options that have the highest potential for energy savings according to interested party feedback on the framework document. This approach was necessary because FER ratings were not available. DOE also selected products that minimized the occurrence of non-efficiency-related premium features, which could inflate the incremental manufacturing cost of achieving higher-efficiency levels.

DOE surveyed the residential furnace fan industry and identified products available to consumers as well as prototypes developed by research efforts. DOE then applied the aforementioned criteria and selected baseline, intermediate, and max-tech units that were as close to the representative characteristics as possible and included the most prevalent technologies on the market.

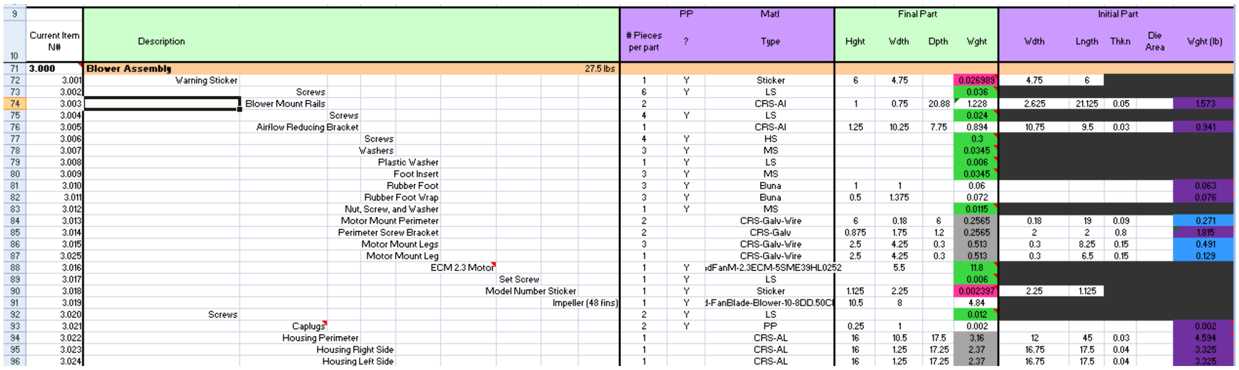
Because the large majority of residential furnace fan shipments fall into the non-weatherized gas product classes (condensing and non-condensing), DOE focused its teardown analysis heavily on non-weatherized gas furnace fans. DOE selected units for teardown that include nine non-weatherized, non-condensing gas furnace fans and three non-weatherized, condensing gas furnace fans. DOE selected the remainder of the units for teardown from the remaining product classes. The furnace fans selected spanned the range of efficiency levels from baseline to EL5. DOE could not reverse engineer a max-tech model because the max-tech efficiency level is based on a prototype. DOE also selected units for teardown with airflow capacities above and below the representative 1,200 cfm. DOE did not identify the model number or manufacturer of the units examined during the teardown analysis because this could expose sensitive information about individual manufacturers' products.

5.5.2 Generation of Bill of Materials

The end result of each teardown is a structured BOM, describing each product component and its relationship to the other parts in the estimated order in which manufacturers assembled them. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed for fabrication (*e.g.*, presses, drills) and the process cycle times. The result is a thorough and explicit model of the production process. The BOMs incorporate all materials, components, and fasteners classified as either raw materials or purchased parts and assemblies. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs). DOE also visited several manufacturing plants (for this rulemaking and other rulemakings that cover the HVAC products in which furnace fans are used) to reinforce its understanding of the industry's current manufacturing practices. For purchased parts, the purchase price is an estimate based on high-volume price quotations and detailed discussions with suppliers and manufacturers. For fabricated parts, the price of intermediate materials (*e.g.*, tube, sheet metal) and the cost of transforming them into finished parts is an estimate based on current industry pricing. For a continued discussion of the cost details and assumptions, refer to section 5.6.2.

The BOM for a catalog teardown is identically structured and provides a description in equal detail to the BOM of a physical teardown. However, it is generated using a slightly different methodology. BOMs for catalog teardowns are generated by modifying the BOM of a similar unit that has been physically torn down. These modifications reflect the major physical differences between the units. Specific to this engineering analysis, the catalog teardown methodology was employed to generate bills of materials for fans with inverter-driven PSC motors and fans with backward-inclined impellers. DOE physically tore down five fans with improved PSC motors and nine fans with constant-airflow BPM motors. Based on these physical teardowns, DOE executed one supplementary PSC with inverter catalog teardown and one supplementary constant-airflow BPM motor with a backward-inclined impeller catalog teardowns.

Figure 5.5.1 below shows an example of a section of a BOM spreadsheet. Each row of the spreadsheet represents a single part of the unit assembly and includes a description of the part, a material type, initial and final dimensions, and weight. These rows also include placeholders for the type and number or duration of fabrication processes (stamping, drilling, etc.) required to create that part. From this information, a part cost is generated, and the part costs are summed across the sheet to create a cost estimate for the entire unit.



9				PP	Matl	Final Part				Initial Part				
10	Current Item N#	Description	# Pieces per part	?	Type	Hght	Wdth	Dpth	Wght	Wdth	Lngth	Thkn	Die Area	Wght (lb)
71	**3.000**	**Blower Assembly** 27.5 lbs												
72	3.001	Warning Sticker	1	Y	Sticker	6	4.75		0.026989	4.75	6			
73	3.002	Screws	6	Y	LS				0.036					
74	3.003	Blower Mount Rails	2		CRS-Al	1	0.75	20.88	1.228	2.625	21.125	0.05		1.573
75	3.004	Screws	4	Y	LS				0.024					
76	3.005	Airflow Reducing Bracket	1		CRS-Al	1.25	10.25	7.75	0.894	10.75	9.5	0.03		0.941
77	3.006	Screws	4	Y	HS				0.3					
78	3.007	Washers	3	Y	MS				0.0345					
79	3.008	Plastic Washer	1	Y	LS				0.006					
80	3.009	Foot Insert	3	Y	MS				0.0345					
81	3.010	Rubber Foot	3	Y	Buna	1	1		0.06					0.063
82	3.011	Rubber Foot Wrap	3	Y	Buna	0.5	1.375		0.072					0.076
83	3.012	Nut, Screw, and Washer	1	Y	MS				0.0115					
84	3.013	Motor Mount Perimeter	2		CRS-Galv-Wire	6	0.18	6	0.2565	0.18	19	0.09		0.271
85	3.014	Perimeter Screw Bracket	2		CRS-Galv	0.875	1.75	1.2	0.2565	2	2	0.8		1.815
86	3.015	Motor Mount Legs	3		CRS-Galv-Wire	2.5	4.25	0.3	0.513	0.3	8.25	0.15		0.491
87	3.025	Motor Mount Leg	1		CRS-Galv-Wire	2.5	4.25	0.3	0.513	0.3	6.5	0.15		0.129
88	3.016	ECM 2.3 Motor	1	Y	dFanM-2.3ECM-5SME39HL0252		5.5		11.8					
89	3.017	Set Screw	1	Y	LS				0.006					
90	3.018	Model Number Sticker	1	Y	Sticker	1.125	2.25		0.002397	2.25	1.125			
91	3.019	Impeller (48 fins)	1	Y	d-FanBlade-Blower-10-8DD.50C	10.5	8		4.84					
92	3.020	Screws	2	Y	LS				0.012					
93	3.021	Caplugs	2	Y	PP	0.25	1		0.002					0.002
94	3.022	Housing Perimeter	1		CRS-AL	16	10.5	17.5	3.16	12	45	0.03		4.594
95	3.023	Housing Right Side	1		CRS-AL	16	1.25	17.25	2.37	16.75	17.5	0.04		3.325
96	3.024	Housing Left Side	1		CRS-AL	16	1.25	17.25	2.37	16.75	17.5	0.04		3.325

Figure 5.5.1: Example of BOM Spreadsheet

5.6 COST MODEL

The cost model is a detailed, component-focused, activity-based tool for estimating the manufacturing cost of a product. Once teardowns were completed, DOE implemented a cost model that could translate the physical information from the BOMs into manufacturing costs. The cost model is based on production activities and divides factory costs into materials, labor, depreciation, and overhead. DOE defines the cost inputs of these broader categories in Table 5.6.1.

Table 5.6.1: Cost Model Categories and Descriptions

Major Category	Sub-Category	Description
Material Costs	Direct	Raw materials (*e.g.*, coils of sheet metal) and purchased parts (*e.g.*, fan motors, compressors)
	Indirect	Material used during manufacturing (*e.g.*, welding rods, die oil, release media)
Manufacturing Labor	Assembly	Part/unit assembly on manufacturing line
	Fabrication	Conversion of raw material into parts ready for assembly
	Indirect	Fraction of overall labor not associated directly with product manufacturing (*e.g.*, forklift drivers, quality control)
	Supervisory	Fraction of indirect labor that is paid a higher wage
Depreciation	Equipment, Conveyor, Building	Straight line depreciation over expected life
	Tooling	Cost is allocated on a per-use basis or obsolescence, whichever is shorter
Other Overhead	Utilities	A fixed fraction of all material costs meant to cover electricity and other utility costs
	Maintenance	Based on installed equipment and tooling investment
	Property Tax and Insurance	A fixed fraction based on total unit costs

DOE entered the cost data from all the BOMs—whether they were obtained through physical teardowns or catalog teardowns—into the cost model. The cost model analysis created cost estimates for each of the products analyzed in the teardown analysis. The cost model uses specific assumptions to provide cost estimates; the following sections describe these assumptions.

5.6.1 Cost Model Overview

This section provides a general overview of the process by which the cost model converts the physical information in each product's BOM into cost information. After gathering component information through physical teardowns and organizing it into BOMs, the resulting data were used as inputs for the cost model spreadsheet. To determine the costs, DOE followed one of two different paths, depending on whether a subassembly was purchased (out-sourced) or produced in-house. For purchased parts, DOE gathered price quotations from major suppliers at different production volumes. For parts produced in-house, DOE reconstructed manufacturing processes for each part using modeling software based on internal expertise. For example, for an access panel, DOE deduced the time required for setup, handling, changeover, and punching holes, as well as the number of holes and hits. By repeating this process, DOE was able to assign labor time, equipment utilization, and other important factors to each subassembly in each of the units considered for this analysis. The last step was to convert the information into dollar values. To perform this task, DOE collected information on such factors as labor rates, tooling depreciation, and costs of purchased raw materials. DOE assumed values for these parameters using internal expertise and confidential information available to its contractors. Figure 5.6.1 provides an illustration of the cost model methodology.

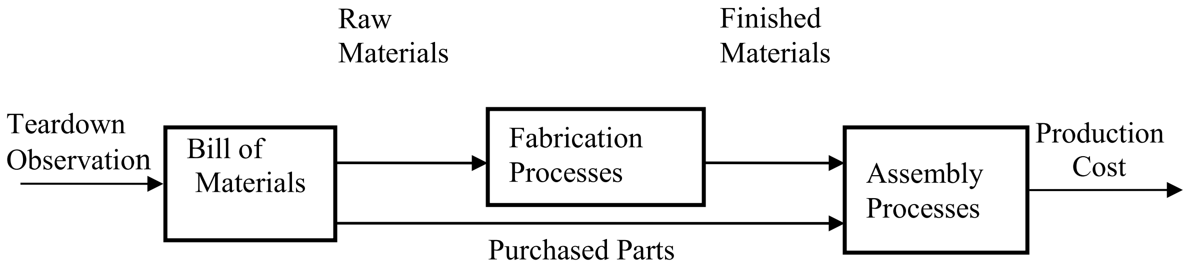


Figure 5.6.1: Cost Model Methodology

In sum, DOE assigned costs of labor, materials, and overhead to each part, whether purchased or produced in-house. DOE then aggregated single-part costs into major assemblies. Furnace fans are a component of HVAC products that include other products not associated with the cost or efficiency of the furnace fan. Therefore, DOE limited the scope of its engineering analysis to the components that comprise the furnace fan assembly, including:

- fan motor and integrated controls;
- primary control board;
- multi-staging components and controls
- impeller;
- fan housing; and
- components used to direct or guide airflow.

DOE summarized these costs in a spreadsheet. DOE repeated this same process for each unit in the engineering analysis, representing a specific efficiency level at the chosen capacity and mapped the resulting cost-efficiency points to use as a basis for developing the cost-efficiency relationships.

5.6.2 Cost Model Assumptions

Assumptions about manufacturer practices and cost structure play an important role in estimating the final cost of the products. DOE used assumptions regarding the manufacturing process parameters, (*e.g.*, equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. It then summed the values of the components into assembly costs and, finally, the total MPC for the product. The MPC includes the material, labor, depreciation, and overhead costs associated with the manufacturing facility. The material costs include both raw materials and purchased part costs. The labor costs include fabrication, assembly, and indirect and overhead (burdened) labor rates. The depreciation costs include equipment depreciation, tooling depreciation, and building depreciation. The overhead costs include indirect process costs, utilities, equipment and building maintenance, and rework. The following sections describe the cost model assumptions related to material prices, purchased parts and factory parameters.

5.6.2.1 Material Prices

DOE determined the cost of raw materials by using prices for copper, steel, and aluminum from the American Metals Market.[3] DOE noted that there have been drastic fluctuations in metal prices over the last few years. To account for these large fluctuations, DOE used prices of metals that reflect a five-year average of the Bureau of Labor Statistics Producer Price Indices (PPIs) spanning 2007 to 2012.[4]

5.6.2.2 Fabricated Parts and Purchased Parts

DOE characterized parts based on whether manufacturers fabricated them in-house or purchased them from outside suppliers. For fabricated parts, DOE estimated the price of intermediate materials (*e.g.*, tube, sheet metal) and the cost of forming them into finished parts. For purchased parts, DOE estimated the purchase price for OEMs based on discussions with the manufacturers. Whenever possible, DOE obtained price quotes directly from suppliers of the manufacturers of the units being analyzed. DOE assumed that the components in Table 5.6.2 were purchased from outside suppliers.

Table 5.6.2: Purchased Furnace Fan Components

Assembly	Purchased Sub-Assemblies
Fan Assembly	Fan Motor
	Motor Capacitor
	Impeller
Controls	Transformer
	PCB
	Multi-Staging Components

Variability in the costs of purchased parts can account for large changes in the overall MPC values calculated. The purchased part prices utilized in this study were typical values based on estimated production volumes and other factors. In actuality, purchased part costs can vary significantly based on the quantities desired and the component suppliers chosen. The role of purchase part prices in the MPC calculation is further magnified because these parts comprise significant portions of these systems by cost. Additionally, some parts, such as molded plastic components, may be produced in-house by some manufacturers and purchased by others. The choice between these options would result in changes to the calculated overall system costs.

The market for HVAC products is highly segmented, as described in chapter 3. Some products like non-weatherized gas furnaces are produced at volumes significantly larger than other products under review. In addition, some manufacturers offer most types of the HVAC products included in this rule, while other manufacturers focus on niches. DOE separated furnace fan product classes into high-volume product classes and low-volume product classes to account for these factors, which contribute to manufacturers' purchasing power and ultimately, purchased part prices. DOE categorized furnace fans used in oil furnaces as low-volume products. DOE categorized all other product classes as high-volume products. Based on feedback from manufacturers, DOE has made estimates regarding the cost of acquiring purchased parts as a function of the manufacturing volume. High-volume manufacturers operating also in lower-volume adjacent markets are expected to have purchased part price efficiencies consistent with their higher overall purchasing volume from their suppliers.

5.6.2.3 Factory Parameters

Certain factory parameters, such as fabrication rates, labor rates, and wages, also affect the cost of each unit produced. DOE factory parameter estimates were based on internal expertise and manufacturer feedback. Table 5.6.3 below lists the factory parameter assumptions used in the cost model. These factory parameters are independent of the efficiency level of the unit produced. DOE recognizes that the current production levels of high-efficiency units may be a small fraction of the current total production, but under a standard, the production levels of these units could rise to baseline levels. As stated in the previous section, DOE divided furnace fan manufacturers into high-volume manufacturers and low-volume manufacturers. The factory parameters shown below are only representative of high-volume manufacturing. Low-volume operations (i.e., oil furnace production) would show much lower manufacturing volumes and fewer shifts per day, among other factors.

Table 5.6.3: Factory Parameter Assumptions

Parameter	Furnace Fan Estimate
Actual Annual Production Volume (units/year)	1,250,000
Work Days Per Year (days)	250
Assembly Shifts Per Day (shifts)	2
Fabrication Shifts Per Day (shifts)	2
Fabrication Labor Wages ($/h)	16
Assembly Labor Wages ($/h)	16
Length of Shift (hrs)	8
Average Equipment Installation Cost (% of purchase price)	10%
Fringe Benefits Ratio	50%
Indirect to Direct Labor Ratio	33%
Average Scrap Recovery Value	30%
Building Cost ($/ft^2)	202
Worker Downtime	10%
Building Life (in years)	25
Burdened Assembly Labor Wage ($/h)	24
Burdened Fabrication Labor Wage ($/h)	24
Supervisor Span (workers/supervisor)	25
Supervisor Wage Premium (over fabrication and assembly wage)	30%

Includes non-weatherized mobile home furnaces.

5.7 MANUFACTURER SELLING PRICE

The output of the cost model is the MPC, which includes all direct costs including production-related labor, materials, depreciation, and overhead costs (as defined in section 5.6). To obtain the MSP, DOE multiplies the MPC by the manufacturer markup. The MSP includes all production and non-production costs as well as profit. The markup includes sales, general and administrative, research and development, other corporate expenses, and profit. The components of MSP are shown in Figure 5.7.1. The MPCs are obtained as an output of the cost model, and the manufacturer markup costs were derived as described in section 5.7.1 below.

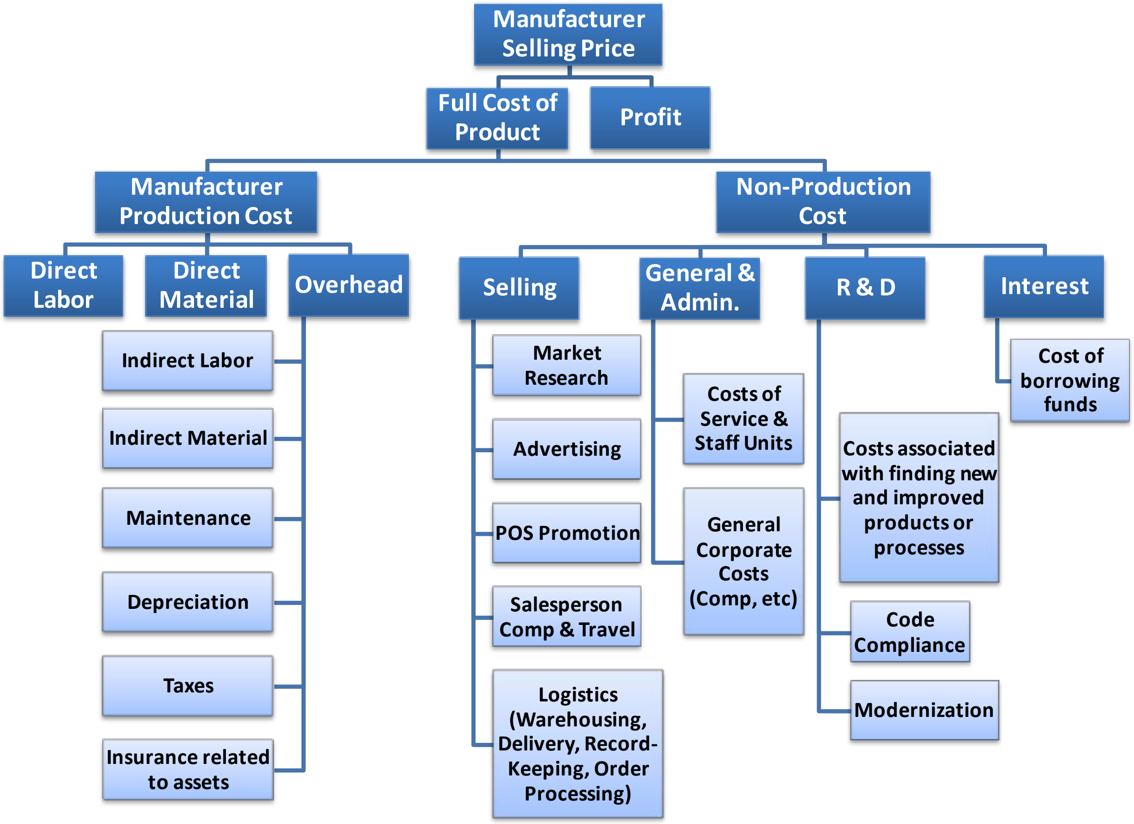


Figure 5.7.1: Components of Manufacturer Selling Price

5.7.1 Manufacturer Markup

In the NOPR, DOE used multiple standards-case markup scenarios to represent the uncertainty about the impacts of energy conservation standards on prices and profitability. In the base case, DOE used the same markups applied in the engineering analysis. In the standards case, DOE modeled two markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of new energy conservation standards: (1) a preservation of gross margin percentage scenario and (2) a preservation of earnings before interest and tax (EBIT) scenario. These scenarios lead to different markups values that, when applied to the inputted MPCs, result in varying revenue and cash flow impacts. This is discussed in detail in Chapter 12, Section 12.4.9 of the TSD.

In the engineering analyses for residential furnaces and CAC and heat pump products, DOE also included shipping costs in the MSP. DOE included shipping costs in the CAC engineering analysis because implementation of certain design options involved increasing the size and weight of the product, which increases shipping costs. DOE also included shipping costs in the furnace rulemaking to be consistent with the CAC rulemaking, even though no size increases were considered for furnaces. DOE did not include shipping costs in the MSP for its engineering analysis of furnace fans because, as discussed in detail in chapter 4 of this TSD, DOE did not consider design options that would impact the size of the HVAC product. Consequently, DOE does not expect use of the design options identified in this rulemaking to impact shipping costs.

5.7.2 MSP in the Downstream Analyses

The MSPs derived in the engineering analysis are important inputs to the life-cycle cost analysis (LCC) and the manufacturer impact analysis (MIA). In the LCC, the MSPs are necessary to calculate the total installed cost of each unit. In the MIA, DOE constructs a number of scenarios that analyze how different pricing schemes impact manufacturers financially. In the MIA, both MSP and the direct production cost components of MSP are important drivers of results. DOE discusses how the engineering analysis is used in the other analyses in chapters 8 and 12 of the TSD.

5.8 INDUSTRY COST-EFFICIENCY RELATIONSHIPS

For residential furnace fans, DOE used the cost model to estimate the MPC of various products across the full range of efficiencies and for many manufacturers with significant market share. DOE used these results as the basis for its cost-efficiency relationship for all furnace fan product classes.

DOE began its construction of the cost efficiency relationship at the baseline efficiency level. To create an industry average cost at the baseline efficiency, DOE calculated a capacity-weighted and market-weighted average of the cost modeling results for each baseline product that was torn down. DOE then calculated the capacity-weighted and market-weighted average incremental increase in cost to achieve each efficiency level above the baseline for each level analyzed up to max-tech.

DOE developed three MPC scenarios for the cost-efficiency relationships; one for the electric furnace/modular blower furnace fan product classes (high-volume product classes); one for all other high volume product classes; and one for oil furnace fan product classes (low-volume product classes). DOE found that MPC did not differ significantly across product classes at a given efficiency level and given production volume because manufacturers use similar components. Therefore, DOE assigned certain MPCs across each efficiency level for all high-volume product classes, and another set of MPCs across each efficiency level for all low-volume product classes. DOE found that the incremental cost of multi-stage electric resistance heat elements compared to single-stage electric heat for electric furnaces is less than the incremental cost of adding multi-stage capabilities to gas or oil furnaces. Consequently, DOE used the same MPC for EF/MB furnace fans as the other high-volume product classes for all non-multi-staging efficiency levels (baseline – EL3), and a lower MPC for all multi-staging efficiency levels (EL4-EL6).

5.9 RESULTS

The final result of the engineering analysis is a set of cost-efficiency relationships. DOE developed relationships for the product classes of furnace fans using the analysis methodology described above. The cost-efficiency results are shown in Table 5.9.2, *QMax **is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.**

Table 5.9.3, and Table 5.9.4 in the form of FER versus MPC for high-volume product classes and low-volume product classes, respectively. The MPC presented is not for the entire HVAC product because furnace fans are a component of the HVAC product in which they are integrated. The presented MPC includes costs only for the components of the HVAC product that impact FER, which DOE considered to be the:

- fan motor and integrated controls;
- primary control board;
- impeller;
- fan housing;
- additional multi-staging components and controls; and
- components used to direct or guide airflow.

Table 5.9.1 presents MPC estimates of the design option components for efficiency levels established using the catalog teardown / design option approach. As stated previously, DOE used the design option approach to estimate the cost and efficiency impacts for technologies that are not commercially available in furnace fan applications.

Table 5.9.1: MPC Estimates for Design Option Approach Efficiency Level Components

Efficiency Level	Design Option	High Volume MPC	Low Volume MPC
2	Inverter Controls for Inverter-Driven PSC	$30.00	$42.29
6	Premium Constant-Airflow BPM Motor	$128.19	$175.85
6	Backward-Curved Impeller	$18.00	$18.32

For efficiency level 2, the MPC represents the cost of an inverter used to drive a PSC furnace fan motor, $30 and $42.29 for high-volume and low-volume products, respectively. DOE estimated these costs based on discussions with manufacturers and on cost estimates for inverter drives used in similar residential applications, such as clothes washers. The MPC for efficiency level 6 includes the cost for a premium constant-airflow BPM motor and the cost of a backward-curved impeller. DOE used a 10% markup on the estimated MPC for a constant-airflow BPM motor as the added cost for a premium constant-airflow BPM motor. DOE found that prototype designs using backward-curved impellers could require constant-airflow BPM motors with premium characteristics that increase the cost of the motor, such as higher RPM capabilities and a smaller outer diameter. DOE used photographs and specifications found in research reports to determine cost model inputs, such as weight and fabrication processes, to estimate the MPC of the backward-curved impeller to be $18.00 and $18.32 for high-volume and low-volume products, respectively.

The MPC for efficiency levels 4, 5, and 6 includes the additional cost of multi-staging components. For gas and oil furnaces, these components include a multi-stage or modulating gas valve, improved inducer assembly, pressure switch, and additional wiring. DOE estimated the cost to achieve multi-staging to be $33.99 for high-volume product classes and $35.76 for low-volume product classes. As mentioned above, DOE developed a different multi-stage MPC for the electric furnace/modular blower product classes. DOE is aware that fewer components are required to achieve multi-staging for electric furnaces and modular blowers. DOE estimated the multi-stage MPC for the EF/MB and MH-EF/MB product classes to be $4.90.This estimate is based on electric resistance heating element kit teardowns and inspection of detailed pictures of electric resistance heat kits provided in product literature.

DOE included the cost of the primary control board (PCB) in the furnace fan MPC. DOE is aware that the MPC of the PCB needed for a constant-airflow BPM motor is higher than the PCB paired with a PSC motor. DOE is also aware that the MPC for a PCB paired with a constant-torque BPM motor is equivalent to that of a PCB needed for a PSC motor. DOE estimated the MPC of a PCB paired with a constant-torque BPM motor or PSC motor to be $15.90 and $19.57 for high-volume and low-volume products, respectively. DOE estimated the MPC of a PCB paired with a constant-airflow BPM motor to be $28.20 and $35.56 for high-volume and low-volume products, respectively.

As stated above, DOE used the cost-efficiency curves from the engineering analysis as an input to the life-cycle cost (LCC) analysis to determine the added price of the more efficient furnace fan components in HVAC equipment sold to the customer (see chapter 8 of the TSD).

Table 5.9.2, *QMax **is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.**

Table 5.9.3, and Table 5.9.4 present the MPC – FER relationship for each product class. Figure 5.9.1 illustrates example MPC vs. FER curves for the three MPC scenarios that DOE described above.

Table 5.9.2: Cost-Efficiency Results for Non-EF/MB High-Volume Product Classes

Efficiency Level	Baseline	EL1	EL2	EL3	EL4	EL5	EL6
Design Option		Improved PSC	PSC + Inverter	Constant-Torque BPM Motor	Constant-Torque BPM Motor and Multi-Staging	Constant-Airflow BPM Motor and Multi-Staging	Premium Constant-Airflow BPM Motor + Multi-Stage + BI Impeller
MPC	$81.11	$86.90	$111.11	$113.71	$147.70	$212.00	$229.56
NWG-NC	$0.057*Q_{Max}+362$	$0.051*Q_{Max}+323$	$0.043*Q_{Max}+271$	$0.033*Q_{Max}+212$	$0.029*Q_{Max}+180$	$0.027*Q_{Max}+172$	$0.025*Q_{Max}+155$
NWG-C	$0.057*Q_{Max}+395$	$0.051*Q_{Max}+354$	$0.043*Q_{Max}+296$	$0.033*Q_{Max}+231$	$0.029*Q_{Max}+196$	$0.027*Q_{Max}+188$	$0.025*Q_{Max}+169$
MH-NWG-NC	$0.057*Q_{Max}+271$	$0.051*Q_{Max}+242$	$0.043*Q_{Max}+203$	$0.033*Q_{Max}+158$	$0.029*Q_{Max}+134$	$0.027*Q_{Max}+128$	$0.025*Q_{Max}+116$
MH-NWG-C	$0.057*Q_{Max}+293$	$0.051*Q_{Max}+262$	$0.043*Q_{Max}+220$	$0.033*Q_{Max}+171$	$0.029*Q_{Max}+146$	$0.027*Q_{Max}+139$	$0.025*Q_{Max}+125$
WG-NC	$0.057*Q_{Max}+271$	$0.051*Q_{Max}+242$	$0.043*Q_{Max}+203$	$0.033*Q_{Max}+158$	$0.029*Q_{Max}+135$	$0.027*Q_{Max}+129$	$0.025*Q_{Max}+116$

$^*Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

Table 5.9.3: Cost-Efficiency Results for EF/MB High-Volume Product Classes

Efficiency Level	Baseline	EL1	EL2	EL3	EL4	EL5	EL6
Design Option		Improved PSC	PSC + Inverter	Constant-Torque BPM Motor	Constant-Torque BPM Motor and Multi-Staging	Constant-Airflow BPM Motor and Multi-Staging	Premium Constant-Airflow BPM Motor + Multi-Stage + BI Impeller
MPC	$81.11	$86.90	$111.11	$113.71	$118.61	$182.92	$200.47
EF/MB	$0.057*Q_{Max}+331$	$0.051*Q_{Max}+297$	$0.043*Q_{Max}+248$	$0.033*Q_{Max}+194$	$0.029*Q_{Max}+165$	$0.027*Q_{Max}+157$	$0.025*Q_{Max}+142$
MH-EF/MB	$0.057*Q_{Max}+211$	$0.051*Q_{Max}+189$	$0.043*Q_{Max}+158$	$0.033*Q_{Max}+123$	$0.029*Q_{Max}+105$	$0.027*Q_{Max}+100$	$0.025*Q_{Max}+90$

Table 5.9.4: Cost-Efficiency Results for Low-Volume Product Classes

Efficiency Level	**Baseline**	**EL1**	**EL2**	**EL3**	**EL4**	**EL5**	**EL6**
Design Option		Improved PSC	PSC + Inverter	Constant-Torque BPM Motor	Constant-Torque BPM Motor and Multi-Staging	Constant-Airflow BPM Motor and Multi-Staging	Premium Constant-Airflow BPM Motor + Multi-Stage + BI Impeller
MPC	\$99.24	\$108.04	\$141.53	\$146.17	\$181.93	\$269.18	\$287.05
NWO-NC	$0.057*Q_{Max}+336$	$0.051*Q_{Max}+301$	$0.043*Q_{Max}+252$	$0.033*Q_{Max}+196$	$0.029*Q_{Max}+167$	$0.027*Q_{Max}+159$	$0.025*Q_{Max}+144$

$^*Q_{Max}$ is the airflow, in cfm, at the maximum airflow-control setting measured during the proposed DOE test procedure.

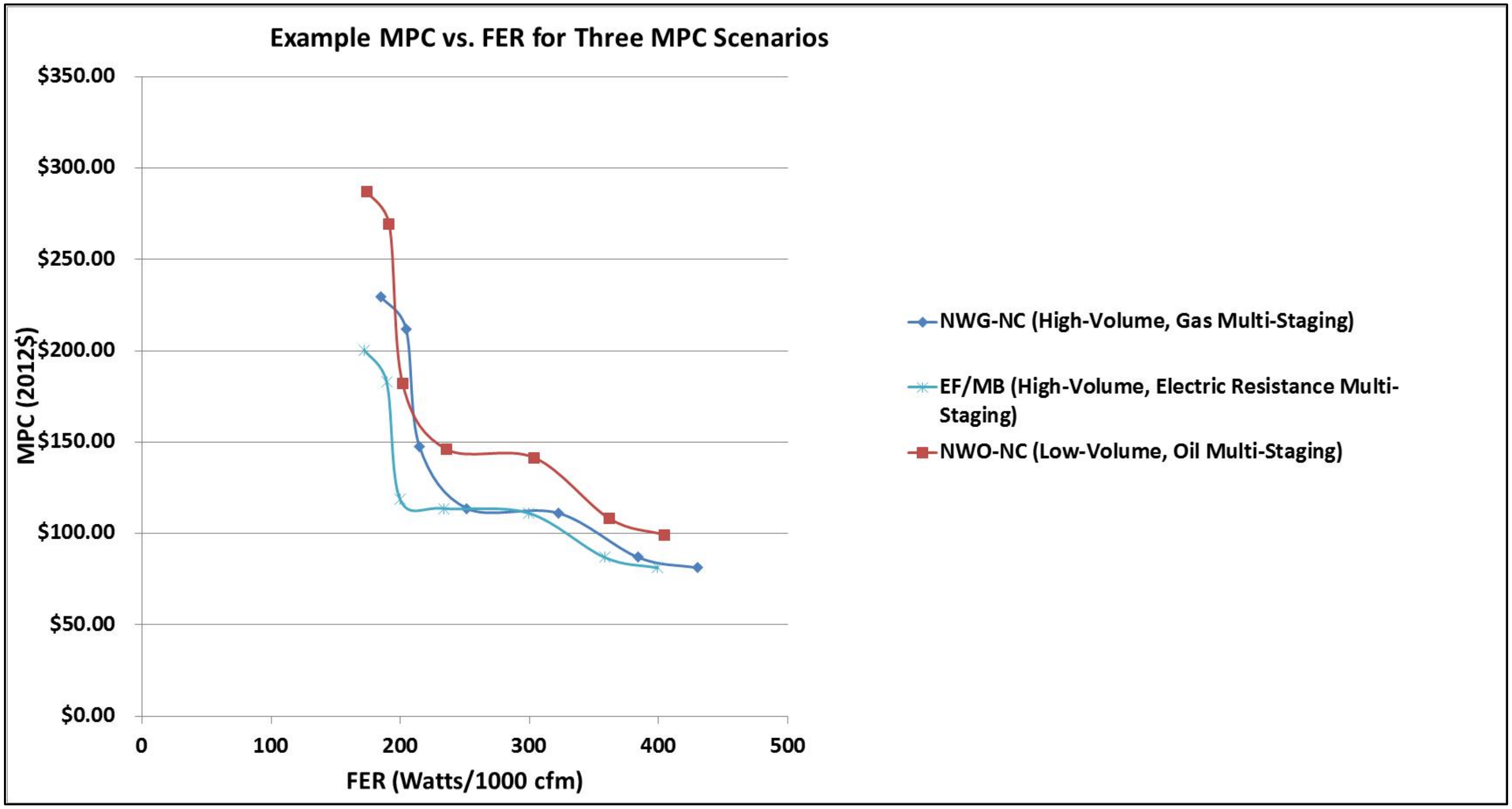


Figure 5.9.1: Example MPC vs. FER Curves for Three MPC Scenarios

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CHAPTER 6. MARKUPS ANALYSIS

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CHAPTER 6. MARKUP ANALYSIS

6.1 INTRODUCTION

To carry out its analyses, the U.S. Department of Energy (DOE) needed to determine the cost to the consumer of baseline products and the cost of more efficient units the consumer would purchase under new energy conservation standards. DOE determined such costs based on engineering estimates of manufacturing costs plus appropriate markups based on the distribution channels for furnace fans.

For wholesalers and contractors, DOE estimated a baseline markup and an incremental markup. DOE defines a baseline markup as a multiplier that converts the manufacturing selling price of equipment with baseline efficiency to the consumer purchase price for the equipment at the same baseline efficiency level. An incremental markup is defined as the multiplier to convert the incremental increase in manufacturing selling price of higher efficiency equipment to the consumer purchase price for the same equipment. Because companies mark up the price to cover business cost and profit margin at each step in the distribution channel, both baseline and incremental markups are dependent on the particular distribution channel, as described in Section 6.2.

The components used to produce a furnace fan are usually purchased by furnace manufacturers who assemble the furnace fan, which is then installed in a furnace. From this point, the furnace fans are passed along the distribution channels as part of furnaces. Essentially, various markups applied to these products by different market participants are also the markups applied to furnace fans, whose manufacturing costs account for a portion of the total manufacturing costs of the finished products. Therefore, DOE developed the markup analysis for furnace fans based on furnaces. According to industry sources, the market for furnace fans replacing a failed furnace fan is very small, and DOE did not include this market in its analysis.

At each point in the distribution channel, companies mark up the price of a product to cover their business costs and profit margin. In financial statements, gross margin is the difference between the company revenue and the company cost of sales or cost of goods sold (*CGS*). The gross margin takes account of the expenses of companies in the distribution channel, including overhead costs (sales, general, and administration); research and development (R&D) and interest expenses; depreciation; and taxes—and company profits. In order for sales of a product to contribute positively to company cash flow, the product's markup must be greater than the corporate gross margin. Products command lower or higher markups, depending on company expenses associated with the product and the degree of market competition.

6.2 DISTRIBUTION CHANNELS

Two types of distribution channels describe how most furnaces (and the furnace fans in them) pass from the manufacturer to the consumer. The first distribution channel applies to furnaces installed in replacement markets. In the replacement distribution channel, the manufacturer generally sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it to the consumer.[a] The second distribution channel applies to furnaces that are installed in new construction and, thus, includes an additional link in the chain—the general contractor. In the new construction distribution channel, the manufacturer sells the equipment to a wholesaler, who in turn sells it to a mechanical contractor, who in turn sells it to a general contractor.

Figure 6.2.1 illustrates the two main distribution channels for most residential furnaces.

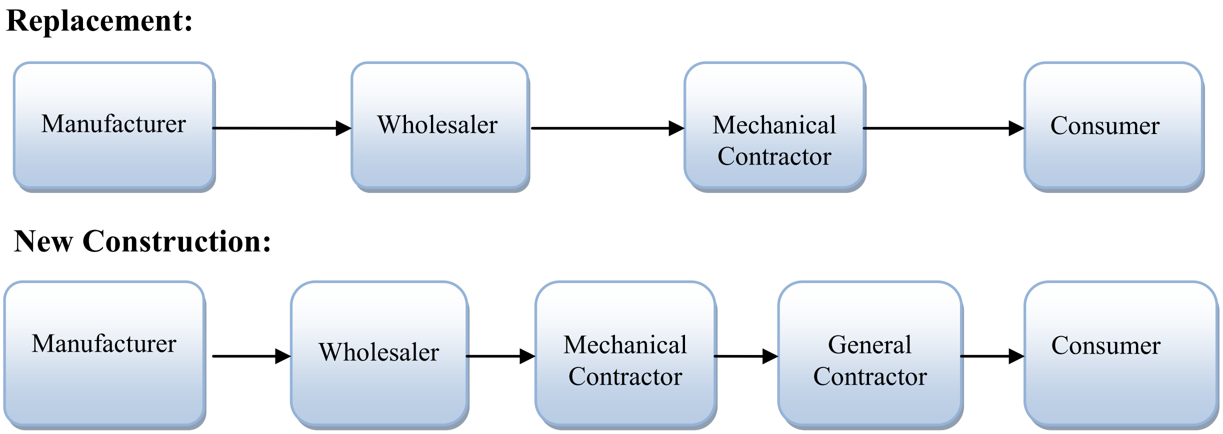

Figure 6.2.1 Distribution Channels for Residential Furnaces

Manufactured home gas furnaces are sold as part of manufactured homes, so these furnaces have a specific distribution chain (Figure 6.2.2) when purchased for the new construction market. The furnace manufacturer sells furnaces to the maker of the manufactured home, who installs the equipment in the home. The manufactured home manufacturer then sells the home to a manufactured home dealer, who in turns sells it to a homebuyer and provides installation services. The equipment manufacturer markup for manufactured home gas furnaces is identical to the manufacturer markup for other furnaces. For manufactured home furnaces purchased for the replacement market, the distribution channel should be the same as the replacement distribution channel for non-weatherized gas furnaces.

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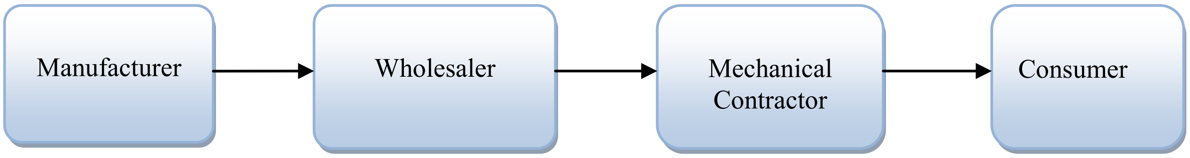
[a] One manufacturer uses a one-step distribution chain (manufacturer to contractor) and is the only known exception. Several large retailers are trying to step between wholesalers and contractors, but most experts do not expect the trend to change the distribution chain significantly in the near term.

Replacement:



New Construction:

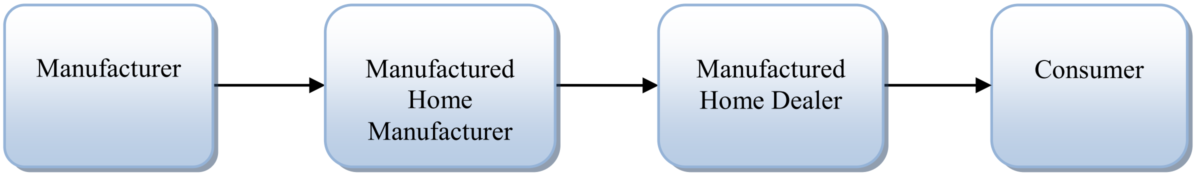


Figure 6.2.2 Distribution Channels for Manufactured Home Gas Furnaces

6.3 MANUFACTURER MARKUP

DOE uses manufacturer markups to transform a manufacturer's product cost into a manufacturer sales price. Using the *CGS* and gross margin (GM), the manufacturer markup can be calculated as follows:

$$MU_{MFG} = \frac{CGS_{MFG} + GM_{MFG}}{CGS_{MFG}}$$

Where:

MU_{MFG} = manufacturer markup,
CGS_{MFG} = manufacturer cost of goods sold, and
GM_{MFG} = manufacturer gross margin.

The manufacturer's *CGS* (or manufacturer production cost (*MPC))* plus its *GM* equals the manufacturer selling price (*MSP*).

The methodology DOE used to determine manufacturer markup for furnace fans is similar to the heating, ventilating, and air conditioning (HVAC) products final rule included in chapter 5 of the HVAC products direct final rule technical support document (TSD).[b] DOE used U.S. Security and Exchange Commission (SEC) 10-K reports from publicly owned residential cooling and heating product companies to estimate manufacturer markups. Table 6.3.1 presents manufacturer markups by eight different product classes considered in this analysis.

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[b] The TSD for the direct final rule for HVAC products is available at the following website: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/hvac_ch_05_engineering_2011-04-22.pdf

Table 6.3.1 Manufacturer Markups by Furnace Fan Product Class

Product Class	Baseline Markup
Non-weatherized, Non-condensing Gas Furnaces	1.30
Non-weatherized, Condensing Gas Furnaces	1.31
Weatherized Gas Furnace	1.27
Oil Furnace	1.35
Electric Furnace / Modular Blower	1.19
Manufactured Home Non-weatherized, Non-condensing Gas Furnaces	1.25
Manufactured Home Non-weatherized, Condensing Gas Furnaces	1.25
Manufactured Home Electric Furnace /Modular Blower	1.15

6.4 WHOLESALER AND CONTRACTOR MARKUPS

DOE examined the manner in which wholesaler and contractor markups may change in response to changes in furnace efficiency levels and other factors. Using the available data, DOE estimated that there are differences between *incremental* markups on incremental equipment costs of higher efficiency products and the *baseline* markup on direct business costs of products with baseline efficiency.

DOE derived the wholesaler and contractor markups from three key assumptions about the costs associated with furnaces. DOE based the wholesaler and mechanical contractor markups on firm-level income statement data, while it based the general contractor markups on U.S. Census Bureau data for the residential building construction industry. DOE obtained the firm income statements from the Heating, Air-conditioning & Refrigeration Distributors International (HARDI) 2012 Profit Report and from the Air Conditioning Contractors of America (ACCA) 2005 Financial Analysis.[1, 2] HARDI and ACCA are trade associations representing wholesalers and mechanical contractors, respectively. DOE used the financial data from the 2007 U.S. Census of Business for developing general contractor markups in the same form as the income statement data for wholesalers and mechanical contractors. These income statements break down the components of all costs incurred by firms that supply and install heating and air-conditioning equipment.[c] The key assumptions used to estimate markups using these financial data are:

1. The firm income statements faithfully represent the various average costs incurred by firms distributing and installing residential furnaces.

2. These costs can be divided into two categories: 1) costs that vary in proportion to the MSP of residential furnaces (variant costs); and 2) costs that do not vary with the MSP of residential furnaces (invariant costs).

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[c] Wholesalers and mechanical contractors to which these reports refer handle multiple commodity lines, including residential and commercial air conditioners and warm-air furnaces.

3. Overall, wholesale and contractor prices for residential furnaces vary in proportion to the wholesale and contractor costs for residential furnaces included in the income statements.

In support of the first assumption, the income statements itemize firm costs into a number of expense categories, including direct costs to purchase or install the equipment, operating labor and occupancy costs, and other operating costs and profit. Although wholesalers and contractors tend to handle multiple commodity lines, including room air conditioners, furnaces, central air conditioners and heat pumps, and boilers, the data provide the most accurate available indication of the expenses associated with residential furnaces.

Information obtained from the trade literature, and from selected HVAC wholesalers, contractors, and consultants, tends to support the second assumption; this information indicates that wholesale and contractor markups vary according to the quantity of labor and materials used to distribute and install appliances. In the following discussion, DOE assumes a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses) and those that do (operating expenses and profit).

In support of the third assumption, the HVAC wholesaler and contractor industry is competitive, and consumer demand for heating and air conditioning is inelastic, *i.e.,* the demand is not expected to decrease significantly with an increase in the price of equipment. The large number of HVAC firms listed in the 2007 Census indicates the competitive nature of the market. For example, there are more than 700 HVAC manufacturers, [3] 5,300 wholesalers of heat pumps and air-conditioning equipment,[4] more than 170,000 general residential contractors, 36,000 commercial and institutional building contractors, [5] and 91,000 HVAC contractors[6] listed in the 2007 Census. Following standard economic theory, competitive firms facing inelastic demand either set prices in line with costs or quickly go out of business.[7]

DOE concluded that markups for more efficient equipment are unlikely to be proportional to all direct costs. When the wholesaler's purchase price of equipment increases, for example, only a fraction of a business' expenses increases, while the remainder may stay relatively constant. For example, if the unit price of a furnace unit increases by 30 percent due to improved efficiency, it is unlikely that the cost of secretarial support in an administrative office will increase by 30 percent also. Therefore, DOE assumed that incremental markups cover only those costs that scale with a change in the MSP (variant costs).

6.4.1 Approach for Wholesaler Markup

Using the above assumptions, DOE developed baseline and incremental markups for wholesalers using the firm income statement from the HARDI 2012 Profit Report (appendix 6-A.1). The baseline markups cover all of the wholesaler's costs (both *invariant costs* and *variant costs*). Here, variant costs were defined as costs that likely vary in proportion to the change in MSP induced by increased efficiency standards; in contrast, invariant costs were defined as costs that are unlikely to vary in proportion to the change in MSP due to increased efficiency standards. DOE calculated the baseline markup for wholesalers using the following equation:

$$MU_{BASE} = \frac{CGS_{WHOLE} + GM_{WHOLE}}{CGS_{WHOLE}} = \frac{CGS_{WHOLE} + (IVC_{WHOLE} + VC_{WHOLE})}{CGS_{WHOLE}}$$

Where:

MU_{BASE} = baseline wholesaler markup,
CGS_{WHOLE} = wholesaler cost of goods sold,
GM_{WHOLE} = wholesaler gross margin,
IVC_{WHOLE} = wholesaler invariant costs, and
VC_{WHOLE} = wholesaler variant costs.

Incremental markups are coefficients that relate the change in the MSP of more energy-efficient models, or those products that meet the requirements of new energy conservation standards, to the change in the wholesaler sales price. Incremental markups cover only those costs that scale with a change in the MSP (variant costs, *VC*). It calculated the incremental markup (MU_{INCR}) for wholesalers using the following equation:

$$MU_{INCR} = \frac{CGS_{WHOLE} + VC_{WHOLE}}{CGS_{WHOLE}}$$

Where:

MU_{INCR} = incremental wholesaler markup,
CGS_{WHOLE} = wholesaler cost of goods sold, and
VC_{WHOLE} = wholesaler variant costs.

6.4.2 Derivation of Wholesaler Markups

Wholesalers reported median data in a confidential survey that HARDI conducted of member firms.[2] In the survey, HARDI itemized revenues and costs into cost categories, including direct equipment expenses (cost of goods sold), labor expenses, occupancy expenses, other operating expenses, and profit. DOE presents these data in full in appendix 6-A.1. Table 6.4.1 summarizes them as cost-per-dollar sales revenue in the first data column.

Table 6.4.1 Wholesaler Expenses and Markups

Descriptions	**Per Dollar Sales Revenue** ***$***	**Per Dollar Cost of Goods** ***$***
Direct Cost of Equipment Sales: Cost of goods sold	0.737	1.000
Labor Expenses: Salaries and benefits	0.151	0.205
Occupancy Expense: Rent, maintenance, and utilities	0.036	0.049
Other Operating Expenses: Depreciation, advertising, and insurance.	0.055	0.075
Operating Profit	0.021	0.028
Wholesaler Baseline Markup ($MU_{WHOLE\ BASE}$)		**1.357**
Incremental Markup ($MU_{WHOLE\ INCR}$)		**1.103**

Source: Heating, Air Conditioning & Refrigeration Distributors International. 2012. 2012 Profit Report (2011 Data).

In this case, direct equipment expenses (cost of goods sold) represent about \$0.74 per dollar sales revenue, so for every \$1 wholesalers take in as sales revenue, \$0.74 is used to pay the direct equipment costs. Labor expenses represent \$0.15 per dollar sales revenue, occupancy expenses represent \$0.04, other operating expenses represent \$0.06, and profit accounts for \$0.02 per dollar sales revenue.

DOE converted the expenses per dollar sales into expenses per dollar cost of goods sold, by dividing each figure in the first data column by \$0.74 (*i.e.,* cost of goods sold per dollar of sales revenue). The data in column two show that, for every \$1.00 the wholesaler spends on equipment costs, the wholesaler allocates \$0.205 to cover labor costs, \$0.049 to cover occupancy expenses, \$0.075 for other operating expenses, and \$0.028 in profits. This totals to \$1.357 in sales revenue earned for every \$1.00 spent on equipment costs. Therefore, the wholesaler baseline markup ($MU_{WHOLE\ BASE}$) is 1.357 (\$1.357 ÷ \$1.00).

DOE also used the data in column two to estimate the incremental markup. The incremental markup depends on which of the costs in Table 6.4.1 are variant and which are invariant with MSP. For example, for a \$1.00 increase in the MSP, if all of the other costs scale with the MSP (*i.e.,* all costs are variant), the increase in wholesale price will be \$1.360, implying that the incremental markup is 1.360, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a \$1.00 increase in the MSP will lead to a \$1.00 increase in the wholesale price, for an incremental markup of 1.0. DOE believes that the labor and occupancy costs will be invariant and that the other operating costs and profit will scale with the MSP (*i.e.,* be variant). In this case, for a \$1.00 increase in the MSP, the wholesale price will increase to match changes in ”other” operating costs and operating profit of \$0.076, which when divided by 73.7 cents in cost of goods sold yields an increase of \$0.103, giving a wholesaler incremental markup ($MU_{WHOLE\ INCR}$) of 1.103. See appendix 6-A.1 for cost details.

6.4.3 Approach for Mechanical and General Contractor Markups

The type of financial data used to estimate markups for wholesalers is also available for mechanical contractors and general contractors from the 2007 Economic Census and ACCA 2005 Financial Analysis. To estimate mechanical contractor markups for furnaces, DOE collected financial data from the *Plumbing and HVAC Contractors* (NAICS 23822) series from the 2007 Economic Census and from ACCA 2005 Financial Analysis. To estimate general contractor markups, DOE collected data from the Residential Building Construction series from the 2007 Economic Census, which is the aggregation of *New Single-Family General Contractors* (NAICS 236115), *New Multifamily Housing Construction* (NAICS 236116), *New Housing Operative Builders* (NAICS 236117), and *Residential Remodelers* (NAICS 236118). ACCA financial data provide GM as percent of sales for the mechanical contractor industry; therefore, baseline markup can be derived with the following equation:

$$MU_{BASE} = \frac{Sales(\%)}{Sales(\%) - GM(\%)}$$

The U.S. Census data include the number of establishments, payroll for construction workers, value of construction, cost of materials, and cost of subcontracted work at both state and national levels. DOE calculated the baseline markup for mechanical contractors and general contractors using the following equation:

$$MU_{BASE} = \frac{V_{CONSTRUCT}}{Pay + MatCost + SubCost}$$

Where:

MU_{BASE} = baseline mechanical contractor or general contractor markup,
$V_{CONSTRUCT}$ = value of construction,
Pay = payroll for construction workers,
$MatCost$ = cost of materials, and
$SubCost$ = cost of subcontracted work.

Analogously, DOE estimated the incremental mechanical contractor and general contractor markups by only marking up those costs that scale with a change in the MSP (variant costs, *VC*) for more energy-efficient products. As stated above, DOE assumes a division of costs between those that do not scale with the manufacturer price (labor and occupancy expenses), and those that do (other operating expenses and profit). Hence, DOE categorized the Census cost data in each major cost category and estimated markups using the following equation:

$$MU_{INCR} = \frac{CGS_{CONT} + VC_{CONT}}{CGS_{CONT}}$$

Where:

MU_{INCR} = incremental contractor markup,
CGS_{CONT} = contractor cost of goods sold, and
VC_{CONT} = contractor variant costs.

6.4.4 Derivation of National Mechanical Contractor Markups

The 2007 Economic Census provides Geographic Area Series for the *Plumbing and HVAC Contractors* (NAICS 23822) sector, which contains national average sales and cost data, including value of construction, cost of subcontract work, cost of materials, and payroll for construction workers. It also provides the cost breakdown of gross margin, including labor expenses, occupancy expenses, other operating expenses, and profit. The gross margin provided by the U.S. Census is disaggregated enough that DOE was able to determine the invariant (labor and occupancy expenses) and variant (other operating expenses and profits) costs for this particular sector. By using the equation mentioned above, baseline and incremental markups were estimated. The markup results are presented in Table 6.4.2. (Appendix 6-A.2 contains the full set of data.)

Table 6.4.2 Mechanical Contractor Expenses and Markups Based on Census Bureau Data

Description	Mechanical Contractor Expenses or Revenue	
	Per Dollar Sales Revenue *$*	Per Dollar Cost of Goods *$*
Direct Cost of Equipment Sales: Cost of goods sold	0.68	1.00
Labor Expenses: Salaries (indirect) and benefits	0.18	0.26
Occupancy Expense: Rent, maintenance, and utilities	0.02	0.03
Other Operating Expenses: Depreciation, advertising, and insurance.	0.08	0.12
Net Profit Before Taxes	0.04	0.06
Baseline Markup ($MU_{MECH\ BASE}$): Revenue per dollar cost of goods		**1.48**
Incremental Markup ($MU_{MECH\ INCR}$): Increased revenue per dollar increase in cost of goods sold		**1.18**

Source: U.S. Census Bureau. 2007. Plumbing, Heating, and Air-Conditioning Contractors. Sector 23: 238220. Construction: Industry Series, Preliminary Detailed Statistics for Establishments, 2007.

The first data column in Table 6.4.2 provides the cost of goods sold and a list of gross margin components as expenses per dollar of sales revenue. As shown in the table, the direct cost of sales represents about $0.68 per dollar sales revenue to the mechanical contractor, and the gross margin totals $0.32 per dollar sales revenue. DOE converted these expenses per dollar sales into revenue per dollar cost of goods sold by dividing each figure in the first data column by $0.68. For every $1.00 the mechanical contractor spends on equipment costs, the mechanical contractor earns $1.00 in sales revenue to cover the equipment cost and $0.48 to cover the other costs. This totals $1.48 in sales revenue earned for every $1.00 spent on equipment costs. This is equivalent to a baseline markup ($MU_{MECH\ CONT\ BASE}$) of 1.48 for mechanical contractors.

DOE was also able to use the data in column two in Table 6.4.2 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (*i.e.,* all costs are variant), the increase in general contractor price will be $1.48, implying that the incremental markup is 1.48 or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a $1.00 increase in the equipment price will lead to a $1.00 increase in the general contractor price, for an incremental markup of 1.0. DOE believes the labor and occupancy costs are invariant and the other operating costs and profit scale with the equipment price (*i.e.,* are variant). In this case, for a $1.00 increase in the equipment price, the general contractor price will increase by $1.18, giving a general contractor incremental markup ($MU_{MECH\ CONT\ INCR}$) of 1.18.

6.4.4.1 Markups for Mechanical Contractors in the Replacement and New Construction Markets

DOE derived the baseline and incremental markups for both replacement and new construction markets using the 2007 Economic Census industrial cost data[8] supplemented with the most recent ACCA 2005 financial data[1]. The 2007 Economic Census provides sufficient detailed cost breakdown for the *Plumbing and HVAC Contractors* (NAICS 23822) sector so that DOE was able to estimate baseline and incremental markups for mechanical contractors. However, the 2007 Economic Census does not separate the mechanical contractor market into replacement and new construction markets. In order to calculate markups for these two markets, DOE utilized 2005 ACCA financial data, which reports gross margin data for the entire mechanical contractor market and for both the replacement and new construction markets.

The HVAC contractors, defined here as mechanical contractors, reported median cost data in an ACCA 2005 financial analysis of the HVAC industry. These data are shown in Table 6.4.3.

Table 6.4.3 Baseline Markup, All Mechanical Contractors

	Contractor Expenses or Revenue	
Description	**Per Dollar Sales Revenue *\$***	**Per Dollar Cost of Goods *\$***
Direct Cost of Equipment Sales: Cost of goods sold	0.73	1.00
Gross Margin: Labor, occupancy, operating expenses, and profit	0.27	0.37
Revenue: Baseline revenue earned per dollar cost of goods		**1.37**
Baseline Markup ($MU_{MECH\ CONT\ BASE}$)		**1.37**

Source: Air Conditioning Contractors of America. 2005. Financial Analysis for the HVACR Contracting Industry.

Table 6.4.4 summarizes the gross margin and resulting baseline markup data for all mechanical contractors that serve the replacement and new construction markets.

Table 6.4.4 Baseline Markups for the Replacement and New Construction Markets, All Mechanical Contractors

	Contractor Expenses or Revenue by Market Type			
	Replacement		New Construction	
Description	**Per Dollar Sales Revenue *\$***	**Per Dollar Cost of Goods *\$***	**Per Dollar Sales Revenue *\$***	**Per Dollar Cost of Goods *\$***
Direct Cost of Equipment Sales: Cost of goods sold	0.70	1.00	0.75	1.00
Gross Margin: Labor, occupancy, operating expenses, and profit	0.30	0.43	0.25	0.33
Baseline Markup ($MU_{MECH\ CONT\ BASE}$): Revenue per dollar cost of goods	NA	**1.43**	NA	**1.33**

Source: Air Conditioning Contractors of America. 2005. Financial Analysis for the HVACR Contracting Industry.

Using the baseline markup data from Table 6.4.4 and results from Table 6.4.3, DOE calculated that the baseline markups for the replacement and new construction markets are 4.4 percent higher and 2.9 percent lower, respectively, than for all mechanical contractors serving all markets.

The markup deviations (*i.e.,* 4.4 percent higher and 2.9 percent lower for the replacement and new construction markets, respectively) derived for all mechanical contractors were then applied to the baseline markup of 1.48 and the incremental markup of 1.18 estimated for the *Plumbing and HVAC Contractors* (NAICS 23822) sector in Table 6.4.2. DOE assumed that this deviation applies equally to the baseline and incremental markups calculated from the 2007 Economic Census. The results of the baseline and incremental markups for the replacement and new construction markets served by mechanical contractors are shown in Table 6.4.5.

Table 6.4.5 Baseline and Incremental Markups for the Replacement and New Construction Markets

	Baseline Markup	Incremental Markup
Replacement Market	1.55	1.23
New Construction Market	1.44	1.15

6.4.5 Derivation of General Contractor Markups

DOE derived markups for general contractors from U.S. Census Bureau data for the residential building construction sector.[9] The residential construction sector includes establishments primarily engaged in construction work, including new construction work, additions, alterations, and repairs. The U.S. Census Bureau data for the construction sector include detailed statistics for establishments with payrolls, similar to the data reported by HARDI for wholesalers. The primary difference is that the U.S. Census Bureau reports itemized revenues and expenses for the construction industry as a whole in total dollars rather than in typical values for an average or representative business. Because of this, DOE assumed that the total dollar values that the U.S. Census Bureau reported, once converted to a percentage basis, represent revenues and expenses for an average or typical contracting business. Similar to the data for wholesalers, Table 6.4.6 summarizes the expenses for general contractors as expenses per dollar sales revenue in the first data column. (Appendix 6-A.3 contains the full set of data.)

Table 6.4.6 General Contractor Expenses and Markups

	General Contractor Expenses or Revenue	
Description	**Per Dollar Sales Revenue** ***$***	**Per Dollar Cost of Goods** ***$***
Direct Cost of Equipment Sales: Cost of goods sold	0.68	1.00
Labor Expenses: Salaries (indirect) and benefits	0.08	0.12
Occupancy Expense: Rent, maintenance, and utilities	0.01	0.01
Other Operating Expenses: Depreciation, advertising, and insurance.	0.06	0.09
Net Profit Before Taxes	0.17	0.25
Baseline Markup ($MU_{GEN\ CONT\ BASE}$): Revenue per dollar cost of goods		**1.48**
Incremental Markup ($MU_{GEN\ CONT\ INCR}$): Increased revenue per dollar increase in cost of goods sold		**1.34**

Source: U.S. Census Bureau. 2007. Residential Building Construction. Sector 23: 236115-236118. Construction: Industry Series: Preliminary Detailed Statistics for Establishments: 2007.

As shown in the first column, the direct cost of sales represents about $0.68 per dollar sales revenue to the general contractor. Labor expenses represent $0.08 per dollar sales revenue, occupancy expenses represent $0.01 per dollar sales revenue, other operating expenses represent $0.03, and profit makes up $0.20 per dollar sales revenue.

DOE converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by $0.68. The data in column two show that, for every $1.00 the general contractor spends on equipment costs, the general contractor earns $1.00

in sales revenue to cover the equipment cost, $0.12 to cover labor costs, $0.01 to cover occupancy expenses, $0.09 for other operating expenses, and $0.25 in profits. This totals to $1.48 in sales revenue earned for every $1.00 spent on equipment costs. Thus, the general contractor baseline markup ($MU_{GEN\ CONT\ BASE}$) is 1.48.

DOE was also able to use the data in column two in Table 6.4.6 to estimate the incremental markups, after classifying the costs as either invariant or variant. At one extreme, if all of the other costs scale with the equipment price (*i.e.,* all costs are variant), the increase in general contractor price will be $1.48, implying that the incremental markup is 1.48, or the same as the baseline markup. At the other extreme, if none of the other costs are variant, then a $1.00 increase in the equipment price will lead to a $1.00 increase in the general contractor price, for an incremental markup of 1.0. DOE believes the labor and occupancy costs are invariant and the other operating costs and profit scale with the equipment price (*i.e.,* are variant). In this case, for a $1.00 increase in the equipment price, the general contractor price will increase by $1.34, giving a general contractor incremental markup ($MU_{GEN\ CONT\ INCR}$) of 1.34.

6.5 DERIVATION OF REGIONAL MARKUPS

In this analysis, DOE considered seven different furnace product classes. DOE assumed a market saturation rate for each product class that varies by geographical region, based on the shipments forecasts for the year 2019. Therefore, regional markups were calculated for each furnace fan product class.

Wholesalers and mechanical and general contractors in the furnace industry were divided into the 30 regions[d] provided by the latest Residential Energy Consumption Survey (RECS)[10]. Regional baseline and incremental markups were derived using the region/state level data from the 2012 HARDI Profit Report and the 2007 Economic Census.

6.5.1 Estimation of Regional Wholesaler Markups

Based on the regional income statement from the 2012 HARDI Profit Report, DOE estimated baseline and incremental markups for the seven HARDI regions (Northeastern, Mid-Atlantic, Southwestern, Great Lakes, Central, Southwestern, and Western) using the methodology shown in Table 6.4.1. Next, each state in each region was assigned the HARDI regional baseline and incremental markups for the region to which it belongs. Third, DOE assigned all states to one of the 30 regions used in the analysis and then calculated projected 2019 housing-weighted[e] baseline and incremental markup averages for each region. The results are summarized in Table 6.5.1.

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[d] RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See appendix 7-A for more details.

[e] See appendix 7-A for more details on the determination of projected 2019 housing estimates by state.

Table 6.5.1 Regional Wholesaler Markups for Furnaces

RECS Regions	State(s)	Baseline MU	Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.366	1.081
2	Massachusetts	1.366	1.081
3	New York	1.366	1.081
4	New Jersey	1.351	1.105
5	Pennsylvania	1.354	1.102
6	Illinois	1.362	1.099
7	Indiana, Ohio	1.357	1.099
8	Michigan	1.357	1.099
9	Wisconsin	1.362	1.099
10	Iowa, Minnesota, North Dakota, South Dakota	1.362	1.099
11	Kansas, Nebraska	1.362	1.099
12	Missouri	1.362	1.099
13	Virginia	1.351	1.105
14	Delaware, District of Columbia, Maryland	1.351	1.105
15	Georgia	1.340	1.106
16	North Carolina, South Carolina	1.340	1.106
17	Florida	1.340	1.106
18	Alabama, Kentucky, Mississippi	1.346	1.103
19	Tennessee	1.340	1.106
20	Arkansas, Louisiana, Oklahoma	1.348	1.119
21	Texas	1.348	1.119
22	Colorado	1.362	1.099
23	Idaho, Montana, Utah, Wyoming	1.411	1.113
24	Arizona	1.416	1.115
25	Nevada, New Mexico	1.387	1.116
26	California	1.416	1.115
27	Oregon, Washington	1.416	1.115
28	Alaska	1.416	1.115
29	Hawaii	1.416	1.115
30	West Virginia	1.357	1.099

6.5.2 Estimation of Regional Mechanical Contractor Markups

The 2007 Economic Census provides Geographic Area Series for the *Plumbing and HVAC Contractors* (NAICS 23822) sector, which contains state-level sale and cost data, including value of construction, cost of subcontract work, cost of materials, and payroll for construction workers. By using the equation mentioned in Section 6.4.3 DOE was able to estimate baseline markups for each state. Because the Census does not provide more disaggregated cost data, DOE was not able to differentiate between invariant and variant cost.

Alternatively, DOE calculated the national baseline and incremental markups (Table 6.4.2) and found that the incremental markup is around 20 percent lower than the baseline markups. DOE further derived the state-level incremental markups by applying this ratio to the baseline markup in each state, assuming that this deviation applies equally to all states. (Appendix 6-A.4.1 contains the full set of data.)

In order to estimate the baseline and incremental markups for both replacement and new construction markets for each state, DOE applied the markup deviations (*i.e.,* 4.4 percent higher and 2.9 percent lower for the replacement and new construction markets, respectively) derived in Section 6.4.4.1 to the statewide baseline and incremental markups. DOE assumed that this deviation of replacement and new construction markets applies equally to the baseline and incremental markups.

Lastly, DOE divided all states among the 30 regions and then calculated projected 2019 housing-weighted average baseline and incremental markups for mechanical contractors for each region, as shown in Table 6.5.2.

Table 6.5.2 Projected 2019 Housing-Weighted Regional Mechanical Contractor Markups for Furnaces

RECS Regions	State(s)	Replacement Baseline MU	Replacement Incremental MU	New Construction Baseline MU	New Construction Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.557	1.246	1.449	1.159
2	Massachusetts	1.538	1.231	1.431	1.145
3	New York	1.600	1.280	1.488	1.191
4	New Jersey	1.583	1.267	1.473	1.178
5	Pennsylvania	1.479	1.183	1.375	1.100
6	Illinois	1.577	1.262	1.467	1.173
7	Indiana, Ohio	1.563	1.250	1.453	1.163
8	Michigan	1.530	1.224	1.423	1.138
9	Wisconsin	1.510	1.208	1.404	1.123
10	Iowa, Minnesota, North Dakota, South Dakota	1.530	1.224	1.423	1.139
11	Kansas, Nebraska	1.460	1.168	1.358	1.086
12	Missouri	1.479	1.183	1.376	1.101
13	Virginia	1.557	1.246	1.448	1.158
14	Delaware, District of Columbia, Maryland	1.491	1.193	1.386	1.109
15	Georgia	1.474	1.179	1.371	1.096
16	North Carolina, South Carolina	1.501	1.201	1.396	1.117
17	Florida	1.512	1.210	1.407	1.125
18	Alabama, Kentucky, Mississippi	1.526	1.220	1.419	1.135
19	Tennessee	1.477	1.182	1.374	1.099
20	Arkansas, Louisiana, Oklahoma	1.541	1.233	1.434	1.147
21	Texas	1.498	1.198	1.393	1.115
22	Colorado	1.531	1.225	1.424	1.139
23	Idaho, Montana, Utah, Wyoming	1.491	1.193	1.387	1.110
24	Arizona	1.580	1.264	1.470	1.176
25	Nevada, New Mexico	1.537	1.230	1.430	1.144
26	California	1.607	1.286	1.495	1.196
27	Oregon, Washington	1.579	1.263	1.469	1.175
28	Alaska	1.766	1.413	1.642	1.314
29	Hawaii	1.835	1.468	1.707	1.366
30	West Virginia	1.528	1.222	1.421	1.137

6.5.3 Estimation of Regional General Contractor Markups

In order to derive regional general contractor markups for the residential building construction sector from the 2007 Economic Census, DOE combined four Geographic Area Series: (1) *New Single-Family General Contractors* (NAICS 236115), (2) *New Multifamily Housing Construction* (NAICS 236116), (3) *New Housing Operative Builders* (NAICS 236117), and (4) *Residential Remodelers* (NAICS 236118). Each series consists of statewide cost data required to calculate baseline markups for each state, as illustrated in Section 6.4.3. Although there is only a new construction (no replacement) channel for general contractors, the same technique shown for mechanical contractors can still be employed to estimate regional baseline and incremental markups. First, DOE estimated the statewide incremental markups by applying the ratio of national baseline and incremental markups (*i.e.,* the national incremental markup is around 9.46 percent lower than the national baseline markup) to the baseline markups for each state. Lastly, DOE divided all states among the 30regions and then calculated projected 2019 housing-weighted average baseline and incremental markups for general contractors for each region. The final results are summarized in Table 6.5.3. (Appendix 6-A.4.2 contains the full set of data.)

Table 6.5.3 Regional General Contractor Markups for Furnaces

RECS Regions	State(s)	Baseline MU	Incremental MU
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.404	1.278
2	Massachusetts	1.343	1.222
3	New York	1.393	1.267
4	New Jersey	1.503	1.368
5	Pennsylvania	1.362	1.239
6	Illinois	1.589	1.446
7	Indiana, Ohio	1.378	1.254
8	Michigan	1.537	1.399
9	Wisconsin	1.340	1.219
10	Iowa, Minnesota, North Dakota, South Dakota	1.368	1.245
11	Kansas, Nebraska	1.351	1.229
12	Missouri	1.325	1.206
13	Virginia	1.450	1.320
14	Delaware, District of Columbia, Maryland	1.419	1.291
15	Georgia	1.428	1.300
16	North Carolina, South Carolina	1.390	1.265
17	Florida	1.528	1.391
18	Alabama, Kentucky, Mississippi	1.355	1.233
19	Tennessee	1.353	1.231
20	Arkansas, Louisiana, Oklahoma	1.372	1.248
21	Texas	1.499	1.364
22	Colorado	1.499	1.364
23	Idaho, Montana, Utah, Wyoming	1.303	1.185
24	Arizona	1.707	1.553
25	Nevada, New Mexico	1.637	1.490
26	California	1.717	1.562
27	Oregon, Washington	1.465	1.333
28	Alaska	1.854	1.687
29	Hawaii	1.417	1.289
30	West Virginia	1.545	1.406

6.6 MARKUP FOR MANUFACTURED HOME GAS FURNACES

Based on the shipments forecast for 2019 (see chapter 9), 50 percent of the manufactured home gas furnaces go to new construction, and the other 50 percent go to replacements. DOE used *Manufactured Home (Mobile Home) Manufacturing* (NAICS 321991) sector[11] and *All Other Specialty Trade Contractors* (NAICS 238990) sector[11] from the 2007 Economic Census to calculate markups for manufactured home gas furnace manufacturers and contractors, respectively.

6.6.1 Markups for Manufactured Home Manufacturers

The *Manufactured Home (Mobile Home) Manufacturing* (NAICS 321991) industrial series includes revenue and expenses associated with making manufactured homes, and the second series accounts for the expenses and revenue associated with performing manufactured (mobile) home setup and tie-down work for new construction. The detailed cost breakdown for manufactured home manufacturers and the final estimates for both baseline and incremental markups are listed in Table 6.6.1. Detailed industrial series data can be found in appendix 6-A.5.

Table 6.6.1 Manufactured Home Manufacturer Expenses and Markups for New Construction

	Manufactured Home Manufacturer Expenses or Revenue	
Description	**Per Dollar Sales Revenue *$***	**Per Dollar Cost of Goods *$***
Direct Cost of Equipment Sales: Cost of goods sold	0.71	1.00
Labor Expenses: Salaries (indirect) and benefits	0.08	0.11
Occupancy Expense: Rent, maintenance, and utilities	0.01	0.02
Other Operating Expenses: Depreciation, advertising, and insurance.	0.09	0.13
Net Profit Before Taxes	0.11	0.15
Baseline Markup ($MU_{MANUFACTURED\ HOME\ BASE}$**):** Revenue per dollar cost of goods		**1.41**
Incremental Markup ($MU_{MANUFACTURED\ HOME\ INCR}$**):** Increased revenue per dollar increase cost of goods sold		**1.28**

Source: U.S. Census Bureau. 2007. Manufactured Home (Mobile Home) Manufacturing. Sector 31: 321991. Manufacturing: Industry Series: Detailed Statistics for Establishments: 2007

As shown in the first column, the direct cost of sales represents about \$0.71 per dollar sales revenue to the manufactured home contractor. Labor expenses represent \$0.08 per dollar sales revenue, occupancy expenses represent \$0.01 per dollar sales revenue, other operating expenses represent \$0.09, and profit makes up \$0.11 per dollar sales revenue. DOE then converted these expenses per dollar sales into revenue per dollar cost of goods sold, by dividing each figure in the first data column by \$0.71. The data in column two show that, for every \$1.00 the manufactured home gas furnace manufacturer spends on equipment costs, the manufactured home gas furnace manufacturer earns \$1.00 in sales revenue to cover the equipment cost, \$0.11 to cover labor costs, \$0.02 to cover occupancy expenses, \$0.13 for other operating expenses, and \$0.15 in profits. Thus, the manufacturer baseline markup for manufactured home gas furnaces ($MU_{MANUFACTURED\ HOME\ MFG\ BASE}$) is 1.41. DOE believes the labor and occupancy costs to be invariant and the other operating costs and profit to scale with the equipment price (*i.e.,* be variant). In this case, for a $1.00 increase in the equipment price, the manufacturer price for manufactured home gas furnaces will increase by $1.28, giving a manufactured home gas furnace manufacturer incremental markup ($MU_{MANUFACTURED\ HOME\ MFG\ INCR}$) of 1.28.

6.6.2 Markups for Manufactured Home Dealers

DOE derived the baseline and incremental markups for manufactured home dealers using the 2007 Economic Census industrial cost data, supplemented with numerous references from credible organizations and business experts in related industries. The 2007 Economic Census provides sufficient detailed cost breakdown for the *All Other Specialty Trade Contractors* (NAICS 238990) sector, which includes businesses associated with set-up and tie-down work of manufactured homes; however, this aggregated industrial series also consists of many other contracting businesses, whose work is not related to the installation of manufactured homes. Therefore, DOE carefully reviewed references from major manufactured home dealers' websites and other sources[12, 13, 14, 15, 16, 17, 18] and estimated that proposed markups for manufactured home dealers generally range from 1.25 to 1.35. From this information, DOE constructed a triangular distribution for dealer markups, with 1.30 as the likeliest baseline markup estimate for manufactured home dealers and 1.25 and 1.35 as the minimum and maximum values of the distribution. Manufactured Housing Institute (MHI) also suggested that the markup by the retailer and shipping costs are traditionally 1/3 of the free on board (FOB) price, which is in line with DOE's baseline markup estimate of 1.30.[19] Note that in the case of the manufactured home market, the term "*retailer*" and "*dealer*" are used interchangeably, and shipping costs are borne by manufactured home dealers and also marked up by them in our analysis as well.

In order to calculate the incremental markup for manufactured home dealers, DOE scaled the baseline markup estimate (1.30) with baseline/incremental markup ratio calculated using the *All Other Specialty Trade Contractors* (NAICS 238990) industrial series. The detailed cost breakdown for *All Other Specialty Trade Contractors* (NAICS 238990) sector from the 2007 Economics Census and the final estimates for both baseline and incremental markups are listed in Table 6.6.2. Detailed industrial series data can be found in appendix 6-A.6.

Table 6.6.2 Contractor Expenses and Markups for All Other Specialty Trade Contractors (NAICS 238990)

	Manufactured Home Contractor Expenses or Revenue	
Description	**Per Dollar Sales Revenue** ***$***	**Per Dollar Cost of Goods** ***$***
Direct Cost of Equipment Sales: Cost of goods sold	0.60	1.00
Labor Expenses: Salaries (indirect) and benefits	0.14	0.24
Occupancy Expense: Rent, maintenance, and utilities	0.03	0.06
Other Operating Expenses: Depreciation, advertising, and insurance.	0.11	0.18
Net Profit Before Taxes	0.11	0.19
Baseline Markup ($MU_{MANUFACTURED\ HOME\ BASE}$): Revenue per dollar cost of goods		**1.66**
Incremental Markup ($MU_{MANUFACTURED\ HOME\ INCR}$): Increased revenue per dollar increase cost of goods sold		**1.37**

Source: U.S. Census Bureau. 2007. All Other Specialty Trade Contractors. Sector 23: 238990. Construction: Summary Series: General Summary: Detailed Statistics for Establishments: 2007.

Based on the baseline and incremental markup estimates shown in Table 6.6.2, DOE concluded that the ratio of baseline to incremental markups is 1.78 (=(1.66-1)/(1.37-1)). DOE then applied this ratio to the baseline markup for manufactured home dealers (1.30) to derive its incremental markup, which is equal to 1.17. Thus, in the final overall markup calculation for furnace fans installed in manufactured home gas furnaces, DOE used 1.30 as the baseline markup ($MU_{MANUFACTURED\ HOME\ CONT\ BASE}$) and 1.17 as the incremental markup ($MU_{MANUFACTURED\ HOME\ CONT\ INCR}$). Based on the distribution channel for manufactured home furnaces in the new construction market that DOE described in Figure 6.2.1, in order to derive the final retail price for manufactured home gas furnaces, the total markup applied to the manufacturing cost of heating equipment equals the product of manufacturer markup for gas furnaces and manufacturer markup and dealer markup for manufactured home gas furnaces. In this case, the baseline and incremental markups for manufactured home gas furnaces installed in new construction are 2.28 and 1.90, respectively. The baseline overall markup of 2.28 for manufactured home gas furnaces reconciles with the comment submitted from the MHI suggesting that the markup of material costs to the home manufacturer to the retailer's sale price to the owner has traditionally been a factor of 2.22.[19] As for those units purchased for replacement, DOE used the same baseline and incremental markups estimated for non-weatherized gas furnaces to apply to the manufacturing price of heating equipment, which are 2.10 and 1.36, respectively.

6.7 SALES TAX

The sales tax represents state and local sales taxes that are applied to the consumer price of the equipment. The sales tax is a multiplicative factor that increases the consumer equipment price. DOE only applied the sales tax to the consumer price of the equipment in the replacement market, not the new construction market. The common practice for selling larger residential appliances like furnaces in the new construction market is that general contractors (or builders) bear the added sales tax for equipment, in addition to the cost of equipment, and then mark up the entire cost in the final listing price to consumers. Therefore, no additional sales tax is necessary to calculate the consumer equipment price for the new construction market.

DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[20] These data represent weighted averages that include county and city rates. DOE then derived projected 2019 housing-weighted average tax values for each RECS region to match the regional markups for wholesalers and mechanical and general contractors, as shown in Table 6.7.1. Detailed sales tax data by each state can be found in appendix 6-A.7.

Table 6.7.1 Average Sales Tax Rates by RECS Region

RECS Regions	State(s)	2019 Housing Projections	Tax Rate (2013) %
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	3,647,588	5.06%
2	Massachusetts	2,994,036	6.25%
3	New York	8,479,435	8.40%
4	New Jersey	3,703,111	6.95%
5	Pennsylvania	5,720,154	6.40%
6	Illinois	5,422,636	8.05%
7	Indiana, Ohio	8,066,086	6.87%
8	Michigan	4,477,323	6.00%
9	Wisconsin	2,714,552	5.45%
10	Iowa, Minnesota, North Dakota, South Dakota	4,659,287	6.84%
11	Kansas, Nebraska	2,174,237	7.21%
12	Missouri	2,813,175	6.60%
13	Virginia	3,733,679	5.00%
14	Delaware, District of Columbia, Maryland	3,392,004	5.22%
15	Georgia	4,528,680	7.10%
16	North Carolina, South Carolina	7,166,755	6.93%
17	Florida	9,980,016	6.65%
18	Alabama, Kentucky, Mississippi	5,613,625	7.27%
19	Tennessee	3,036,563	9.45%
20	Arkansas, Louisiana, Oklahoma	5,351,903	8.51%
21	Texas	11,717,997	7.95%
22	Colorado	2,546,760	6.10%
23	Idaho, Montana, Utah, Wyoming	2,684,547	5.09%
24	Arizona	3,148,993	8.15%
25	Nevada, New Mexico	2,262,114	7.31%
26	California	15,020,600	8.40%
27	Oregon, Washington	5,050,698	5.70%
28	Alaska	354,287	1.35%
29	Hawaii	577,627	4.40%
30	West Virginia	898,385	6.05%
Projected 2019 Housing-Weighted Average			**7.08%**

6.8 OVERALL MARKUPS

The overall markup for each distribution channel is the product of the appropriate markups, as well as the sales tax in the case of replacement applications (Table 6.8.1).

DOE used the overall baseline markup to estimate the consumer product price of baseline models, given the manufacturer cost of the baseline models. As stated previously, DOE considers baseline models to be products sold under existing market conditions (*i.e.,* without new energy conservation standards). The following equation shows how DOE used the overall baseline markup to determine the product price for baseline models.

$$CPP_{BASE} = COST_{MFG} \times \left(MU_{MFG} \times MU_{BASE} \times Tax_{SALES} \right) = COST_{MFG} \times MU_{OVERALL\_BASE}$$

Where:

CPP_{BASE} = consumer product price for baseline models,
$COST_{MFG}$ = manufacturer cost for baseline models,
MU_{MFG} = manufacturer markup,
MU_{BASE} = baseline replacement or new home channel markup,
Tax_{SALES} = sales tax (replacement applications only), and
$MU_{OVERALL\_BASE}$ = baseline overall markup.

Similarly, DOE used the overall incremental markup to estimate changes in the consumer product price, given changes in the manufacturer cost from the baseline model cost resulting from an energy conservation standard to raise product energy efficiency. The total consumer product price for more energy-efficient models is composed of two components: the consumer product price of the baseline model and the change in consumer product price associated with the increase in manufacturer cost to meet the new energy conservation standard. The following equation shows how DOE used the overall incremental markup to determine the consumer product price for more energy-efficient models (*i.e.,* models meeting new energy conservation standards).

$$\begin{aligned} CPP_{STD} &= COST_{MFG} \times MU_{OVERALL\_BASE} + \Delta COST_{MFG} \times \left(MU_{MFG} \times MU_{INCR} \times Tax_{SALES} \right) \\ &= CPP_{BASE} + \Delta COST_{MFG} \times MU_{OVERALL\_INCR} \end{aligned}$$

Where:

CPP_{STD} = consumer product price for models meeting new energy conservation standards,
CPP_{BASE} = consumer product price for baseline models,
$COST_{MFG}$ = manufacturer cost for baseline models,
$\Delta COST_{MFG}$ = change in manufacturer cost for more energy-efficient models,
MU_{MFG} = manufacturer markup,
MU_{INCR} = incremental replacement or new home channel markup,

Tax_{SALES} = sales tax (replacement applications only),
$MU_{OVERALL\_BASE}$ = baseline overall markup (product of manufacturer markup, baseline replacement or new home channel markup, and sales tax), and
$MU_{OVERALL\_INCR}$ = incremental overall markup.

National average baseline and incremental markups for each market participant are summarized in Table 6.8.1 and Table 6.8.2 for non-manufactured home furnace fans and manufactured home furnace fans, respectively. Based on furnace shipment forecasts for the year 2019 (see chapter 9), DOE estimated that 25 percent of gas and electric furnaces, 50 percent of manufactured home gas and electric furnaces, and 10 percent of oil-fired furnaces go to new construction. On the other hand, 75 percent of gas and electric furnaces, 50 percent of manufactured home gas and electric furnaces, and 90 percent of oil-fired furnaces go to the replacement market. By weighing the markups by the market shares for each type of furnace and market, total markups are listed in Table 6.8.3.

Table 6.8.1 Summary of National Average Markups on Non-Manufactured Home Furnace Fans

	Baseline Markup	**Incremental Markup**
Manufacturer	1.19 to 1.35 (see Table 6.3.1)	
Wholesaler	1.37	1.10
Mechanical Contractor (new construction/replacement)	1.43/1.54	1.15/1.23
General Contractor (new construction only)	1.47	1.34
Sales Tax (replacement only)	1.07	1.07

Table 6.8.2 Summary of National Average Markups on Manufactured Home Furnace Fans

	Baseline Markup	Incremental Markup
Manufacturer	1.15 to 1.25 (see Table 6.3.1)	
Wholesaler (replacement only)	1.37	1.10
Mechanical Contractor (replacement only)	1.54	1.23
Manufactured Home Manufacturer (new construction only)	1.41	1.28
Manufactured Home Dealer (new construction only)	1.30	1.17
Sales Tax (replacement only)	1.07	1.07

Table 6.8.3 Summary of Total Markup by Furnace Fan Product Class

Product Class	Baseline Markup	Incremental Markup
Non-weatherized, Non-condensing Gas Furnaces	3.18	2.00
Non-weatherized, Condensing Gas Furnaces	3.11	1.96
Weatherized Gas Furnace	3.08	1.95
Oil Furnace	3.09	1.96
Electric Furnace / Modular Blower	2.84	1.80
Manufactured Home Non-weatherized, Non-condensing Gas Furnaces	2.55	1.84
Manufactured Home Non-weatherized, Condensing Gas Furnaces	2.54	1.83
Manufactured Home Electric Furnace /Modular Blower	2.32	1.69

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APPENDIX 6-A. DETAILED DATA FOR EQUIPMENT PRICE MARKUPS

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6-A.1 DETAILED WHOLESALER COST DATA

Based on data provided by the Heating Air-conditioning & Refrigeration Distributors International (HARDI), Table 6.4.1 of chapter 6 shows wholesaler revenues and costs in aggregated form. Table 6-A.1.1 in this appendix provides the complete breakdown of costs and expenses. The column labeled "Scaling" in Table 6-A.1.1 indicates which expenses the U.S. Department of Energy (DOE) assumed to scale with only the baseline markup and which with both the baseline and incremental markups. As described in chapter 6, section 6.4, only those expenses that scale with both baseline and incremental costs are marked up when there is an incremental change in equipment costs.

Table 6-A.1.1 Disaggregated Costs and Expenses for Wholesalers

Item	**Percent of Revenue %**	**Scaling**
Cost of Goods Sold	**73.7**	
Gross Margin	**26.3**	
Payroll Expenses	**15.1**	Baseline
Executive Salaries & Bonuses	1.7	
Branch Manager Salaries and Commissions	1.5	
Sales Executive Salaries & Commissions	0.5	
Outside Sales Salaries & Commissions	2.1	
Inside/Counter Sales/Wages	2.8	
Purchasing Salaries/Wages	0.4	
Credit Salaries/Wages	0.2	
IT Salaries/Wages	0.1	
Warehouse Salaries/Wages	1.4	
Accounting	0.5	
Delivery Salaries/Wages	0.7	
All Other Salaries/Wages & Bonuses	0.8	
Payroll Taxes	1.0	
Group Insurance	1.1	
Benefit Plans	0.3	
Occupancy Expenses	**3.6**	Baseline
Utilities: Heat, Light, Power, Water	0.4	
Telephone	0.3	
Building Repairs & Maintenance	0.2	
Rent or Ownership in Real Estate	2.7	

Item	Percent of Revenue %	Scaling
Other Operating Expenses	**5.5**	Baseline & Incremental
Sales Expenses (incl. advertising & promotion)	0.9	
Insurance (business liability & casualty)	0.2	
Depreciation	0.4	
Vehicle Expenses	1.4	
Personal Property Taxes/Licenses	0.1	
Collection Expenses	0.3	
Bad Debt Losses	0.2	
Data Processing		
All Other Operating Expenses	1.7	
Total Operating Expenses	**24.2**	
Operating Profit	**2.1**	Baseline & Incremental
Other Income	0.4	
Interest Expense	0.5	
Other Non-operating Expenses	0.0	
Profit Before Taxes	**2.0**	

Source: Heating, Air-conditioning & Refrigeration Distributors International. 2012. 2012 Profit Report (2011 Data).
Note: The wholesaler costs and expenses are percentage values as opposed to the per-dollar of sales revenue values shown in Table 6.4.1.

6-A.2 DETAILED MECHANICAL CONTRACTOR DATA

Tables 6.4.2, 6.4.3, and 6.4.4 of chapter 6 provide mechanical contractor revenues and costs in aggregated form by ‘Cost of Goods Sold’ and ‘Gross Margin.’ The tables are based on data in the 2005 edition of *Financial Analysis for the HVACR Contracting Industry,* published by the Air Conditioning Contractors of America (ACCA). The ACCA report did not provide a more disaggregated tabulation of these costs and expenses. As in section 6-A.1, the gross margin category was assumed to scale only with the baseline markup.

A further disaggregated breakdown of costs used to scale the incremental markup are shown in Table 6-A.2.1 by both dollar value and percentage terms from the 2007 Census of Business. As the ACCA data were used to calculate the baseline markup, in Table 6-A.2.1 only the categories in the ‘Scaling’ column that are scaled with both the baseline and incremental markups are marked when there is an incremental change in equipment costs.

Table 6-A.2.1 Mechanical Contractor Expenses and Markups Used To Scale the Incremental Markups

Item	Dollar Value $1,000	Percentage %	Scaling
Total Cost of Equipment Sales	**107,144,428**	**67.80**	
Total payroll, construction workers wages	31,373,558	19.85	
Cost of materials, components, and supplies	59,023,964	37.35	
Cost of construction work subcontracted out to others	13,646,192	8.63	
Total cost of selected power, fuels, and lubricants	3,100,714	1.96	
Gross Margin	**50,895,129**	**32.20**	
Payroll Expenses	**28,065,632**	**17.76**	Baseline
Total payroll, other employees wages	14,041,336	8.88	
Total fringe benefits	13,585,040	8.60	
Temporary staff and leased employee expenses	439,256	0.28	
Occupancy Expenses	**3,436,208**	**2.17**	Baseline
Rental costs of machinery and equipment	1,047,026	0.66	
Rental costs of buildings	1,231,263	0.78	
Communication services	640,851	0.41	
Cost of repair to machinery and equipment	517,068	0.33	
Other Operating Expenses	**12,671,194**	**8.02**	Baseline & Incremental
Purchased professional and technical services	843,641	0.53	
Data processing and other purchased computer services	98,016	0.06	
Expensed computer hardware and other equipment	255,474	0.16	
Expensed purchases of software	64,195	0.04	
Advertising and promotion services	1,018,265	0.64	
All other expenses	6,944,674	4.39	
Refuse removal (including hazardous waste) services	153,241	0.10	
Taxes and license fees	996,138	0.63	
Total depreciation ($1,000)	2,297,550	1.45	
Net Profit Before Income Taxes	**6,722,095**	**4.25**	Baseline & Incremental

Source: U.S. Census Bureau. 2007. Plumbing, Heating, and Air-Conditioning Contractors: 2007. Sector 23: 238220. Construction: Geographic Area Series. Detailed Statistics for Establishments: 2007.

Note: Mechanical contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.2.

6-A.3 DETAILED GENERAL CONTRACTOR COST DATA

Based on U.S. Department of Census data, Table 6.4.6 of chapter 6, section 6.4, *General Contractor Expenses and Markups* shows general contractor revenues and costs in aggregated form. Table 6-A.3.1 in this appendix shows the complete breakdown of costs and expenses provided by the U.S. Department of Census. The column labeled "Scaling" in Table 6-A.3.1 indicates which expenses DOE assumed to scale with only the baseline markup and which are scaled with both the baseline and incremental markups. As described in chapter 6, section 6.4, only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in equipment costs.

Table 6-A.3.1 General Contractor Expenses and Markups

Item	Dollar Value *$1,000*	Percentage *%*	Scaling
Total Cost of Equipment Sales	**238,431,389**	**67.55**	
Total payroll, construction workers wages	16,629,321	4.71	
Cost of materials, components, and supplies	126,764,975	35.91	
Cost of construction work subcontracted out to others	90,956,668	25.77	
Total cost of selected power, fuels, and lubricants	4,080,425	1.16	
Gross Margin	**114,558,247**	**32.45**	
Payroll Expenses	**28,806,792**	**8.16**	Baseline
Total payroll, other employees wages	20,843,029	5.90	
Total fringe benefits	7,464,670	2.11	
Temporary staff and leased employee expenses	499,093	0.14	
Occupancy Expenses	**3,558,796**	1.01	Baseline
Rental costs of machinery and equipment	572,783	0.16	
Rental costs of buildings	1,532,841	0.43	
Communication services	810,436	0.23	
Cost of repair to machinery and equipment	642,736	0.18	
Other Operating Expenses	**21,341,175**	**6.05**	Baseline & Incremental
Purchased professional and technical services	1,834,816	0.52	
Data processing and other purchased computer services	141,344	0.04	
Expensed computer hardware and other equipment	261,701	0.07	
Expensed purchases of software	105,338	0.03	
Advertising and promotion services	2,544,687	0.72	
All other expenses	10,840,757	3.07	
Refuse removal (including hazardous waste) services	520,907	0.15	
Taxes and license fees	1,791,539	0.51	
Total depreciation ($1,000)	3,300,086	0.93	
Net Profit Before Income Taxes	**60,851,484**	**17.24**	Baseline & Incremental

Source: U.S. Census Bureau. 2007. Residential Building Construction. Sector 23: 236115 through 236118. Construction, Industry Series, Preliminary Detailed Statistics for Establishments: 2007.

Note: General contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.5.6.

6-A.4 ESTIMATION OF CONTRACTOR MARK-UP BY STATE

Table 6-A.4.1 Mechanical Contractor Markup Estimation by State, 2007

State	Value of Const. *$1,000*	Cost of Goods Sold *$1,000*	Baseline MU	Incremental MU	Replacement Baseline MU	Replacement Incremental MU	New Const. Baseline MU	New Const. Incremental MU
Alabama	2,010,305	1,401,223	1.435	1.148	1.498	1.198	1.393	1.114
Alaska	583,171	344,729	1.692	1.353	1.766	1.413	1.642	1.314
Arizona	3,522,116	2,326,475	1.514	1.211	1.580	1.264	1.470	1.176
Arkansas	1,065,754	743,395	1.434	1.147	1.496	1.197	1.392	1.113
California	16,726,969	10,865,201	1.539	1.232	1.607	1.286	1.495	1.196
Colorado	3,056,988	2,084,454	1.467	1.173	1.531	1.225	1.424	1.139
Connecticut	1,704,668	1,135,871	1.501	1.201	1.566	1.253	1.457	1.166
Delaware	481,900	D	1.421	1.137	1.483	1.186	1.379	1.104
District of Columbia	34,600	D	1.458	1.167	1.522	1.218	1.416	1.133
Florida	9,061,426	6,254,391	1.449	1.159	1.512	1.210	1.407	1.125
Georgia	4,700,799	3,329,842	1.412	1.129	1.474	1.179	1.371	1.096
Hawaii	800,221	455,122	1.758	1.407	1.835	1.468	1.707	1.366
Idaho	900,698	617,165	1.459	1.168	1.523	1.219	1.417	1.133
Illinois	7,641,642	5,058,047	1.511	1.209	1.577	1.262	1.467	1.173
Indiana	4,002,323	2,605,238	1.536	1.229	1.604	1.283	1.491	1.193
Iowa	1,868,483	1,305,883	1.431	1.145	1.493	1.195	1.389	1.111
Kansas	1,395,359	966,707	1.443	1.155	1.507	1.205	1.401	1.121
Kentucky	1,747,925	1,157,360	1.510	1.208	1.576	1.261	1.466	1.173
Louisiana	1,997,044	1,317,429	1.516	1.213	1.582	1.266	1.472	1.177
Maine	580,816	394,847	1.471	1.177	1.535	1.228	1.428	1.142
Maryland	5,329,135	3,739,560	1.425	1.140	1.487	1.190	1.383	1.107
Massachusetts	4,099,301	2,781,377	1.474	1.179	1.538	1.231	1.431	1.145
Michigan	4,420,638	3,015,948	1.466	1.173	1.530	1.224	1.423	1.138
Minnesota	3,402,921	2,315,330	1.470	1.176	1.534	1.227	1.427	1.141
Mississippi	1,025,452	715,571	1.433	1.146	1.496	1.197	1.391	1.113
Missouri	3,335,124	2,353,598	1.417	1.134	1.479	1.183	1.376	1.101
Montana	483,578	345,458	1.400	1.120	1.461	1.169	1.359	1.087
Nebraska	1,004,296	755,338	1.330	1.064	1.388	1.110	1.291	1.033
Nevada	2,327,842	1,600,555	1.454	1.164	1.518	1.214	1.412	1.130
New Hampshire	620,761	D	1.472	1.178	1.537	1.230	1.429	1.144
New Jersey	5,062,336	3,337,013	1.517	1.214	1.583	1.267	1.473	1.178

State	Value of Const. *$1,000*	Cost of Goods Sold *$1,000*	Baseline MU	Incremental MU	Replacement Baseline MU	Replacement Incremental MU	New Const. Baseline MU	New Const. Incremental MU
New Mexico	891,914	595,659	1.497	1.198	1.563	1.250	1.454	1.163
New York	10,364,779	6,760,337	1.533	1.227	1.600	1.280	1.488	1.191
North Carolina	5,111,396	3,631,802	1.407	1.126	1.469	1.175	1.366	1.093
North Dakota	360,683	255,057	1.414	1.131	1.476	1.181	1.373	1.098
Ohio	5,618,591	3,809,806	1.475	1.180	1.539	1.231	1.432	1.145
Oklahoma	1,352,943	924,264	1.464	1.171	1.528	1.222	1.421	1.137
Oregon	1,893,678	1,237,956	1.530	1.224	1.597	1.277	1.485	1.188
Pennsylvania	6,487,476	4,579,367	1.417	1.133	1.479	1.183	1.375	1.100
Rhode Island	631,202	410,653	1.537	1.230	1.604	1.284	1.492	1.194
South Carolina	1,991,303	1,326,690	1.501	1.201	1.567	1.253	1.457	1.166
South Dakota	386,186	239,017	1.616	1.293	1.686	1.349	1.569	1.255
Tennessee	2,595,613	1,834,242	1.415	1.132	1.477	1.182	1.374	1.099
Texas	10,810,308	7,532,064	1.435	1.148	1.498	1.198	1.393	1.115
Utah	1,746,398	1,235,004	1.414	1.131	1.476	1.181	1.373	1.098
Vermont	294,806	D	1.472	1.178	1.537	1.230	1.429	1.144
Virginia	4,623,151	3,099,329	1.492	1.193	1.557	1.246	1.448	1.158
Washington	4,111,543	2,734,093	1.504	1.203	1.570	1.256	1.460	1.168
West Virginia	655,100	D	1.464	1.171	1.528	1.222	1.421	1.137
Wisconsin	2,926,545	2,023,634	1.446	1.157	1.510	1.208	1.404	1.123
Wyoming	289,391	198,105	1.461	1.169	1.525	1.220	1.418	1.135

Sources: U.S. Bureau of the Census. American Factfinder: 2007. Sector 23: Plumbing, Heating, and Air-Conditioning Contractors (NAICS 238220), Detailed Statistics for Establishments: 2007
http://factfinder.census.gov/servlet/IBQTable?_bm=y&-ds_name=EC0723A1&-NAICS2007=238220&-_lang=en and
Geographic Area Series: Detailed Statistics for Establishments: 2007.
Notes: The Census Bureau withheld data for some states.
Markups may vary across states for several reasons, including differences in firm size.
Due to sample size and/or magnitude of reporting error relative to the mean, disaggregated information not provided for all of the Subcontract, Materials, and Fuels fields. In these cases, the state markup ratio is calculated as an average of neighboring states (ex. Delaware, District of Columbia, New Hampshire, Vermont, and West Virginia)

Table 6-A.4.2 Residential General Contractor Baseline Markups by State, 2007

State	Value of Residential Construction *$1,000*	Cost of Goods Sold *$1,000*	Baseline Markup	Incremental Markup
Alabama	4,232,349	3,106,308	1.363	1.234
Alaska	598,572	322,897	1.854	1.678
Arizona	14,743,264	8,636,727	1.707	1.546
Arkansas	821,493	638,546	1.287	1.165
California	49,325,592	28,727,843	1.717	1.555
Colorado	9,711,667	6,478,218	1.499	1.357
Connecticut	2,835,015	1,914,706	1.481	1.341
Delaware	912,121	714,609	1.276	1.156
District of Columbia	177,004	115,545	1.532	1.387
Florida	33,290,091	21,780,175	1.528	1.384
Georgia	12,492,752	8,745,668	1.428	1.293
Hawaii	2,739,122	1,933,143	1.417	1.283
Idaho	2,565,176	2,014,522	1.273	1.153
Illinois	13,035,923	8,206,105	1.589	1.438
Indiana	4,637,976	3,418,576	1.357	1.228
Iowa	1,846,602	1,449,114	1.274	1.154
Kansas	1,940,745	1,443,265	1.345	1.217
Kentucky	3,074,656	2,244,283	1.370	1.240
Louisiana	2,429,529	1,650,884	1.472	1.332
Maine	821,980	630,393	1.304	1.181
Maryland	6,616,960	4,635,717	1.427	1.292
Massachusetts	7,693,991	5,728,767	1.343	1.216
Michigan	5,383,752	3,501,797	1.537	1.392
Minnesota	5,558,816	3,847,679	1.445	1.308
Mississippi	1,241,083	939,692	1.321	1.196
Missouri	4,754,552	3,588,694	1.325	1.200
Montana	1,148,453	919,206	1.249	1.131
Nebraska	577,746	424,822	1.360	1.231
Nevada	6,697,489	4,026,111	1.664	1.506
New Hampshire	292,227	228,854	1.277	1.156
New Jersey	8,492,015	5,649,618	1.503	1.361
New Mexico	2,236,262	1,395,073	1.603	1.451
New York	16,958,113	12,176,837	1.393	1.261
North Carolina	16,254,736	11,579,895	1.404	1.271
North Dakota	D	D	1.331	1.205

State	Value of Residential Construction *$1,000*	Cost of Goods Sold *$1,000*	Baseline Markup	Incremental Markup
Ohio	6,788,825	4,883,462	1.390	1.259
Oklahoma	1,419,859	1,075,586	1.320	1.195
Oregon	5,519,819	4,019,693	1.373	1.243
Pennsylvania	9,971,624	7,323,399	1.362	1.233
Rhode Island	309,403	205,383	1.506	1.364
South Carolina	5,921,453	4,350,205	1.361	1.232
South Dakota	297,424	228,839	1.300	1.177
Tennessee	5,243,037	3,874,974	1.353	1.225
Texas	32,123,700	21,429,103	1.499	1.357
Utah	4,201,276	3,095,214	1.357	1.229
Vermont	527,837	387,905	1.361	1.232
Virginia	12,761,751	8,799,880	1.450	1.313
Washington	11,158,559	7,361,497	1.516	1.372
West Virginia	348,291	225,500	1.545	1.398
Wisconsin	3,820,533	2,850,921	1.340	1.213
Wyoming	524,809	418,215	1.255	1.136

Sources: U.S. Bureau of the Census, American Factfinder. 2007 Economic Census. Sector 23: Subsectors 236115 (residential single-family), 236116 (residential multifamily), 236117 (operative builders), and 236118 (residential remodelers). Sector 23: EC0723A1: Construction: Geographic Area Series: Detailed Statistics for Establishments: 2007.
Notes: The Census Bureau withheld data for some states.
Markups may vary across states for several reasons, including differences in firm size.
Due to sample size and/or magnitude of reporting error relative to the mean, disaggregated information not provided for all of the Subcontract, Materials, and Fuels fields. In these cases, the state markup ratio is calculated as an average of neighboring states (ex. North Dakota).

6-A.5 DETAILED MANUFACTURED HOME MANUFACTURING COST DATA

Based on U.S. Department of Census data, Table 6.6.1 of chapter 6, section 6.6.1, *Markups for Manufactured Home Manufacturers* shows mobile home manufacturer revenues and costs in aggregated form. Table 6-A.5.1 in this appendix shows the complete breakdown of costs and expenses provided by the U.S. Department of Census. The column labeled “Scaling” in Table 6-A.5.1 indicates which expenses DOE assumed to scale with only the baseline markup and which scaled with both the baseline and incremental markups. As described in chapter 6, section 6.5, only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in equipment costs.

Table 6-A.5.1 Manufactured Home Manufacturer Expenses and Markups

Item	Dollar Value *$1,000*	Percentage %	Scaling
Total Cost of Equipment Sales	**4,307,968**	71.17	
Total payroll, construction workers wages	853,156	14.10	
Cost of materials, components, and supplies	3,355,251	55.43	
Cost of construction work subcontracted out to others	45,533	0.75	
Total cost of selected power, fuels, and lubricants	54,028	0.89	
Gross Margin	**1,744,723**	28.83	
Payroll Expenses	**466,896**	7.71	Baseline
Total payroll, other employees wages	53,309	0.88	
Total fringe benefits	391,239	6.46	
Temporary staff and leased employee expenses	22,348	0.37	
Occupancy Expenses	**78,216**	1.29	Baseline
Rental costs of machinery and equipment	10,612	0.18	
Rental costs of buildings	29,535	0.49	
Communication services	9,882	0.16	
Cost of repair to machinery and equipment	28,187	0.47	
Other Operating Expenses	**561,308**	9.27	Baseline & Incremental
Purchased professional and technical services	24,940	0.41	
Data processing and other purchased computer services	1,943	0.03	
Expensed computer hardware and other equipment	2,451	0.04	
Expensed purchases of software	672	0.01	
Advertising and promotion services	19,941	0.33	
All other expenses	358,478	5.92	
Refuse removal (including hazardous waste) services	47,861	0.79	
Taxes and license fees	25,498	0.42	
Total depreciation ($1,000)	79,524	1.31	
Net Profit Before Income Taxes	**638,303**	10.55	Baseline & Incremental

Source: U.S. Census Bureau. 2007. Manufactured Home (Mobile Home) Manufacturing. Sector 31: 321991. Manufacturing: Industry Series: Preliminary Detailed Statistics for Establishments: 2007.

6-A.6 DETAILED MANUFACTURED HOME DEALER COST DATA

Based on U.S. Department of Census data, Table 6.6.2 of chapter 6, section 6.6.2, *Markups for Manufactured Home Dealers* shows mobile home contractor revenues and costs in the new construction market in aggregated form. Table 6-A.6.1 in this appendix shows the complete breakdown of costs and expenses provided by the U.S. Department of Census. The column labeled “Scaling” in Table 6-A.6.1 indicates which expenses DOE assumed to scale with only the baseline markup and which scaled with both the baseline and incremental markups. As described in chapter 6, section 6.5, only those expenses that scale with baseline and incremental costs are marked up when there is an incremental change in equipment costs.

Table 6-A.6.1 Manufactured Home Contractor Expenses and Markups

Item	Dollar Value *$1,000*	Percentage %	Scaling
Total Cost of Equipment Sales	**23,435,485**	60.09	
Total payroll, construction workers wages	5,955,136	15.27	
Cost of materials, components, and supplies	12,877,819	33.02	
Cost of construction work subcontracted out to others	3,328,722	8.53	
Total cost of selected power, fuels, and lubricants	1,273,808	3.27	
Gross Margin	**15,567,895**	39.91	
Payroll Expenses	**5,626,453**	14.43	Baseline
Total payroll, other employees wages	3,247,619	8.33	
Total fringe benefits	2,253,444	5.78	
Temporary staff and leased employee expenses	125,390	0.32	
Occupancy Expenses	**1,319,033**	3.38	Baseline
Rental costs of machinery and equipment	469,659	1.20	
Rental costs of buildings	303,861	0.78	
Communication services	160,085	0.41	
Cost of repair to machinery and equipment	385,428	0.99	
Other Operating Expenses	**4,262,987**	10.93	Baseline & Incremental
Purchased professional and technical services	212,923	0.55	
Data processing and other purchased computer services	19,927	0.05	
Expensed computer hardware and other equipment	66,392	0.17	
Expensed purchases of software	15,905	0.04	
Advertising and promotion services	328,278	0.84	
All other expenses	1,765,345	4.53	
Refuse removal (including hazardous waste) services	50,145	0.13	
Taxes and license fees	334,769	0.86	
Total depreciation ($1,000)	1,469,303	3.77	
Net Profit Before Income Taxes	**4,359,422**	11.18	Baseline & Incremental

Source: U.S. Census Bureau. 2007. All Other Specialty Trade Contractor. Sector 23: 238990. Construction, Industry Series, General Summary: Detailed Statistics for Establishments: 2007.

Note: Mobile home contractor costs and expenses are first presented as *total dollar* values and then converted to *percentage* values. This is in contrast to the *cost per dollar of sales revenue* values shown in Table 6.7.1.

6-A.7 STATE SALES TAX RATES

Table 6-A.7.1 State Sales Tax Rates

State	Combined State and Local Tax Rate %	State	Combined State and Local Tax Rate %	State	Combined State and Local Tax Rate %
Alabama	8.55	Kentucky	6.00	North Dakota	5.90
Alaska	1.35	Louisiana	8.75	Ohio	6.80
Arizona	8.15	Maine	5.00	Oklahoma	8.35
Arkansas	8.35	Maryland	6.00	Oregon	--
California	8.40	Massachusetts	6.25	Pennsylvania	6.40
Colorado	6.10	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.20	South Carolina	7.10
Delaware	--	Mississippi	7.00	South Dakota	5.40
Dist. of Columbia	6.00	Missouri	6.60	Tennessee	9.45
Florida	6.65	Montana	--	Texas	7.95
Georgia	7.10	Nebraska	6.00	Utah	6.70
Hawaii	4.40	Nevada	7.85	Vermont	6.05
Idaho	6.05	New Hampshire	--	Virginia	5.00
Illinois	8.05	New Jersey	6.95	Washington	8.90
Indiana	7.00	New Mexico	6.60	West Virginia	6.05
Iowa	6.85	New York	8.40	Wisconsin	5.45
Kansas	8.00	North Carolina	6.85	Wyoming	5.35

Source: The Sales Tax Clearinghouse at https://thestc.com/STRates.stm (Accessed on March 14, 2013)

CHAPTER 7. ENERGY USE ANALYSIS

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CHAPTER 7. ENERGY USE ANALYSIS

7.1 INTRODUCTION

The purpose of the energy use analysis is to determine the annual energy consumption of furnace fans in representative U.S. homes and to assess the energy savings potential of increased fan efficiency. In contrast to the U.S. Department of Energy (DOE) test procedure, which uses typical operating conditions in a laboratory setting, the energy use analysis seeks to estimate the range of energy consumption of the products in the field. DOE estimated the annual energy consumption of furnace fans at specified energy efficiency levels across a range of climate zones and household characteristics. The energy use analysis provides estimates of the distribution of annual energy consumption for furnace fans at the efficiency standard levels considered.

DOE developed energy consumption estimates for the key product classes analyzed in the engineering analysis (chapter 5 of the technical support document (TSD)). These are listed in Table 7.1.1.

Table 7.1.1 Furnace Fan Product Classes Analyzed

Non-Weatherized, Non-Condensing Gas Furnace Fan
Non-Weatherized, Condensing Gas Furnace Fan
Weatherized Gas Furnace Fan
Oil Furnace Fan
Electric Furnace / Modular Blower Fan
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan
Manufactured Home Electric Furnace / Modular Blower Fan

7.2 GENERAL APPROACH TO THE ENERGY USE ANALYSIS

Estimating annual energy consumption of furnace fans requires calculating the energy use at different operating modes: heating, cooling, constant circulation, and standby. DOE estimated the total annual energy consumption of furnace fans for each household sampled using the following equation:

$$
\begin{aligned}
FFEU_{total} = {} & FFOH_{heating} \times FFP_{heating} + FFOH_{cooling} \times FFP_{cooling} + FFOH_{cont\,fan} \\
& \times FFP_{cont\,fan} + FFOH_{standby} \times FFP_{standby}
\end{aligned}
$$

Where:

$FFEU_{total}$ = total annual energy consumption by furnace fan, kW/yr,

$FFOH_{heating}$ = furnace fan operating hours during heating system operation, h,

$FFP_{heating}$ = furnace fan power during the heating operation, kW,

$FFOH_{cooling}$ = furnace fan operating hours during cooling system operation, h,

$FFP_{cooling}$ = furnace fan power during the cooling operation, kW,

$FFOH_{cont\ fan}$ = furnace fan operating hours during constant circulation fan operation, h,

$FFP_{cont\ fan}$ = furnace fan power during constant circulation fan operation, kW,

$FFOH_{standby}$ = furnace fan operating hours during standby, h, and

$FFP_{standby}$ = furnace fan power during standby operation, kW.

7.3 HOUSEHOLD SAMPLE

DOE's calculation of the annual energy use of residential furnace fans relied on data from Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS 2009).[1] RECS collects energy-related data for occupied primary housing units in the United States. The RECS 2009 included data from 12,083 housing units that represent almost 113.6 million households. The subset of RECS 2009 records used to study furnace fans met all of the following criteria:

- used a furnace as the main or secondary source of heat;
- used a heating fuel that is natural gas, liquefied petroleum gas (LPG), electricity, or fuel oil;
- heated only one housing unit; and
- had a heating energy consumption greater than zero.

DOE divided the furnace subset into further subsets designed to include households that use one of the furnace fan product classes (Table 7.3.1). Appendix 7-A presents the variables included and their definitions.

The RECS 2009 weighting indicates how commonly each household configuration occurs in the general population in 2009. DOE made some adjustments to EIA's weightings for each RECS 2009 household in order to create furnace fan population weights. Appendix 7-A provides further details on these adjustments.

The first adjustment was to separate weatherized gas furnaces from the larger gas furnace category. The sample for weatherized gas furnaces includes homes with gas furnaces that also have a central air conditioner.

For non-weatherized gas furnaces, DOE estimated shares for condensing and non-condensing types based on historical shipments of condensing furnaces by state.[2]

For electric furnaces, DOE believes that the reported RECS number (15.5 million) is overestimated. Historical U.S. Census new construction data indicate that the number is much lower, which suggests that for some homes a heat pump was misidentified as an electric furnace.

DOE's analysis suggests that about half of the reported RECS number of electric furnaces consists of heat pumps.

Finally, DOE adjusted the weightings to account for households with multiple furnaces.

To estimate the furnace stock in 2019, DOE took into account the growth in population by region from 2009 to 2019 based on the growth rate from 2008 to 2012 U.S. Census state population data.[3]

Table 7.3.1 Household Samples for Furnace Fan Products

Product Class	**Algorithm**	**No. of Records**	**RECS 2009**	**DOE 2019**
			Number of Houses ***million***	**Number of Furnaces** ***million***
Non-Weatherized, Non-Condensing Gas Furnaces	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = non-mobile home	4839	45.3*	18.6
Non-Weatherized, Condensing Gas Furnaces				26.7
Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = non-mobile home Primary or Secondary Cooling Equipment = Central Air Conditioner	3690	34.3	3.9
Oil Furnace	Primary or Secondary Heating Equipment = Oil Furnace Housing Type = non-mobile home	293	2.6	2.7
Electric Furnace / Modular Blower	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = non-mobile home; Primary or Secondary Cooling Equipment = not a Heat Pump	1849	15.5	6.9
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = mobile home	156	2.0*	1.5
Manufactured Home Non-Weatherized, Condensing Gas Furnaces				0.6
Manufactured Home Electric Furnace /Modular Blower	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = mobile home	149	2.0	0.9

* Same sample used.

7.4 FURNACE FAN POWER CONSUMPTION

The electricity consumption (and overall efficiency) of a furnace fan depends on the speed at which the motor operates, the external static pressure difference across the blower, and the airflow through the blower. The power consumption of the furnace fan is determined using the individual sample housing unit operating conditions (the pressure and airflow) at which a particular furnace fan will operate when performing heating, cooling, and constant circulation functions.

These operating conditions can be graphically displayed as the intersection of a system curve of the air-distribution system in the housing unit (which plots the airflow across the supply and return air ducts as a function of static pressure) with the fan curve of the furnace (which plots the airflow through the furnace as a function of static pressure).[4] The intersection of these two curves is the airflow and the static pressure at which the furnace will operate in that housing unit.

Furnace fan curves, reported as tables of airflow rise versus static pressure through the furnace, are available from manufacturers in the product literature for most furnace models. Some of the manufacturers also supply blower-motor input power as a function of static pressure across the furnace.

Air power is calculated from the air speed through the furnace and the pressure rise across the furnace. The overall air-moving efficiency is air power divided by the electric power to the blower motor.

All of the electric power of the blower motor eventually is converted into heat that contributes heat to the building's interior. DOE takes this into account by increasing the heating load, decreasing the cooling load, or both for more-efficient furnace fans.

7.4.1 System Curves

DOE modeled system curves as quadratic curves, which is standard in heating, ventilating, and air conditioning (HVAC) design and fan selection handbooks.[5] The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$Q = \sqrt{\frac{P}{\alpha}}$$

Where:

Q = airflow (cfm),

P = external static pressure (in.w.g.), and

α = a constant coefficient.

DOE selected the external static pressure (ESP) in the system curve equation for each sample housing unit. DOE identified four installation types with unique ESP considerations: units paired with an evaporator coil; heating-only units or units with an internal evaporator coil; manufactured home units paired with an evaporator coil; and manufactured home heating-only units. To develop distributions of ESP values for each of these types, DOE gathered field data from available studies and research reports to determine an appropriate distribution of ESP values. DOE compiled more than 1,300 field ESP measurements from several studies that included furnace fans in single-family and manufactured homes in different regions of the country. The data and sources are described in appendix 7-B. Table 7.4.1 gives the weighted average ESP values for each type. DOE designed each distribution as a normal distribution based on the field studies. DOE randomly sampled a static pressure value at the nominal maximum airflow from one of the four distributions, depending on the type of equipment installed in the housing unit.

Table 7.4.1 Values Used for External Static Pressure

Installation Type	Associated Product Class	Weighted Average ESP (in. w.c.)	Standard Deviation (in. w.c.)
Units paired with an evaporator coil	Furnaces paired with a central air conditioner (CAC) unit	0.73	0.24
Heating-only units or Units with an internal evaporator coil	Furnaces not paired with a CAC unit or Weatherized gas furnaces	0.52	0.18
Manufactured home paired with an evaporator coil	Manufactured home furnaces paired with a CAC unit	0.37	0.12
Manufactured home heating-only units	Manufactured home furnaces not paired with a CAC unit	0.17	0.06

Figure 7.4.1 shows an example of a plot of system curves intersecting a furnace fan curve.

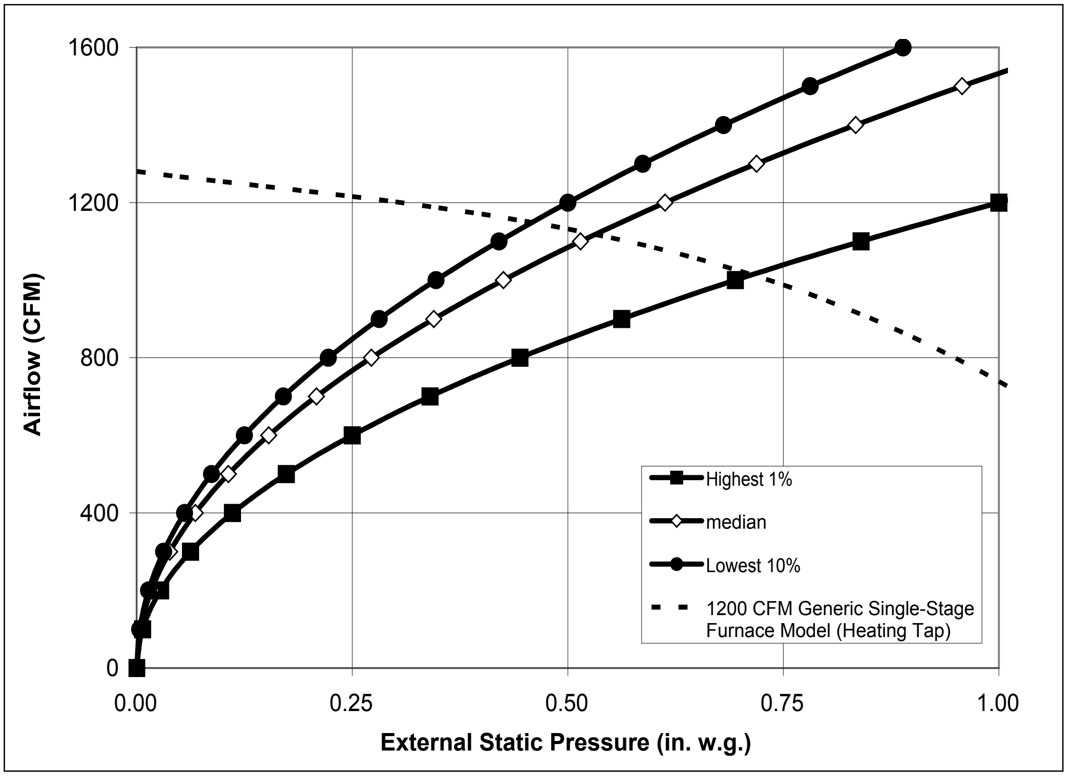

Figure 7.4.1 **Sample of System Curves with a Typical Fan Curve**

7.4.2 Furnace Fan Curves

Depending on the resistance (measured as static pressure) of the supply and return air ducts, a furnace will move more or less air. When these airflow values are plotted graphically against pressure, they are referred to as fan curves.

DOE developed fan curves for permanent split capacitor (PSC), improved PSC, constant-torque brushless permanent magnet (BPM), and constant-airflow BPM furnace models by fitting airflow and pressure data points from manufacturer product literature and measurements conducted during the engineering analysis to a second-order polynomial (see appendix 7-C for further details). DOE did this separately for each of the four main nominal air handler sizes (2-ton, 3-ton, 4-ton, and 5-ton). The cubic feet per minute (cfm) is given by the following equation:

$$cfm = m_0 + m_1 \times (P) + m_2 \times (P^2)$$

Where:

cfm = airflow in cfm reported by manufacturer,

$m_{0,1,2,and\ 3}$ = coefficients derived from 2nd degree polynomial approximation, and

P = external static pressure (in. w.g.).

7.4.3 Fan Power

Once the operating point of air flow and static pressure is determined, by finding the intersection of the fan performance curve and the system curve, the watts per cfm of airflow are determined from the equations developed by DOE using manufacturer product literature and measurements conducted during the engineering analysis. The power consumption of the fan at this operating point, FFP, is calculated by multiplying the watts/cfm by the cfm at the operating point:

$$FFP = \left(\frac{Watts}{CFM}\right) \times Q$$

Where:

FFP = circulating air fan electrical energy consumption (watts),

Watts/cfm = blower electricity consumption in watts reported by manufacturer divided by the airflow in cfm at the same static pressure (watts/cfm), and

Q = airflow (cfm).

Some manufacturers of furnace fans report watts across a range of external static pressures. Furthermore, DOE conducted measurements on several furnace fan models during the engineering analysis. For these models, DOE divided watts at these pressures by air flow in cfm at these same pressures. These values of watts per cfm across a range of pressures were fit to a second-order polynomial for the basic furnace models made by the manufacturer (see appendix 7-C for further details). The value of watts per cfm is given by the following equation:

$$\frac{Watts}{CFM} = m_0 + m_1 \times (P) + m_2 \times (P^2)$$

Where:

Watts/cfm = blower electricity consumption in watts reported by manufacturer divided by the airflow in cfm at the same static pressure,

$m_{0,1,and\ 2}$ = coefficients derived from second-degree polynomial approximation, and

P = external static pressure (in. w.g.).

7.4.4 Determination of Fan Performance by Product Class and Efficiency Level

In order to generate the fan performance data used in the analysis DOE applied the following procedure:

STEP 1: Using the airflow and power curves at each airflow speed (heating, cooling, and constant circulation), DOE found the airflow and power at DOE's proposed furnace fan test procedure conditions.

STEP 2: DOE used the FFP equation in section 7.4.3 to calculate the FFP at each airflow speed (heating, cooling, and constant circulation) with DOE's proposed furnace fan test procedure conditions.

STEP 3: Using the calculated maximum airflow cfm and FFP values at the external static pressure prescribed by DOE's reference system curve, Furnace Efficiency Rating (FER) values were evaluated.

STEP 4: The constant curve fit parameter m_0, that is derived from plotting the watts/cfm vs. the ESP, is then used to adjust the airflow and power curve in order to match the FER values derived from the engineering analysis (for all product classes and efficiency levels).

Table 7.4.2 shows the airflow (cfm) vs. pressure coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level (EL). Figure 7.4.4 to Figure 7.4.6 show the resulting curves at various pressures and operating modes. See appendix 7-C for further details and figures for the performance curves.

Table 7.4.2 Coefficients for CFM equation for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton

EL	Heating (High)			Heating (Low)			Cooling			Constant Circulation		
	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	1133	49	-570	1028	49	-570	1318	49	-570	923	49	-570
1	1133	49	-570	1028	49	-570	1318	49	-570	923	49	-570
2	1071	267	-338	783	267	-338	1151	267	-338	633	267	-338
3	1283	-456	8	998	-456	8	1426	-456	8	856	-456	8
4	1283	-456	8	998	-456	8	1426	-456	8	856	-456	8
5	1095	99	-103	800	99	-103	1176	99	-103	647	99	-103
6	1095	99	-103	800	99	-103	1176	99	-103	647	99	-103

Table 7.4.3 shows the watts/cfm vs. pressure curves coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level. See appendix 7-C for further details and figures for the performance curves.

Table 7.4.3 Coefficients for Watts/CFM Equation for Non-Weatherized (Non-Condensing) Gas Furnaces, 3-Ton

EL	Heating (High)			Heating (Low)			Cooling			Constant Circulation		
	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	0.52	-0.20	0.19	0.52	-0.20	0.19	0.52	-0.20	0.19	0.52	-0.20	0.19
1	0.47	-0.20	0.19	0.47	-0.20	0.19	0.47	-0.20	0.19	0.47	-0.20	0.19
2	0.27	0.14	0.06	0.27	0.14	0.06	0.27	0.14	0.06	0.27	0.14	0.06
3	0.19	0.12	0.07	0.19	0.12	0.07	0.19	0.12	0.07	0.19	0.12	0.07
4	0.15	0.12	0.07	0.15	0.12	0.07	0.15	0.12	0.07	0.15	0.12	0.07
5	0.12	0.25	-0.01	0.12	0.25	-0.01	0.12	0.25	-0.01	0.12	0.25	-0.01
6	0.10	0.25	-0.01	0.10	0.25	-0.01	0.10	0.25	-0.01	0.10	0.25	-0.01

7.5 OPERATING HOURS

The DOE test procedures for furnaces and air conditioners were used to estimate heating and cooling mode operating hours for the furnace fan.

7.5.1 Heating Mode

DOE used the furnace test procedure[6] to determine furnace fan operating hours[a] during the heating season using the following formula:

$$FFOH_{heating} = y \times BOH, \text{ for single stage furnaces.}$$

Where:

$FFOH_{heating}$ = furnace fan operating hours during the heating season,

y = ratio of blower on-time to average burner on-time, and

BOH = burner operating hours, h.

Using DOE's furnace test procedure, the ratio of blower on-time to average burner on-time (y) is calculated using the following formula:

$$y = 1 + \frac{t^{+} - t^{-}}{t_{ON}}$$

Where:

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[a] Approach described for single-stage operation only; see Appendix 7-E for multistage details

t^+ = off-period (blower off delay) between burner shutdown and blower shutdown in minutes,

t^- = on-period (blower on delay) between burner shutdown and blower shutdown in minutes, and

t_{ON} = average burner on-time in minutes.

The blower off-delay (t^+) and blower on-delay (t^-) values are derived from manufacturer default blower delay settings for non-weatherized gas furnace models in the 2007 Furnace Database from DOE's 2007 Furnace and Boiler Final Rule.[7] The median values using these data are 120 seconds (or 2 minutes) for blower off-delay (t^+) and 30 seconds (or 0.5 minutes) for blower on-delay (t^-). The average burner on-time (t_{ON}) is equal to 3.87 minutes for single-stage furnaces with a fan delay based on DOE's furnace test procedure. Therefore, the ratio of blower on-time to average burner on-time (y) is estimated to be 1.39 using the median values.

The burner operating hours are calculated using the following formula[b]:

$$BOH = A * HHL\text{, for single-stage furnaces.}$$

Where:

$A = 100{,}000 / [341300(y_P * PE + y_{IG} * PE_{IG} + y * FFP) + Q_{IN} * Effy_{HS}]$,

y_P = ratio of induced or forced draft blower on-time to average burner on-time,

PE = burner (or draft inducer) electrical power input at full-load steady-state operation in kW,

y_{IG} = ratio of burner interrupted-ignition device on-time to average burner on-time,

PE_{IG} = electrical input rate to the interrupted ignition device on the burner,

y = ratio of blower or pump on-time to burner on-time,

FFP = furnace fan electrical energy input rate in kW,

Q_{IN} = steady-state nameplate input rate in Btu/h,

$Effy_{HS}$ = ratio of the average length of the heating season in hours to the average heating load hours, and

HHL = house heating load in MMBtu/h.

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[b] Approach described for single-stage operation and a furnace without pilot ignition only; see Appendix 7-E for multistage operation details and derivation of the formula.

Details about the calculation of the parameters used to calculate the value A (such as y_P, PE, y_{IG}, PE_{IG}, y, FFP, Q_{IN}, and $Effy_{HS}$) are provided in appendix 7-E.

The annual house-heating load (*HHL*) is the total amount of heat output from the furnace that the house needs during the heating season. This includes heat from the burner and heat from the blower and the blower motor. DOE determined HHL for each sampled housing unit, based on the burner operating hours (*BOH*) and the characteristics of the assigned existing furnace, using the following calculations:

$$HHL = \left(Q_{YR,RECS} \times AFUE_{ex} + 3.412 \times FFP \times \left[BOH_{ex} + N \times \left(\frac{t^{+} + t^{-}}{3600}\right)\right]\right) \times Adj\_Factor$$

Where:

$Q_{YR,RECS}$ = annual fuel consumption for heating based on RECS 2009 (kBtu/yr),

$AFUE_{ex}$ = AFUE of the existing furnace (see appendix 7-E),

3.412 = constant to convert kW to kBtu/hr,

FFP = power consumption of the blower motor of the existing furnace (kW),

BOH_{ex} = burner operating hours of existing household (hr/yr),

N = number of cycles per hour (set equal to 5 for furnaces),

t^{+} = off delay (seconds),

t^{-} = on delay (seconds), and

Adj_Factor = adjustment factors (discussed below).

DOE calculated BOH_{ex} for the existing furnace as:

$$BOH_{ex} = \frac{Q_{YR,RECS}}{Q_{IN,ex}}$$

Where:

BOH_{ex} = burner operating hours of existing household (hr/yr),

$Q_{YR,RECS}$ = as defined above (kBtu/yr), and

$Q_{IN,ex}$ = input capacity of the existing furnace (see appendix 7-E) (kBtu/hr).

DOE made adjustments to the HHL to reflect the expectation that housing units in 2019 will have a somewhat different HHL than the housing units in the RECS 2009 sub-sample. The adjustment involves multiplying the calculated HHL for each RECS 2009 housing unit by a building shell efficiency index[c] derived from the National Energy Modeling System (NEMS) simulation performed for EIA's *AEO 2012*.[8]

DOE also made adjustments to the HHL calculated using RECS 2009 data to reflect historical average climate conditions. Table 7.5.1 shows the 2003-2012 average heating degree-days (HDD) as well as the 2009 average HDD for the 30 geographical areas. The adjustment factors are calculated using the following equation.

$$Adj\_Factor_{average\_climate} = \frac{HDD_{10\_yr\_avg}}{HDD_{res\_stock\_2009}}$$

Where:

$HDD_{res\_stock\_2009}$ = HDD in 2009 for the specific region where the housing unit is located, and

$HDD_{10\_yr\_avg}$ = 10-year average HDD (2003–2012) based on National Oceanic and Atmospheric Administration (NOAA) data[9] for the specific region where the housing unit is located.[d]

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[c] The building shell efficiency index sets the heating load value at 1.00 for an average home in 2005 (by type) in each census division. The values listed represent the change in heating load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows). This factor differs for new construction and replacement households. For this analysis 2009 is selected as the base year to match RECS 2009 sample. The space heating value for households in 2019 is 0.92 for replacements and 0.96 for new construction, which means that the average new home in 2019 will require less heat energy to maintain indoor comfort for heating (compared to households in 2009).

[d] The last 10-year average is used to normalize the HDD values, which is similar to what is done in *AEO 2012*.

Table 7.5.1 Heating Degree-Day Adjustment Factors

Geographical Area		Average HDD		Adjustment Factor
		2003-2012	2009	
1	CT, ME, NH, RI, VT	6497	6868	0.95
2	MA	6128	6438	0.95
3	NY	5720	6055	0.94
4	NJ	5059	5261	0.96
5	PA	5604	5842	0.96
6	IL	5955	6427	0.93
7	IN, OH	5625	5857	0.96
8	MI	6572	6995	0.94
9	WI	7281	7849	0.93
10	IA, MN, ND, SD	7761	8434	0.92
11	KS, NE	5379	5885	0.91
12	MO	4846	5186	0.93
13	VA	4178	4395	0.95
14	DE, DC, MD	4653	4909	0.95
15	GA	2748	2928	0.94
16	NC, SC	3126	3320	0.94
17	FL	679	666	1.02
18	AL, KY, MS	3201	3361	0.95
19	TN	3695	3856	0.96
20	AR, LA, OK	2668	2850	0.94
21	TX	1797	1856	0.97
22	CO	7030	7309	0.96
23	ID, MT, UT, WY	6895	7299	0.94
24	AZ	1929	1890	1.02
25	NV, NM	3921	4032	0.97
26	CA	2569	2562	1.00
27	OR, WA	5278	5516	0.96
28	AK	NA	NA	0.96
29	HI	NA	NA	1.00
30	WV	5021	5190	0.97

Note: RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See Appendix 7-A for more details. Data for Alaska and Hawaii were not available. The region 27 adjustment factor was used for Alaska, while the region 26 adjustment factor was used for Hawaii.

For households for which it is clear that the fuel use for heating is associated solely with the use of furnace equipment as the primary or secondary heating equipment, DOE used the annual fuel consumption for heating the housing unit from RECS 2009. DOE adjusted the house heating load for households that used both a furnace (either as the primary or secondary heating equipment) and other heating equipment using the same fuel. RECS 2009 reports the percentage of heating energy consumption attributable to secondary products. DOE derived the HHL applicable to the furnace by subtracting the estimated amount of heat provided by the other heating system. In the cases when it was determined that a household had multiple furnaces, the HHL was divided by the number of furnaces. Details are presented in appendix 7-D.

Table 7.5.2 shows the results for the range in adjusted heating load among sample households.

Table 7.5.2 Range of Adjusted Heating Load for Each Furnace Fan Product Class, MMBtu/year

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.16	239.72	30.05	7.32	15.19	25.43	39.68	65.79
Non-Weatherized, Condensing Gas Furnace Fan	0.17	236.86	42.34	12.31	27.37	38.72	52.56	83.23
Weatherized Gas Furnace Fan	0.28	212.74	27.11	6.89	14.89	23.61	35.02	58.97
Oil Furnace Fan	9.07	269.54	53.28	19.57	32.22	47.06	64.99	107.98
Electric Furnace / Modular Blower Fan	0.01	132.24	14.00	2.21	4.86	7.69	14.88	47.53
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	1.29	118.12	27.66	8.00	18.35	25.49	34.61	52.80
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	1.28	119.42	32.93	11.37	23.35	29.94	41.63	61.87
Manufactured Home Electric Furnace / Modular Blower Fan	1.27	28.42	9.35	2.76	6.57	8.98	10.76	19.70

Table 7.5.3 shows the results for the baseline heating furnace fan operating hours among sample households.

Table 7.5.3 Range of Baseline Furnace Fan Heating Operating Hours for Each Furnace Fan Product Class, hours

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	6	3706	516	163	304	466	654	1055
Non-Weatherized, Condensing Gas Furnace Fan	5	5268	681	235	459	624	818	1324
Weatherized Gas Furnace Fan	3	4126	479	160	294	437	602	947
Oil Furnace Fan	55	4031	706	243	470	653	865	1313
Electric Furnace / Modular Blower Fan	0	8760	579	66	152	289	662	2074
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	24	2701	592	217	418	565	732	1064
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	17	3325	575	272	413	521	698	989
Manufactured Home Electric Furnace / Modular Blower Fan	44	2681	389	109	235	342	503	826

7.5.2 Cooling Mode

Furnace fan operating hours during the cooling season are calculated using the following formula:

$$FFOH_{cooling} = y_C \times COH$$

Where:

$FFOH_{cooling}$ = furnace fan operating hours during the cooling season,

y_C = ratio of blower on-time to average compressor on-time, and

COH = cooling operating hours.

Some furnace fans come with a cooling blower off delay feature. To account for this DOE estimated the ratio of blower on-time to average compressor on-time (y_C) using the following formula:

$$y_C = 1 + \frac{t_C^+ - t_C^-}{t_{ON,C}}$$

Where:

t_C^+ = off-period (blower off delay in cooling mode) between compressor shutdown and blower shutdown in minutes,

t_C^- = on-period (blower on delay in cooling mode) between compressor start-up and blower start-up in minutes, and

$t_{ON,C}$ = average compressor on-time in minutes.

The blower off-delay (t_C^+) and blower on-delay (t_C^-) values are derived from manufacturer default blower delay settings. The median values using these data are 45 seconds for blower off-delay (t_C^+) and 2 seconds for blower on-delay (t_C^-). The average burner on-time ($t_{ON,C}$) is equal to 6 minutes for single-stage central air conditioners based on DOE's central air conditioner test procedure. Using these assumptions, the ratio of blower on-time to average burner on-time (y_C) is estimated to be 1.12.

The cooling operating hours are calculated using the following formula:

$$COH = \frac{HCL}{CoolingCapacity} \times Adj\_Factor_{motor}$$

Where:

COH = cooling operating hours, hour/year,

HCL = house cooling load, MMBtu/year,

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h (see appendix 7-F), and

Adj_Factor_{motor} = adjustment factor to account for impact of motor heat on cooling operating hours.

The house cooling load (HCL) assumes that the household has a default furnace fan motor power output of 365 watts per 1000 cfm (used in the central air conditioner (CAC) test procedure). To properly account for increased or decreased cooling operating hours due to the higher or lower motor power output for different furnace fan efficiencies, DOE used the following equation to determine the adjustment factor:

$$Adj\_Factor_{motor} = \frac{1}{(1 + 3.412 \times \frac{\frac{365}{1000} * CFM - FFPcooling}{CoolingCapacity})}$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output used for calculating SEER (seasonal energy efficiency ratio), watts,

CFM = nominal cooling load cfm measured at 400 cfm per AC ton, cu. Ft. per min,

$FFP_{cooling}$ = furnace fan power during the cooling operation, kW, and

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h.

The HCL is derived using the EIA's RECS 2009[1] cooling energy use data for the sample households as follows:

$$HCL = \frac{CoolingEnergyUseRECS \times SEER_{ex}}{CoolingCapacity_{ex}} \times Adj\_Factor$$

Where:

HCL = house cooling load, mmbtu/year,

$CoolingEnergyUseRECS$ = annual electricity consumption for cooling based on RECS 2009 (kBtu/yr),

$SEER_{ex}$ = SEER of the existing central air conditioner (see appendix 7-F),

$CoolingCapacity$ = cooling capacity of existing central air conditioner, Btu/h (see appendix 7-F), and

Adj_Factor = adjustment factors (discussed below).

DOE made adjustments to the HCL to reflect the expectation that housing units in 2019 will have a somewhat different HCL than the housing units in the RECS 2009 sub-sample. Similar to furnace fan energy use calculation above, the building shell efficiency index sets the cooling load value at 1.00 for an average home in 2005 (by type) in each census division. For this analysis we used 2009 as the base year.[e]

DOE also made adjustments to the HCL calculated using RECS 2009 data to reflect historical average climate conditions. Table 7.5.4 shows the 2003-2012 average HDD as well as the 2009 average cooling degree-days (CDD) for the 30 geographical areas. The adjustment factors are calculated using the following equation.

$$Adj\_Factor_{average\_climate} = \frac{CDD_{10\_yr\_avg}}{CDD_{res\_stock\_2009}}$$

Where:

$CDD_{res\_stock\_2009}$ = CDD in 2009 for the specific region where the housing unit is located, and

$CDD_{10\_yr\_avg}$ = 10-year average CDD (2003–2012) based on NOAA data[9] for the specific region where the housing unit is located.

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[e] DOE developed adjustment factors to represent the change in cooling load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows). This factor differs for new construction and replacement households. For this analysis 2009 is selected as the base year to match RECS 2009 sample. The space cooling value for households in 2019 is 0.93 for replacements and 0.98 for new construction (compared to households in 2009)..

Table 7.5.4 Cooling Degree Day Adjustment Factors

Geographical Areas		Average CDD		Adjustment Factor
		2003-2012	2009	
1	CT, ME, NH, RI, VT	489	348	1.41
2	MA	525	377	1.39
3	NY	737	509	1.45
4	NJ	934	689	1.36
5	PA	764	570	1.34
6	IL	935	630	1.48
7	IN, OH	878	655	1.34
8	MI	626	384	1.63
9	WI	558	324	1.72
10	IA, MN, ND, SD	646	402	1.61
11	KS, NE	1335	961	1.39
12	MO	1347	987	1.36
13	VA	1205	1025	1.18
14	DE, DC, MD	1119	930	1.20
15	GA	1831	1693	1.08
16	NC, SC	1647	1503	1.10
17	FL	3549	3611	0.98
18	AL, KY, MS	1807	1616	1.12
19	TN	1516	1301	1.17
20	AR, LA, OK	2291	2049	1.12
21	TX	2876	2799	1.03
22	CO	357	208	1.72
23	ID, MT, UT, WY	583	487	1.20
24	AZ	3177	3198	0.99
25	NV, NM	1707	1662	1.03
26	CA	933	978	0.95
27	OR, WA	232	271	0.86
28	AK	NA	NA	0.86
29	HI	NA	NA	0.95
30	WV	856	678	1.26

Note: RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See Appendix 7-A for more details. Data for Alaska and Hawaii were not available. The region 27 adjustment factor was used for Alaska, while the region 26 adjustment factor was used for Hawaii.

DOE calculates multi-stage cooling the same way as single-stage equipment (*i.e.,* at the highest cooling mode only) and, therefore, used the same number of operating hours, for these two reasons:

1) Multi-stage heating is not necessarily associated with multi-stage cooling equipment (*e.g.,* multi-stage cooling is much less common than multi-stage furnace equipment); and

2) SEER already captures cases when multi-stage heating and cooling equipment are matched.

For households for which it is clear that the electricity use for cooling is associated solely with the use of central air conditioning equipment, DOE used the annual electricity consumption for cooling the household from RECS 2009. DOE adjusted the HCL for households that used both a central air conditioner and a room air conditioner. RECS 2009 reports the percentage of cooling energy consumption attributable to room air conditioners. DOE derived the HCL applicable to the central air conditioner by subtracting the estimated amount of cooling provided by the other cooling system.

Table 7.5.5 shows the range in cooling load among sample households for each furnace fan product class. The table also provides the fraction of households that have a CAC.

Table 7.5.5 Range of Annual Cooling Load for Each Furnace Fan Product Class, MMBtu/year

Product Class	Fraction with CAC*	Min	Max	Average	Percentiles				
					5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	77.8%	0.19	347.20	38.74	3.34	11.70	26.91	52.03	107.05
Non-Weatherized, Condensing Gas Furnace Fan	78.8%	0.54	347.20	23.61	2.33	7.03	14.72	31.44	75.18
Weatherized Gas Furnace Fan	100.0%	0.21	324.78	38.69	3.70	13.50	28.23	52.05	104.52
Oil Furnace Fan	41.2%	1.01	107.36	17.73	2.16	5.63	11.66	23.38	45.31
Electric Furnace / Modular Blower Fan	78.8%	0.25	284.34	32.30	2.95	10.62	22.66	45.00	91.09
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	54.3%	0.83	59.97	19.24	2.72	9.30	14.28	22.09	46.34
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	59.7%	0.83	59.97	15.62	2.47	8.71	11.55	20.72	43.73
Manufactured Home Electric Furnace / Modular Blower Fan	73.5%	1.79	94.19	32.87	5.80	15.71	29.61	45.83	71.98

* Accounts only for households that use their CAC. A small fraction of households have CAC, but do not use it.

Table 7.5.6 shows the results for the baseline furnace fan cooling operating hours among sample households.

Table 7.5.6 Range of Baseline Furnace Fan Cooling Operating Hours for Each Furnace Fan Product Class, hours

Product Class	Min	Max	Average	Percentiles				
				5%	25%	50%	75%	95%
Non-Weatherized, Non-Condensing Gas Furnace Fan	0	5861	695	0	87	479	1074	2104
Non-Weatherized, Condensing Gas Furnace Fan	0	5864	442	0	69	278	630	1482
Weatherized Gas Furnace Fan	6	5434	899	120	378	729	1242	2137
Oil Furnace Fan	0	2110	169	0	0	0	237	815
Electric Furnace / Modular Blower Fan	0	5387	766	0	118	577	1205	2192
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	0	2218	345	0	0	162	545	1274
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	0	2309	287	0	0	158	448	1117
Manufactured Home Electric Furnace / Modular Blower Fan	0	2593	787	0	0	681	1255	2089

7.5.3 Constant Circulation Mode

The amount of constant-circulation hours is based on data from two surveys, which are also used for the proposed furnace fan test procedure. One survey was conducted in Wisconsin in 2003.[10] The second survey was conducted by the Center for Energy and the Environment (CEE) in Minnesota, the results of which were provided by CEE in a written comment for this standards rulemaking.[11] DOE combined both studies by adding the number of respondents and derived average annual furnace fan constant-circulation operating hours from the combined surveys, as shown in Table 7.5.7.

DOE assumed a value for average number of fan constant-circulation hours for each survey response, similar to what is assumed in the proposed furnace fan test procedure. For "no constant circulation" responses, DOE assumed zero constant-circulation hours. For "year-round" responses, DOE assumed 100 percent of non-heating or cooling furnace fan operating hours, which DOE calculated by subtracting furnace fan heating and cooling operating hours from the total annual hours (8,760). For "during heating season" responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For "during cooling season" responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For other or "some constant circulation" responses, DOE assumed 5 percent of non-heating or cooling furnace fan operating hours.

Similar to what was done in the test procedure, DOE did not use these data directly, because it believes they are not representative of consumer practices for the United States as a whole. In Wisconsin and Minnesota, many homes have low air infiltration, and there is a high awareness of indoor air quality issues, which leads to significant use of constant circulation. To account for this, DOE developed separate regional fractions that took into account information from manufacturer product literature and regional climate conditions. Furnace fan manufacturer literature states that constant circulation fan operation is not recommended for humid climates. Therefore, DOE assumed that the fraction using constant circulation in the South Hot Humid region[f] would only be 10 percent of what was reported in the Wisconsin and Minnesota studies (*i.e.,* 3.1 percent compared to 31 percent in the studies). For the rest of the country (North and South Hot Dry regions), DOE assumed that the fraction using constant circulation would be 50 percent of what was reported in the Wisconsin and Minnesota studies (*i.e.,* 15.5 percent compared to 31 percent in the studies). To take into account the sensitivity of these assumptions on the energy use results, DOE developed sensitivity scenarios, which are furthered described in appendix 7-C.

Table 7.5.7 Results from Constant-Circulation Use Studies and Estimated National Constant-Circulation Practices

	Combined Data from Studies			
How Often is Constant Circulation Fan Used?	**Number of Households**	**Percentage (%)**	**Estimated North and South-Hot Dry Region Shares for LCC Analysis**	**Estimated South-Hot Humid Region Shares for LCC Analysis**
No constant fan	69	68%	84%	97%
Year-round	14	14%	6.9%	1.4%
During heating season	4	4%	2.0%	0.40%
During cooling season	4	4%	2.0%	0.40%
Other (some constant fan)	10	10%	5.0%	1.0%
Total	101	100%	100%	100%

Table 7.5.8 shows the results for the average baseline constant circulation furnace fan operating hours among sample households.

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[f] Regions as defined in the Furnace and Central Air Conditioner Final Rule:[12] North (Alaska, Colorado, Connecticut, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Washington, West Virginia, Wisconsin, and Wyoming), South Hot Dry (Arizona, California, Nevada, and New Mexico), and South Hot Humid (Alabama, Arkansas, Delaware, Florida, Georgia, Hawaii, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia, and the District of Columbia).

Table 7.5.8 Average Baseline Constant Circulation Furnace Fan Operating Hours for Each Furnace Fan Product Class

Product Class	Fraction of Households using Constant Circulation	Hours/year
Non-Weatherized, Non-Condensing Gas Furnace Fan	11%	404
Non-Weatherized, Condensing Gas Furnace Fan	14%	497
Weatherized Gas Furnace Fan	9%	314
Oil Furnace Fan	14%	566
Electric Furnace / Modular Blower Fan	7%	302
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	12%	475
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	14%	560
Manufactured Home Electric Furnace / Modular Blower Fan	6%	202

7.6 FURNACE FAN STANDBY ENERGY USE

Furnaces with higher efficiency furnace fans tend to have higher standby energy use. To account for this effect, DOE first estimated the difference in power consumption between the baseline efficiency level (EL 0) and the higher furnace fan efficiencies.[g] This difference in power consumption was estimated to be 0 watts for EL1 and EL2 and 3 watts for EL3 and above, based on test data from the 2011 Furnace rulemaking.[12] The power consumption is then multiplied by the standby hours calculated for each sampled household.

7.7 CHANGES IN HEATING AND AIR-CONDITIONING ENERGY USE WITH MORE-EFFICIENT FURNACE FANS

DOE accounted for the effect of improved furnace fan efficiency on the heating and cooling load of the sample homes. With improved furnace fan efficiency there is less heat from the motor, which means that the heating system needs to operate more and the cooling system needs to operate less.

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[g] EISA 2007 requires that standby energy consumption be considered in energy consumption unless the test procedure already accounts for standby mode and off mode energy use. Furnace fans are integrated in the electrical systems of the HVAC products in which they are used and controlled by the main control board. Therefore, there is no standby mode and off mode energy use associated with furnace fans used in these products that would not already be measured by the established test procedures.

7.7.1 Impact on Furnace Fuel Use with More-Efficient Furnace Fans

DOE accounted for the fact that more-efficient furnace fans will tend to contribute less heat and, thereby, require additional furnace operation. Because the heating load of each sample housing unit is known, it is possible to estimate what the furnace energy consumption would be if more efficient fan equipment, rather than the baseline equipment, were used in each housing unit.

DOE calculated the furnace fuel consumption (*FuelUse*) for each furnace fan efficiency level using the following formula[h]:

$$FuelUse = BOH \times Q_{IN}\text{, for single-stage furnace}$$

Where:
BOH = steady-state burner operating hours (hr), and
Q_{IN} = input capacity of existing furnace (kBtu/hr).

Recall from section 7.5.1 that BOH is calculated using BE (furnace fan electrical energy input rate), which is equal to the $FFP_{heating}$ (furnace fan power during the heating operation) variable calculated for each furnace fan efficiency level. The differential in fuel use between the baseline equipment (EL 0) and more-efficient design options (EL 1 and above) for each efficiency level is shown in the results tables in section 7.8.

DOE also calculated the non-furnace fan furnace electricity consumption (i.e., the electricity used by the induce draft blower and the electricity used by the ignitor) for each furnace fan efficiency level using the following formula:

$ElecUse_{non-furnace\_fan} = BOH_{ss} \times \left(y \times FFP + y_p \times PE + y_{ig} \times PE_{ig}\right)$,[h] for single-stage furnace,

Where:

BOH = as defined above,

y_P = ratio of induced-draft blower on-time to burner on-time,

PE = power consumption of the draft-inducer blower-motor (kW),

y_{IG} = ratio of ignitor on-time to burner on-time, and

PE_{IG} = power consumption of the ignitor (kW).

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[h] For natural draft equipment this formula is modified to include the pilot light consumption.

The differential in non-furnace fan furnace electricity consumption between the baseline equipment (EL 0) and more-efficient design options (EL 1 and above) for each efficiency level is included in the total electricity use shown in the results tables in section 7.8.

The details for calculating furnace energy consumption at each considered fan efficiency level appear in appendix 7-E.

7.7.2 Impact on Central Air Conditioner Energy Use with More-Efficient Furnace Fans

DOE accounted for the fact that more-efficient furnace fans will tend to contribute less heat and, thereby, require less cooling operation by the CAC. Because the cooling load of each sample housing unit is known, it is possible to estimate what the air conditioner energy consumption would be if more efficient fan equipment, rather than the baseline equipment, were used in each housing unit.

DOE calculated the non-furnace fan cooling energy using the following formula:

$$CoolingEnergyUse_{non-furnace\_fan} = COH \times Power_{non-furnace\_fan}$$

Where:

COH = as defined above in section 7.5.2,

$Power_{non\text{-}furnace\_fan}$ = power consumption of all non-furnace fan components of the central air conditioner (kW).

DOE calculated the non-furnace fan cooling power consumption as follows:

$$Power_{non-furnace\_fan} = (\frac{CoolingCapacity}{SEER} - \frac{365}{1000} * CFM)$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output, watts,

CFM = nominal cooling load cfm measured at 400 cfm per AC ton, cfm,

$SEER$ = SEER of central air conditioner, Btu/(W.h), and

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h.

In addition, DOE took into account that the amount of airflow impacts the efficiency of the central air conditioner. In general, it was observed in a recent 2008 study in Wisconsin that the efficiency increased with more airflow and decreased with less airflow.[13] From this study, DOE calculated that the energy use of the CAC varied by 5% per 100 CFM from the 400 CFM/AC ton commonly recommended setting, which was then used in the analysis.

The differential in non-furnace fan furnace electricity consumption between the baseline equipment (EL 0) and more-efficient design options (EL 1 and above) for each efficiency level is included in the total electricity use shown in the results tables in section 7.8.

The details for calculating the CAC energy consumption at each considered fan efficiency level appear in appendix 7-F.

7.8 SUMMARY OF ENERGY USE RESULTS

This section presents the average annual energy use and the average energy savings for each considered energy efficiency level compared to the baseline energy efficiency for each furnace fan product class. For the efficiency levels that are greater than the baseline, the electricity use includes the difference from the baseline in the non-furnace fan cooling energy use, non-furnace fan furnace electricity consumption, and furnace standby energy use. Thus, the electricity savings account for these indirect impacts on the higher furnace fan efficiency levels.

For the life-cycle cost (LCC) and payback period (PBP) analyses, DOE used the full distribution of energy use values calculated for the sample households.

Table 7.8.1 Average Annual Energy Consumption and Savings for Furnace Fans Used in Non-Weatherized Gas Furnaces

Efficiency Level	Non- Condensing Furnace			Condensing Furnace		
	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)
Baseline PSC	1014	0	0.00	1100	0	0.00
Improved PSC	894	119	0.13	980	120	0.16
Inverter-driven PSC	746	268	0.14	828	273	0.16
Constant-torque BPM motor	572	442	0.45	634	467	0.55
Constant-torque BPM motor + multi-stage	475	539	0.54	541	560	0.64
Constant-airflow BPM motor + multi-stage	471	543	0.52	542	558	0.60
Constant-airflow BPM motor + multi-stage + backward-curved impeller	420	593	0.58	488	612	0.68

Table 7.8.2 Average Annual Energy Consumption and Savings for Furnace Fans Used in Weatherized Gas Furnace Fans and Oil-Fired Furnaces

Efficiency Level	Weatherized Gas Furnace			Oil-fired Furnace		
	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)
Baseline PSC	913	0	0.00	951	0	0.00
Improved PSC	805	108	0.10	851	100	0.19
Inverter-driven PSC	688	225	0.14	706	245	0.21
Constant-torque BPM motor	520	393	0.35	550	401	0.67
Constant-torque BPM motor + multi-stage	434	480	0.41	471	480	0.81
Constant-airflow BPM motor + multi-stage	451	463	0.43	466	485	0.77
Constant-airflow BPM motor + multi-stage + backward-curved impeller	407	506	0.48	425	526	0.86

Table 7.8.3 Average Annual Energy Consumption and Savings for Furnace Fans Used in Manufactured Home Gas Furnaces

Efficiency Level	Non- Condensing Furnace			Condensing Furnace		
	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)	Annual Electricity Use (kWh)	Electricity Use Savings (kWh)	Additional Fuel Use (MMBtu)
Baseline PSC	558	0	0.00	689	0	0.00
Improved PSC	496	61	0.10	614	75	0.10
Inverter-driven PSC	431	126	0.11	538	151	0.09
Constant-torque BPM motor	349	209	0.36	434	255	0.34
Constant-torque BPM motor + multi-stage	299	258	0.42	377	311	0.39
Constant-airflow BPM motor + multi-stage	296	261	0.41	375	314	0.38
Constant-airflow BPM motor + multi-stage + backward-curved impeller	273	285	0.45	345	344	0.43

Table 7.8.4 Average Annual Energy Consumption and Savings for Furnace Fans Used in Electric Furnaces and Manufactured Home Electric Furnaces

Efficiency Level	Electric Furnace		Manufactured Home Electric Furnace	
	Annual Electricity Use (kWh)	Net Electricity Use Savings* (kWh)	Annual Electricity Use (kWh)	Net Electricity Use Savings* (kWh)
Baseline PSC	601	0	334	0
Improved PSC	532	69	294	40
Inverter-driven PSC	431	170	249	85
Constant-torque BPM motor	335	266	204	129
Constant-torque BPM motor + multi-stage	266	335	163	171
Constant-airflow BPM motor + multi-stage	272	329	170	164
Constant-airflow BPM motor + multi-stage + backward-curved impeller	243	358	154	179

* Accounts for additional energy used for heating.

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APPENDIX 7-A. RECS 2009 VARIABLES AND VALUES

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APPENDIX 7-A. RECS 2009 VARIABLES AND VALUES

7-A.1 INTRODUCTION

Using Microsoft ACCESS, DOE created a database containing a subset of the records and variables from DOE's Energy Information Administration (EIA)'s RECS 2009.[1] DOE used this RECS subset in the life-cycle cost (LCC) analysis of the Furnace Fan Rulemaking. This appendix explains the variable name abbreviations and provides definitions of the variable values. For the entire RECS 2009 dataset, refer to http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=microdata.

7-A.2 SAMPLE DETERMINATION

The subset of RECS 2009 records used to study furnace fans met all of the following criteria:

- used a furnace as the main or secondary source of heat;
- used a heating fuel that is natural gas, liquefied petroleum gas (LPG), fuel oil, or electricity;
- heated only one housing unit; and
- had an energy consumption greater than zero.

DOE divided the furnace subset into several subsets designed to include households that use one of the three furnace product classes (Table 7-A.2.1).

Figure 7-A.2.1 depicts the RECS selection process:

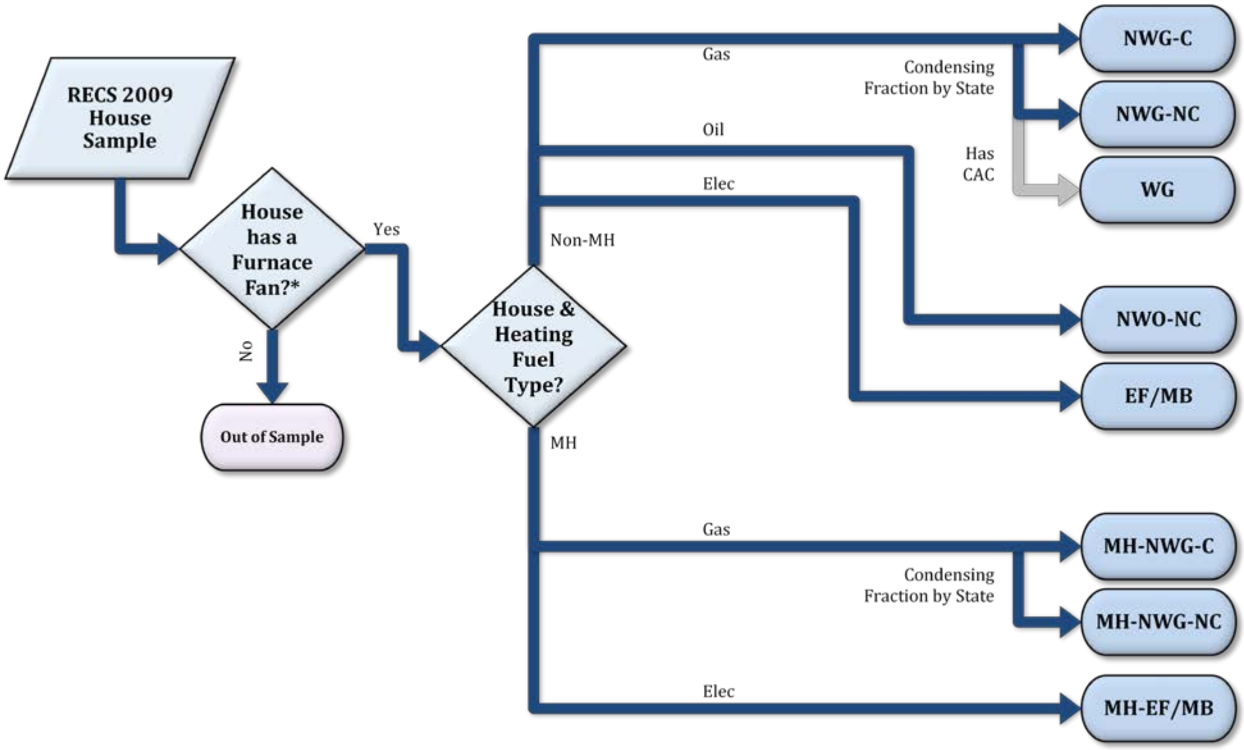

Figure 7-A.2.1 RECS Selection Process

The RECS 2009 weighting indicates how commonly each household configuration occurs in the general population. DOE made some adjustments to EIA's weightings for each RECS 2009 household in order to create a furnace fan population weight for 2019.

The first adjustment was to compensate for the fact that the RECS 2009 sample does not distinguish between weatherized and non-weatherized gas furnaces. Therefore, to account for the furnace fans associated with non-weatherized gas furnaces, DOE assumed that a fraction of the households with both a central air conditioner and gas furnace were using weatherized furnaces. Based on AHRI shipment data for weatherized and non-weatherized furnaces (which shows that about 10% of total furnace shipments are weatherized furnaces) and regional shipments (i.e., North, South Hot Dry, South Hot Humid) of both gas furnaces and packaged AC units, DOE multiplied the RECS 2009 weight for households for each region with both a central air conditioner and gas furnace by the regional factor.[2]

Next to account for the number of condensing and non-condensing shipments, DOE used historical AHRI shipments data by region and by state to derive 2019 fraction of condensing furnaces by RECS 2009 geographical regions. Each household weight was then multiplied by this factor to get the appropriate weighting for each gas furnace product class. (Note that for manufactured home gas furnaces the weighting of condensing furnaces by geographical area was assumed to be half that non-manufactured home furnaces.) Based on these assumptions it was assumed that 33 percent of the south region shipments would be condensing by 2019, while 77 percent north region shipments would be condensing.

For electric furnaces, DOE reviewed available data from U.S. Census new housing characteristics and believes that the number of RECS 2009 households with electric furnaces is overestimated. The majority of these households likely are associated with heat pump equipment. To take this into account DOE decreased the weighting of electric furnace households by 40%.

DOE also took into account the growth in households by region from 2009 to 2019 based on U.S. Census population projections and household estimates by state. Finally, DOE adjusted the weightings to account for households with multiple furnaces. DOE believes that the household records, along with their adjusted weightings, are representative of housing nationwide in 2019.

Table 7-A.2.1 Selection of RECS 2009 Records for Furnace Fans

Product Class	**Algorithm**	**No. of Records**	**RECS 2009**	**DOE 2019**
			Number of Houses ***million***	**Number of Furnaces** ***million***
Non-Weatherized, Non-Condensing Gas Furnaces	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = non-mobile home	4839	45.3*	18.6
Non-Weatherized, Condensing Gas Furnaces				26.7
Weatherized Gas Furnace	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = non-mobile home Primary or Secondary Cooling Equipment = Central Air Conditioner	3690	34.3	3.9
Oil Furnace	Primary or Secondary Heating Equipment = Oil Furnace Housing Type = non-mobile home	293	2.6	2.7
Electric Furnace / Modular Blower	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = non-mobile home; Primary or Secondary Cooling Equipment = not a Heat Pump	1849	15.5	6.9
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	Primary or Secondary Heating Equipment = Gas Furnace Housing Type = mobile home	156	2.0*	1.5
Manufactured Home Non-Weatherized, Condensing Gas Furnaces				0.6
Manufactured Home Electric Furnace /Modular Blower	Primary or Secondary Heating Equipment = Electric Furnace Housing Type = mobile home	149	2.0	0.9

* Same sample used.

Table 7-A.2.2 lists the variables use in the analysis.

Table 7-A.2.2 List of RECS 2009 Variables Used for Furnace Fans

Variable	Description
Location Variables	
REGIONC	Census Region
DIVISION	Census Division
REPORTABLE_DOMAIN	Reportable states and groups of states
CDD65	Cooling degree days in 2009, base temperature 65F
CDD30YR	Cooling degree days, 30-year average 1981-2010, base 65F
HDD65	Heating degree days in 2009, base temperature 65F
HDD30YR	Heating degree days, 30-year average 1981-2010, base 65F
Household Characteristics Variables	
DOEID	Unique identifier for each respondent
NWEIGHT	Final sample weight
TYPEHUQ	Type of housing unit
YEARMADE	Year housing unit was built
STORIES	Number of stories in a single-family home
BTUNGSPH	Natural Gas usage for space heating, in thousand BTU, 2009
BTULPSPH	LPG/Propane usage for space heating, in thousand BTU, 2009
BTUFOSPH	Fuel Oil usage for space heating, in thousand BTU, 2009
BTUELCOL	Electricity usage for air-conditioning, central and window/wall (room), in thousand BTU, 2009
EQUIPM	Type of main space heating equipment used
FUELHEAT	Main space heating fuel
HEATOTH	Main space heating equipment heats other homes, business, or farm
MAINTHT	Routine service or maintenance performed on main space heating equipment
WARMAIR	Central warm-air furnace used for secondary space heating
FURNFUEL	Fuel used by warm-air furnace for secondary space heating
REVERSE	Heat pump used for secondary space heating
EQUIPAGE	Age of main space heating equipment
RADFUEL	Fuel used by hot water system for secondary space heating
PIPEFUEL	Fuel used by pipeless furnace for secondary space heating
RMHTFUEL	Fuel used by built-in electric units for secondary space heating
HSFUEL	Fuel used by heating stove for secondary space heating
FPFUEL	Fuel used by fireplace for secondary space heating
RNGFUEL	Fuel used by cooking stove for secondary space heating
DIFFUEL	Fuel used by other secondary space heating equipment
EQMAMT	Portion of space heating provided by main space heating equipment (for homes with main and secondary heating only)
AUTOHEATNITE	Programmable thermostat lowers temperature at night
AUTOHEATDAY	Programmable thermostat lowers temperature during the day
NUMTHERM	Number of thermostats

Variable	Description
COOLTYPE	Type of air conditioning equipment used
CENACHP	Central air conditioner is a heat pump
USECENAC	Frequency central air conditioner used in summer 2009
AGECENAC	Age of central air conditioner
ACOTHERS	Central air conditioner cools other homes, business, or farm
USEWWAC	Frequency most-used window/wall air conditioning unit used in summer 2009
MAINTAC	Routine service or maintenance performed on central air conditioner
AUTOCOOLNITE	Programmable thermostat adjusts temperature at night
AUTOCOOLDAY	Programmable thermostat adjusts temperature during the day
TOTSQFT	Total square footage (includes all attached garages, all basements, and finished/heated/cooled attics)
TOTSQFT_EN	Total square footage (includes heated/cooled garages, all basements, and finished/heated/cooled attics). Used for EIA data tables.
NHSLDMEM	Number of household members
Seniors*	Number of household members age 65 or older
POVERTY100	Household income at or below 100% of poverty line
StationID*	ID number of weather station identified with household (See Appendix 7-D)
KWH	Total Site Electricity usage, in kilowatt-hours, 2009
DOLLAREL	Total Electricity cost, in whole dollars, 2009
BTUNG	Total Natural Gas usage, in thousand BTU, 2009
DOLLARNG	Total Natural Gas cost, in whole dollars, 2009
BTULP	Total LPG/LPG/Propane usage, in thousand BTU, 2009
DOLLARLP	Total cost of LPG/Propane, in whole dollars, 2009
BTUFO	Total Fuel Oil usage, in thousand BTU, 2009
DOLLARFO	Total cost of Fuel Oil, in whole dollars, 2009

* Not part of RECS 2009 variables.

7-A.3 RECS 2009 DATABASE VARIABLE RESPONSE CODES

Table 7-A.3.1 provides the response codes for all RECS 2009 variables used in the Heating Products samples.

Table 7-A.3.1 Definitions of RECS 2009 Variables Used in Life-Cycle Cost Analysis

Variable	Definition
ACOTHERS	Central air conditioner cools other homes, business, or farm 0 = No 1 = Yes -2 = Not Applicable

Variable	**Definition**
AGECENAC	Age of central air conditioner 1 = Less than 2 years old 2 = 2 to 4 years old 3 = 5 to 9 years old 41 = 10 to 14 years old 42 = 15 to 19 years old 5 = 20 years or older -2 = Not Applicable"
AUTOCOOLDAY	Programmable thermostat adjusts temperature during the day 0 = No 1 = Yes -2 = Not Applicable
AUTOCOOLNITE	Programmable thermostat adjusts temperature at night 0 = No 1 = Yes -2 = Not Applicable
AUTOHEATDAY	Programmable thermostat lowers temperature during the day 0 = No 1 = Yes -2 = Not Applicable
AUTOHEATNITE	Programmable thermostat lowers temperature during at night 0 = No 1 = Yes -2 = Not Applicable
BTUELCOL	Electricity usage for air-conditioning, central and window/wall (room), in thousand BTU, 2009
BTUFO	Total Fuel Oil usage, in thousand BTU, 2009
BTUFOSPH	Fuel Oil usage for space heating, in thousand BTU, 2009
BTULP	Total LPG/LPG/Propane usage, in thousand BTU, 2009
BTULPSPH	LPG/Propane usage for space heating, in thousand BTU, 2009
BTUNG	Total Natural Gas usage, in thousand BTU, 2009
BTUNGSPH	Natural Gas usage for space heating, in thousand BTU, 2009
CDD30YR	Cooling degree days, 30-year average 1981-2010, base 65F
CDD65	Cooling degree days in 2009, base temperature 65F
CENACHP	Central air conditioner is a heat pump
COOLTYPE	Type of air conditioning equipment used
DIFFUEL	Fuel used by other secondary space heating equipment 0 = No 1 = Yes -2 = Not Applicable

Variable	**Definition**
DIVISION	Census Division 1 = New England Census Division (CT, MA, ME, NH, RI, VT) 2 = Middle Atlantic Census Division (NJ, NY, PA) 3 = East North Central Census Division (IL, IN, MI, OH, WI) 4 = West North Central Census Division (IA, KS, MN, MO, ND, NE, SD) 5 = South Atlantic Census Division (DC, DE, FL, GA, MD, NC, SC, VA, WV) 6 = East South Central Census Division (AL, KY, MS, TN) 7 = West South Central Census Division (AR, LA, OK, TX) 8 = Mountain North Sub-Division (CO, ID, MT, UT, WY) 9 = Mountain South Sub-Division (AZ, NM, NV) 10 = Pacific Census Division (AK, CA, HI, OR, WA)
DOEID	Unique identifier for each respondent 00001 - 12083
DOLLAREL	Total Electricity cost, in whole dollars, 2009
DOLLARFO	Total cost of Fuel Oil, in whole dollars, 2009
DOLLARLP	Total cost of LPG/Propane, in whole dollars, 2009
DOLLARNG	Total Natural Gas cost, in whole dollars, 2009
EQMAMT	Portion of space heating provided by main space heating equipment (for homes with main and secondary heating only) 1 = Almost all 2 = About three-fourths 3 = Closer to half 4 = Not Applicable
EQUIPAGE	Age of main space heating equipment 1 = Less than 2 years old 2 = 2 to 4 years old 3 = 5 to 9 years old 41 = 10 to 14 years old 42 = 15 to 19 years old 5 = 20 years or older -2 = Not Applicable
EQUIPM	Type of main space heating equipment used 2 = Steam or Hot Water System 3 = Central Warm-Air Furnace 4 = Heat Pump 5 = Built-In Electric Units 6 = Floor or Wall Pipeless Furnace 7 = Built-In Room Heater 8 = Heating Stove 9 = Fireplace 10 = Portable Electric Heaters 11 = Portable Kerosene Heaters 12 = Cooking Stove 21 = Other Equipment -2 = Not Applicable"

Variable	Definition
FPFUEL	Fuel used by fireplace for secondary space heating 1 = Natural Gas 2 = Propane/LPG 7 = Wood 21 = Other Fuel -2 = Not Applicable
FUELHEAT	Main space heating fuel 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene 5 = Electricity 7 = Wood 8 = Solar 9 = District Steam 21 = Other Fuel -2 = Not Applicable
FURNFUEL	Fuel used by warm-air furnace for secondary space heating 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene 5 = Electricity 7 = Wood 8 = Solar 9 = District Steam 21 = Other Fuel -2 = Not Applicable
HDD30YR	Heating degree days, 30-year average 1981-2010, base 65F
HDD65	Heating degree days in 2009, base temperature 65F
HEATOTH	Main space heating equipment heats other homes, business, or farm 0 = No 1 = Yes -2 = Not Applicable
HSFUEL	Fuel used by heating stove for secondary space heating 7 = Wood 21 = Other Fuel -2 = Not Applicable
KWH	Total Site Electricity usage, in kilowatt-hours, 2009
MAINTAC	Routine service or maintenance performed on central air conditioner 0 = No 1 = Yes -2 = Not Applicable

Variable	Definition
MAINTHT	Routine service or maintenance performed on main space heating equipment 0 = No 1 = Yes -2 = Not Applicable
NHSLDMEM	Number of household members 0-15
NUMTHERM	Number of thermostats 1-5 = Number of thermostats -2 = Not Applicable
NWEIGHT	Final sample weight
PIPEFUEL	Fuel used by pipeless furnace for secondary space heating 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene 5 = Electricity 7 = Wood 8 = Solar 9 = District Steam 21 = Other Fuel -2 = Not Applicable
POVERTY100	Household income at or below 100% of poverty line 0 = No 1 = Yes
RADFUEL	Fuel used by hot water system for secondary space heating 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene 5 = Electricity 7 = Wood 8 = Solar 9 = District Steam 21 = Other Fuel -2 = Not Applicable
REGIONC	Census Region 1 = Northeast Census Region 2 = Midwest Census Region 3 = South Census Region 4 = West Census Region

Variable	Definition
REPORTABLE_DOMAIN	Reportable states and groups of states 1 = Connecticut, Maine, New Hampshire, Rhode Island, Vermont 2 = Massachusetts 3 = New York 4 = New Jersey 5 = Pennsylvania 6 = Illinois 7 = Indiana, Ohio 8 = Michigan 9 = Wisconsin 10 = Iowa, Minnesota, North Dakota, South Dakota 11 = Kansas, Nebraska 12 = Missouri 13 = Virginia 14 = Delaware, District of Columbia, Maryland, West Virginia 15 = Georgia 16 = North Carolina, South Carolina 17 = Florida 18 = Alabama, Kentucky, Mississippi 19 = Tennessee 20 = Arkansas, Louisiana, Oklahoma 21 = Texas 22 = Colorado 23 = Idaho, Montana, Utah, Wyoming 24 = Arizona 25 = Nevada, New Mexico 26 = California 27 = Alaska, Hawaii, Oregon, Washington
REVERSE	Heat pump used for secondary space heating 0 = No 1 = Yes -2 = Not Applicable
RMHTFUEL	Fuel used by built-in electric units for secondary space heating 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene -2 = Not Applicable

Variable	Definition
RNGFUEL	Fuel used by cooking stove for secondary space heating 1 = Natural Gas 2 = Propane/LPG 3 = Fuel Oil 4 = Kerosene 5 = Electricity 7 = Wood 21 = Other Fuel -2 = Not Applicable
Seniors*	Number of household members age 65 or older
StationID*	Weather station identified with household (see appendix 7D)
STORIES	Number of stories in a single-family home 10 = One story 20 = Two stories 31 = Three stories 32 = Four or more stories 40 = Split-level 50 = Other type -2 = Not Applicable
TOTSQFT	Total square footage (includes all attached garages, all basements, and finished/heated/cooled attics)
TOTSQFT_EN	Total square footage (includes heated/cooled garages, all basements, and finished/heated/cooled attics). Used for EIA data tables.
TYPEHUQ	Type of housing unit 1 = Mobile Home 2 = Single-Family Detached 3 = Single-Family Attached 4 = Apartment in Building with 2 - 4 Units 5 = Apartment in Building with 5+ Units
USECENAC	Frequency central air conditioner used in summer 2009 1 = Turned on only a few days or nights when really needed 2 = Turned on quite a bit 3 = Turned on just about all summer -2 = Not Applicable
USEWWAC	Frequency most-used window/wall air conditioning unit used in summer 2009 1 = Turned on only a few days or nights when really needed 2 = Turned on quite a bit 3 = Turned on just about all summer -2 = Not Applicable
WARMAIR	Central warm-air furnace used for secondary space heating 0 = No 1 = Yes -2 = Not Applicable
YEARMADE	Year housing unit was built 1600 - 2009

* Not part of RECS 2009 variables.

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APPENDIX 7-B. SYSTEM CURVE DERIVATION FOR FURNACE FANS

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APPENDIX 7-B. SYSTEM CURVE DERIVATION FOR FURNACE FANS

7-B.1 INTRODUCTION

The system curve of the air-distribution system is a graphical representation of the airflow through the supply and return ducts in a house for different static pressures. The airflow and pressure drop at which the furnace will operate can be determined by the intersection of the system curve of the house and the fan curve of the furnace fan.[1] Figure 7-B.1.1 shows an example of a plot of system curves intersecting a furnace fan curve.

DOE modeled system curves as quadratic curves, which is standard in heating, ventilation, and air conditioning (HVAC) design and fan selection handbooks.[2] The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$Q = \sqrt{\frac{P}{\alpha}}$$

Where:

Q = airflow (cfm),
P = static pressure (in.w.g.), and
α = a constant coefficient.

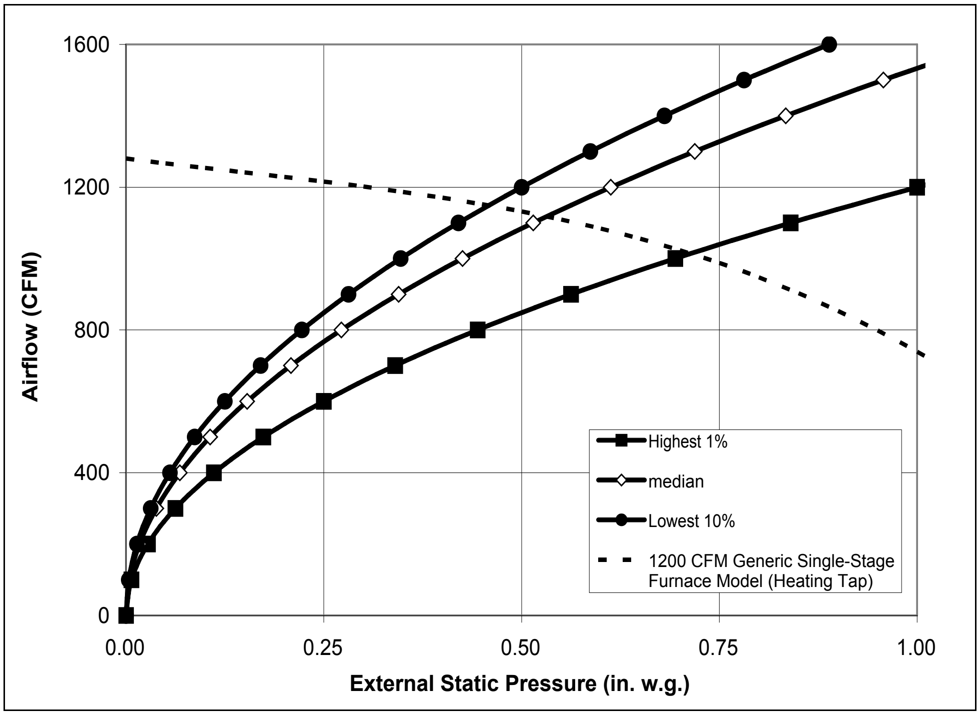

Figure 7-B.1.1 Sample of System Curves with a Typical Fan Curve

7-B.2 FURNACE FANS REFERENCE SYSTEM CURVES

In DOE's proposed furnace fan test procedure, the reference system curve is defined as follows:

$$K_{ref} = \frac{ESP_{ref}}{Q_{max}{}^2}$$

where:

K_{ref} = a constant that characterizes the reference system;
ESP_{ref} = Reference System External Static Pressure (ESP); and
$Q_{max} = a_{max}ESP_{ref}{}^2 + b_{max}ESP_{ref} + c_{max}$

The operating point in the maximum airflow-control setting is defined by the reference system criteria: ESP_{ref} and Q_{max}. External static pressure (ESP) is the portion of the fan total pressure that exists by virtue of degree of compression external to the HVAC product in which the furnace fan is contained. ESP does not include the pressure drop across appurtenances internal to the HVAC product. In the field, ESP is measured as the difference in pressure between the HVAC product inlet and outlet points, and includes the ductwork, inlet filter, and coil outside of the unit if applicable.

In the field there are four distinct reference system ESPs associated with specific equipment:

a) **Units with Cooling Option (Coil Outside of Unit):** This includes non-weatherized gas furnaces and oil-furnaces. Reference system is measured at the maximum default cooling airflow control setting. ESP includes a fraction of units in the field that include the evaporator coil.

b) **Heating only units:** Reference system is measured at the default heating airflow control setting. ESP does not include evaporator coil.

c) **Units with Coil inside Unit:** This includes weatherized gas and oil-fired furnaces. Reference system is measured at the maximum default cooling airflow control setting. ESP does not include evaporator coil.

d) **Manufactured Home Units:** This includes manufactured home gas or oil-fired furnaces. Reference system is measured at the cooling airflow control setting for these units. ESP includes a fraction of units in the field that include the evaporator coil.

7-B.3 FIELD STUDIES

DOE gathered field data from available studies and research reports to determine an appropriate ESP value to propose for the reference system. DOE compiled over 1300 field ESP measurements from 27 studies that included furnace fans in single family and manufactured homes in different regions of the country. Table 7-B.3.1summarizes the field data for single family homes at cooling airflow setting. Table 7-B.3.2 summarizes the field data for manufactured homes at cooling airflow setting. The average measured ESP values are the actual values measured in each study. Some studies did not include the evaporator coil or filter in the ESP measurement. To account for this DOE added the filter pressure drop to all adjusted ESP values ("Adj. w/o Coil" and "Adj. w/ Coil"). In addition, DOE subtracted the pressure drop of the evaporator coil for "Adj. w/o Coil" and added the pressure drop of the evaporator coil for "Adj. w/ Coil" when appropriate. See next section for the determination of average filter and evaporator pressure drop values.

Table 7-B.3.1 Single Family Field Data ESP at Cooling Airflow Setting

Study	**Sample Size**	**Average ESP *(in. w.c.)***			**Notes**
		Measured	**Adj. w/o Coil**	**Adj. w/ Coil**	
Blasnik et al. 1995[3]	40	0.41	0.41	0.61	1
Blasnik et al. 1996[4]	28	0.48	0.48	0.68	1
Parker 1997[5]	9	0.55	0.55	0.75	1
Proctor et al. 1995[6]	40	0.53	0.53	0.73	1
Proctor et al. 1996[7]	36	0.51	0.51	0.71	1
Proctor et al. 1998[8]	15	0.45	0.45	0.65	1
Proctor 1998[9]	36	0.42	0.42	0.62	1
Proctor 2005[10]	78	0.48	0.48	0.68	1
Proctor et al. 2007[11]	4	1.01	0.81	1.01	
Proctor 2000[12]	5	0.50	0.50	0.70	1
Proctor 2001[13]	69	0.54	0.54	0.74	1
Proctor 2003[14]	69	0.53	0.53	0.73	1
Proctor 1996a[15]	8	0.45	0.45	0.65	1
Proctor 1996b[16]	92	0.31	0.52	0.73	1,2
Wilcox et. al. 2006[17]	51	0.77	0.57	0.77	
Dickenhoff 1998[18]	13	0.54	0.54	0.74	1
Baylon et al. 2005[19]	148	0.36	0.57	0.78	1,2
Ueno 2010 (2008 Study)[20]	4	0.90	0.70	0.90	
Ueno 2010 (2009 Study)[20]	1	1.12	0.92	1.12	
Pigg 2008 (2007 Study)[21]	76	0.73	0.53	0.73	
Pigg 2008 (2005 Study)[21]	37	0.53	0.53	0.73	1
Pigg 2003[22]	31	0.55	0.55	0.75	1
Weighted Average	890	0.50	0.52	0.73	

1 ESP measurement includes Coil
2 ESP measurement includes Filter

Table 7-B.3.2 Manufactured Home Field Data

Study	Sample Size	Average ESP *(in. w.c.)*			Notes
		Measured	Adj. w/o Coil	Adj. w/ Coil	
Baylon et al. 1995[23]	164	0.18	0.18	0.38	1
Davis et al. 2000[24]	36	0.23	0.23	0.43	1
Davis et al. 2004[25]	100	0.12	0.12	0.32	1
Ecotope 2006[26]	69	0.23	0.23	0.43	1
Baylon et al. 2009[27]	89	0.12	0.12	0.32	1
Weighted Average	458	0.17	0.17	0.37	

1 ESP measurement does not include Coil
2 ESP measurement does not include Filter

7-B.4 DETERMINATION OF REFERENCE SYSTEM CURVES FOR DOE FURNACE FAN TEST PROCEDURE

Using field data from 3 studies, DOE estimated average filter and coil pressures in order to adjust field data that did not include the filter or coil. On average, the pressure drop measured for the evaporator coil was 0.20 in w.c. (as shown in Table 7-B.4.1) and the pressure drop for the filter was 0.21 in w.c. (as shown in Table 7-B.4.2).

Table 7-B.4.1 Evaporator Coil Pressure Data

Study	Sample Size	Average Pressure Drop *(in. w.c.)*
Pigg 2008 (2007 Study)[21]	75	0.20
Pigg 2008 (2005 Study)[21]	19	0.19
Wilcox et. al. 2006[17]	51	0.21
Weighted Average	145	0.20

Table 7-B.4.2 Filter Pressure Data

Study	Sample Size	Average Pressure Drop *(in. w.c.)*
Pigg 2008 (2007 Study)[21]	76	0.25
Pigg 2008 (2005 Study)[21]	37	0.21
Wilcox et. al. 2006[17]	46	0.16
Weighted Average	159	0.21

Using EIA's RECS 2005 data, DOE estimated the fraction of furnace installations with and without a coil in the ESP. For units with a cooling option (coil outside unit), DOE looked at all households with either a gas or oil-fired furnace and determined that 72.9% of these households had central air-conditioners.[a] For manufactured home units DOE looked at all

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[a] For simplicity, electric furnaces are excluded since they are mostly associated with heat pumps. Also, RECS does not provide information to distinguish which households have hydronic air-handlers. Adding electric furnaces and hydronic equipment will increase the fraction of households with central air-conditioners, since this equipment tends to be located in warmer climates.

manufactured home households with either a gas or oil-fired furnace and determined that 50.2% of these households had central air-conditioners. DOE estimated that these two fractions would represent the fraction of installations with evaporator coil in the ESP. Table 7-B.4.3 data shows the results for each of the distinct reference systems. None of the heating only units or units with coil inside are assumed to have an evaporator coil in the ESP.

Table 7-B.4.3 Fraction of Installations with Evaporator Coil in ESP

Product Description	Fraction of Installations with Evaporator Coil in ESP
Units with Cooling Option (Coil Outside Unit)	72.9%
Heating only units	0%
Units with Coil inside	0%
Manufacture Home	50.2%

Table 7-B.4.4 presents the final results of this analysis for each distinct reference system curve used in DOE's NOPR furnace fan test procedure. The results take into account the fraction of units with the coil included in the ESP.

Table 7-B.4.4 Summary of Weighted Average Reference System ESP Values

Product Description	Airflow Control Setting	Weighted Average ESP *(in. w.c.)*
Units with Cooling Option (Coil Outside Unit)	Cooling	0.65
Heating only units	Heating	0.50
Units with Coil inside	Cooling	0.50
Manufacture Home[b]	Cooling	0.30

(All Values Rounded)

The results are determined as follows:

1) for units with cooling option (coil outside unit), 72% of the furnace fans are installed with CAC (see Table 7-B.4.3), so 72% * 0.73 in. w.c. + 28% * 0.52 in. w.c., which is rounded to 0.65 in w.c.;
2) for manufactured homes furnace fans, 50% of the furnaces are installed with CAC (see Table 7-B.4.3), so 50% * 0.17 in. w.c. + 50% * 0.37 in. w.c., which is rounded to 0.30 in w.c.;
3) for heating only units and units with coil inside the weighted average ESP is rounded from 0.52 in. w.c. to 0.50 in w.c.

7-B.4.1 Other reference system curves

Manufacturers Rating for Cooling – 0.5 in.w.c. at cooling airflow setting [manufacturer product literature]

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[b] Manufactured home external static pressure is much smaller due to the fact there is no return air ductwork in manufactured homes. Also HUD requirements stipulate that the ductwork for cooling should be set at 0.3 in. w.c.

DOE test procedure for Cooling - 0.1 to 0.2 in.w.c. for conventional split systems [Subpart B Appendix M of Title 10 Part 430 of the Code of Federal Regulations (CFR)]

DOE test procedure for Furnaces – 0.12 – 0.58 in.w.c. minimum static pressure values depend on equipment type as follows [Subpart B Appendix N of Title 10 Part 430 of the Code of Federal Regulations (CFR), which references ANSI/ASHRAE 103, table 4 and 5]:

a) Gas furnaces and Oil furnaces (w/ temp rise greater than 65 deg) - 0.18 to 0.33 in. w.c. (depending on input capacity)
b) Oil furnace (w/ temp rise less than or equal to 65 deg) – 0.38 - 0.58 in w.c. (depending on input capacity)
c) Electric furnaces - 0.12 to 0.25 in.w.c. (dependant on Standard Air Quantity (SCFM))

Canadian Furnace Fan Standard – 0.3 inches WC (Recommended practice) and 0.6 inches WC (Common Practice) at heating airflow setting [CSA. C823-11: Performance of air handlers in residential space conditioning systems. May 2011.]

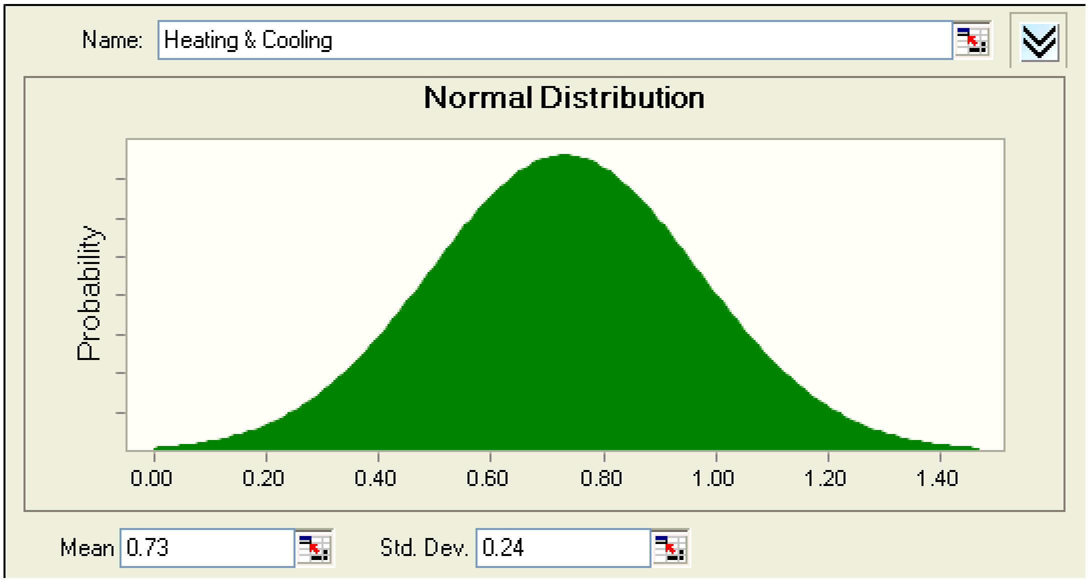
HUD for Manufactured Home with comfort cooling certificate – 0.3 inches WC at cooling airflow setting [Title 24 of the HUD code PART 3280--Manufactured Home Construction and Safety Standards, Part 3280.715 (a) (3) (ll)]

7-B.5 DISRIBUTION OF SYSTEM CURVES USED IN LCC ANALYSIS

For the LCC analysis, DOE used the field data above to generate normal distributions for the various equipment installation variations as shown in Table 7-B.5.1. Figure 7-B.5.1 to Figure 7-B.5.4 show the external static pressure distributions used in the analysis.

Table 7-B.5.1 Reference System ESP Distribution Parameters Values by Product Class

Product Classes	**Household Has Central AC**	**Average ESP** *(in. w.c.)*	**Standard Deviation** *(in. w.c.)*
Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan	Yes	0.73	0.24
	No	0.52	0.18
Weatherized Gas Furnace Fan	Yes	0.52	0.18
Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan	Yes	0.37	0.12
	No	0.17	0.06

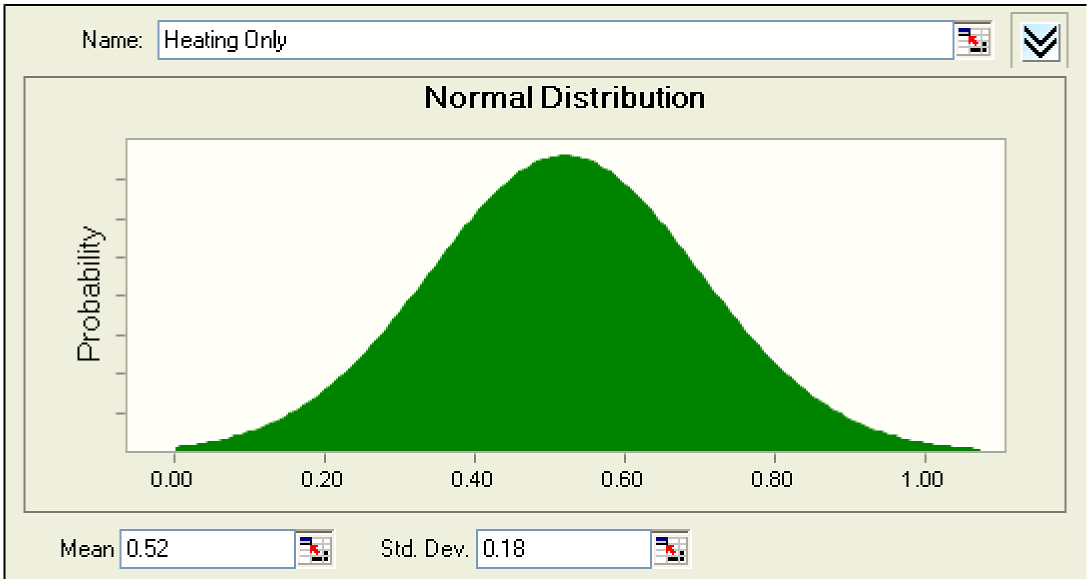


Name: Heating & Cooling

Mean 0.73

Std. Dev. 0.24

Figure 7-B.1.1 External Static Pressure Distribution for Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan

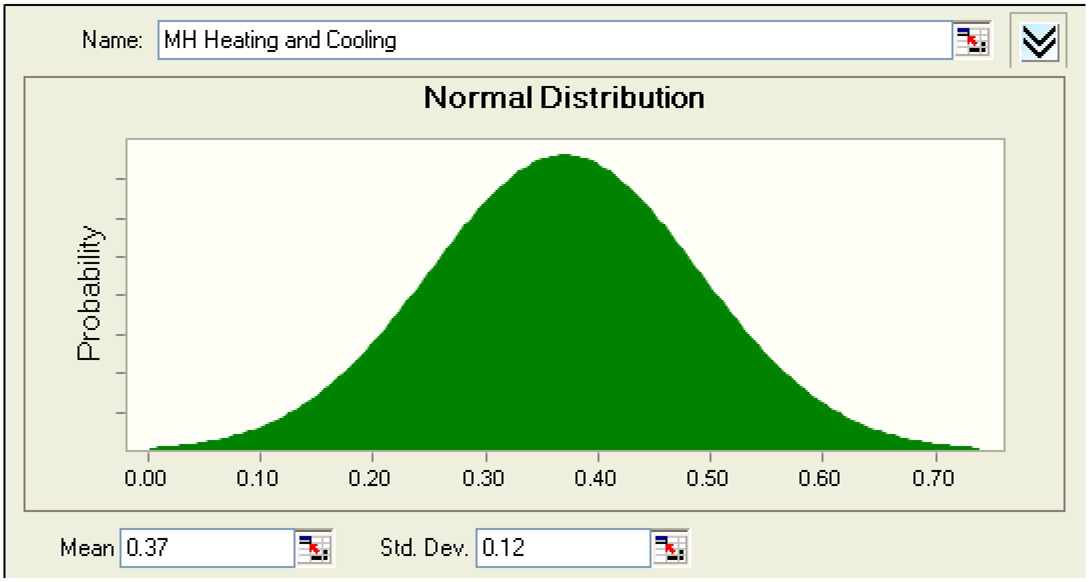


Name: Heating Only

Mean 0.52

Std. Dev. 0.18

Figure 7-B.1.2 External Static Pressure Distribution for Non-Weatherized Gas Furnace Fan; Oil Furnace Fan; Electric Furnace / Modular Blower Fan

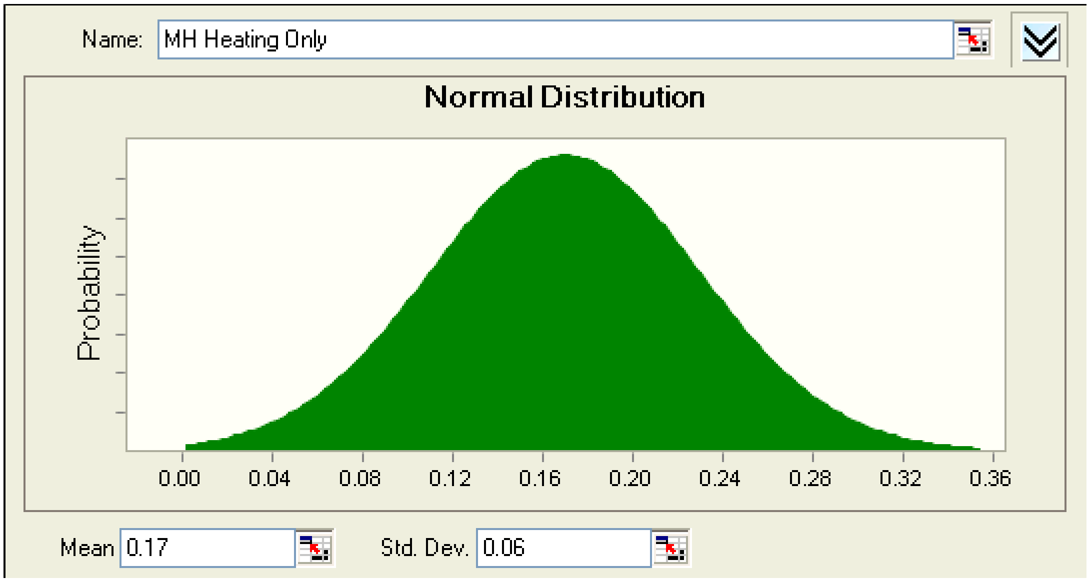


Name: MH Heating and Cooling

Mean 0.37

Std. Dev. 0.12

Figure 7-B.1.3 External Static Pressure Distribution for Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan with Central Air Conditioning



Name: MH Heating Only

Mean 0.17

Std. Dev. 0.06

Figure 7-B.1.4 External Static Pressure Distribution for Manufactured Home Non-Weatherized Gas Furnace Fans; Manufactured Home Electric Furnace / Modular Blower Fan without Central Air Conditioning

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APPENDIX 7-C. CALCULATION OF FURNACE BLOWER FAN ENERGY CONSUMPTION

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APPENDIX 7-C. CALCULATION OF FURNACE BLOWER FAN ENERGY CONSUMPTION

7-C.1 INTRODUCTION

The electricity consumption (and overall efficiency) of a blower motor depends on the speed at which the motor operates, the external static pressure difference across the blower, and the airflow through the blower. To calculate blower-motor electricity consumption, DOE determined the operating conditions (the pressure and airflow) at which a particular furnace in a particular housing unit will operate. These operating conditions can be graphically displayed as the intersection of a system curve of the ducts in the housing unit (which plots the airflow across the supply and return air ducts as a function of static pressure) with the fan curve of the furnace (which plots the airflow through the furnace as a function of static pressure). The intersection of these two curves is the airflow and the static pressure at which the furnace will operate in that housing unit. See Figure 7-C.1.1 for a graphical representation of the power determination.

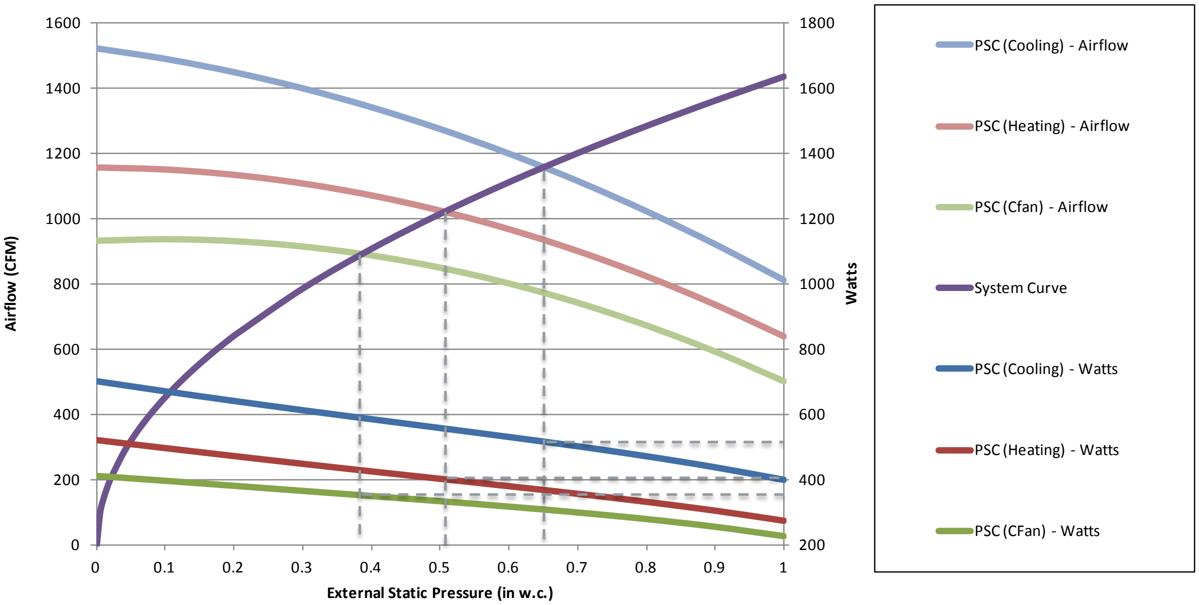


Figure 7-C.1.1 Power Determination

Furnace fan curves, reported as tables of airflow rise versus static pressure through the furnace, are available from manufacturers in the product literature for each furnace. Some of the manufacturers also supply blower-motor input power as a function of static pressure across the furnace.

Air power is calculated from the air speed through the furnace and the pressure rise across the furnace. The overall air-moving efficiency is air power divided by the electric power to the blower motor. All the electric power of the blower motor eventually is converted to heat that contributes to meeting the building heating load.

Figure 7-C.1.2 shows the energy use determination methodology.

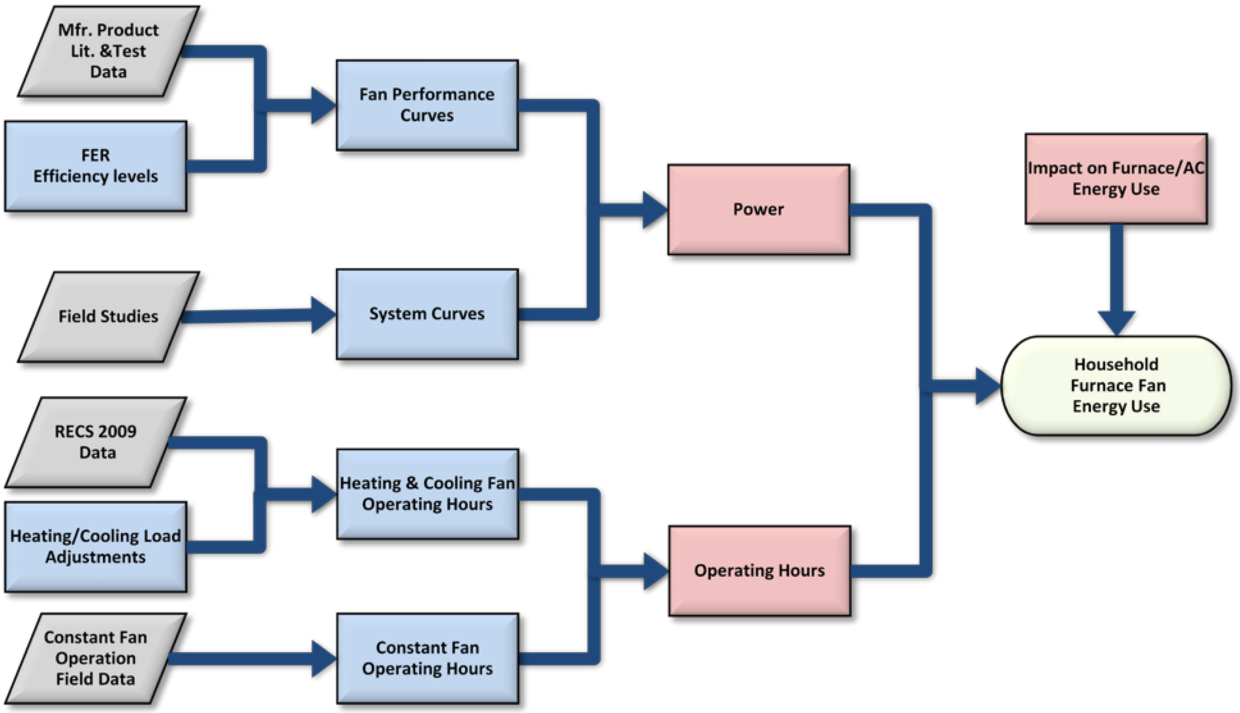


Figure 7-C.1.2 Energy Use Methodology

7-C.2 SYSTEM CURVES

The system curve of the air-distribution system is a graphical representation of the airflow through the supply and return ducts in a house for different static pressure. The airflow and pressure drop at which the furnace will operate can be determined by the intersection of the system curve of the house and the fan curve of the furnace circulating air blower.[1]

The Department modeled system curves as quadratic curves, which is standard in heating, ventilation, and air conditioning (HVAC) design and fan selection handbooks.[2] The curves are based on Bernoulli's equations for fluid flow and are expressed as the following equation:

$$Q = \sqrt{\frac{P}{\alpha}}$$

where:

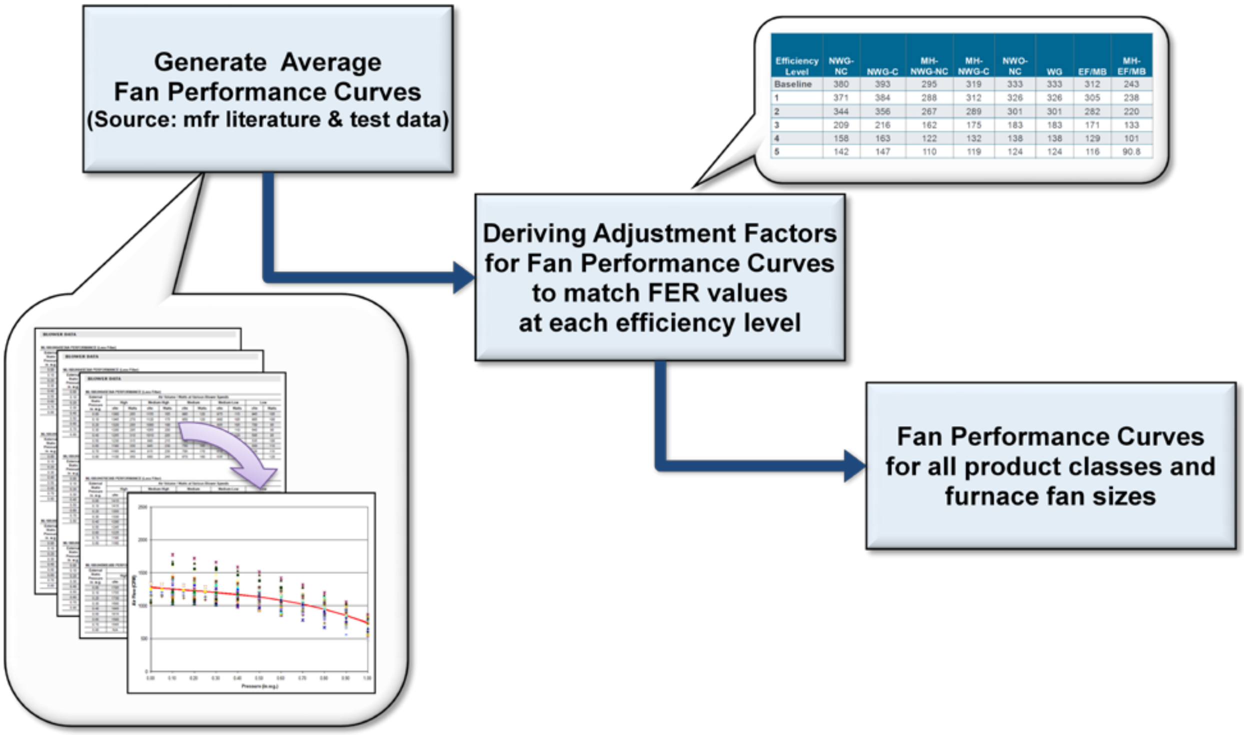
Q = airflow (cfm),
P = static pressure (in.w.g.), and
α = a constant coefficient.

The Department selected the coefficient in the system curve equation for each housing unit. It randomly sampled a coefficient from one of four distributions (See Appendix 7-B).

7-C.3 FURNACE FAN CURVES

7-C.3.1 Fan Airflow Curves

Depending on the resistance (measured as static pressure) of the supply and return air ducts, a furnace will move more or less air. When these airflow values are plotted graphically against pressure, they are referred to as fan curves. Figure 7-C.3.1 shows the performance curves determination



Efficiency Level	NWG-NC	NWG-C	MH-NWG-NC	MH-NWG-C	NWO-NC	WG	EF/MB	MH-EF/MB
Baseline	380	393	295	319	333	333	312	243
1	371	384	288	312	326	326	305	238
2	344	356	267	289	301	301	282	220
3	209	216	162	175	183	183	171	133
4	158	163	122	132	138	138	129	101
5	142	147	110	119	124	124	116	90.8

Figure 7-C.3.1 Performance Curves Determination

The Department developed fan curves for Cooling, High Fire, Low Fire, and Continuous Fan modes) by fitting the airflow and pressure data points from the model furnaces and test data to a second-order polynomial. The Department used the non-constant coefficients (assuming that they are similar enough that they do not change with different air handler sizes or furnace fan operating modes) and used the following methodology to come up with the constant coefficients:

COOLING MODE: cooling airflow passes through 0.5 in w.g. at a rate of 400 CFM/ton for non-mobile home furnaces and 0.3 in w.g. at a rate of 400 CFM/ton.

HEATING MODE (HIGH): heating airflow passes through minimum static pressure set in the TP at a rate of [based on test procedure assumptions and common practice]:

* 2 Ton: 40 kBtu/h output capacity per (1.08 * 50 degree temp rise[a]) = 741 CFM at 0.18 in w.g.
* 3 Ton: 60 kBtu/h output capacity per (1.08 * 50 degree temp rise) = 1111 CFM at 0.20 in w.g.
* 4 Ton: 80 kBtu/h output capacity per (1.08 * 50 degree temp rise) =
1481 CFM at 0.23 in w.g.
* 5 Ton: 100 kBtu/h output capacity per (1.08 * 50 degree temp rise) = 1852 CFM at 0.28 in w.g.

OR typical med-high airflow settings (whichever is higher) as follows

PSC = 86% of cooling mode
PSC w/controls = 80% of cooling mode
BPM (constant torque) = 91% of cooling mode

HEATING MODE (LOW): heating airflow passes through minimum static pressure set in the TP at a rate of 0.7 of the above assumptions or at typical med-low airflow settings as follows:

PSC = 78% of cooling mode
PSC w/controls = 70% of cooling mode
BPM (constant torque) = 65% of cooling mode

CONTINUOUS FAN MODE: Are set equal to a fraction of the cooling mode airflow settings as follows:

PSC = 0.70 of cooling mode
BPM (constant torque) = 0.60 of cooling mode
PSC with controls and BPM (constant airflow) = 0.55 of cooling mode

In addition the following assumptions apply:

1) slope of airflow and watts/CFM does not vary within one and the same motor technology

2) it is assumed that BPM (constant airflow) and PSC with controls maintain the same airflow always

3) if AC unit is smaller than AC tonnage of furnace fan then the fan speed is adjusted to match the lower AC unit at 400 CFM/ton

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[a] Typically the temperature rise maximum is 60 to 70 degrees, 50 degrees temp rise is assuming a 65 degree temperature rise minus 15 degrees to be in the middle point of the temperature rise range

4) temp rise of heating is checked to make sure it is met at the external static pressure of the sampled household (if not CFM is raised to match it)

5) the system curve is set by matching a distribution of static pressures with AC tonnage at 400 CFM/tons

The CFM for the blower motors is given by the following equation:

$$CFM = m_0 + m_1 \times (P) + m_2 \times (P^2) \quad \textbf{Eq. 1}$$

where,

CFM = airflow in CFM,
$m_{0,1,2,and\ 3}$ = coefficients derived from 2nd degree polynomial approximation, and
P = external static pressure (in.w.g.).

The coefficients derived are show in Tables 7-C.3.1 to 7-C.3.4 for non-manufactured home furnaces.

Table 7-C.3.1 Coefficients for CFM equation for PSC motors (non-manufactured home furnaces)

	Cooling			**Heating, High**		**Heating, Low**			**Continuous Fan**		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2	m_0	m_1	m_2
2-ton	918	49	-570	789	49	-570	716	49	-570	643	49	-570
3-ton	1318	49	-570	1133	49	-570	1028	49	-570	923	49	-570
4-ton	1718	49	-570	1500	49	-570	1340	49	-570	1203	49	-570
5-ton	2118	49	-570	1883	49	-570	1652	49	-570	1483	49	-570

Table 7-C.3.2 Coefficients for CFM equation for PSC motors (with controls, non-manufactured home furnaces)

	Cooling			**Heating, High**		**Heating, Low**			**Continuous Fan**		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2	m_0	m_1	m_2
2-ton	751	267	-338	704	267	-338	511	267	-338	413	267	-338
3-ton	1151	267	-338	1071	267	-338	783	267	-338	633	267	-338
4-ton	1551	267	-338	1438	267	-338	1055	267	-338	853	267	-338
5-ton	1951	267	-338	1804	267	-338	1327	267	-338	1073	267	-338

Table 7-C.3.3 Coefficients for CFM equation for BPM motors (constant-torque, non-manufactured home furnaces)

	Cooling			Heating, High			Heating, Low			Continuous Fan		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2	m_0	m_1	m_2
2-ton	1026	-456	8	923	-456	8	718	-456	8	616	-456	8
3-ton	1426	-456	8	1283	-456	8	998	-456	8	856	-456	8
4-ton	1826	-456	8	1643	-456	8	1278	-456	8	1096	-456	8
5-ton	2226	-456	8	2003	-456	8	1558	-456	8	1336	-456	8

Table 7-C.3.4 Coefficients for CFM equation for BPM motors (constant-airflow, non-manufactured home furnaces)

	Cooling			Heating, High			Heating, Low			Continuous Fan		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2	m_0	m_1	m_2
2-ton	776	99	-103	726	99	-103	528	99	-103	427	99	-103
3-ton	1176	99	-103	1095	99	-103	800	99	-103	647	99	-103
4-ton	1576	99	-103	1464	99	-103	1072	99	-103	867	99	-103
5-ton	1976	99	-103	1832	99	-103	1344	99	-103	1087	99	-103

7-C.3.2 Fan Power Curves

Once the operating point of air flow and static pressure is determined by finding the intersection of the fan curve and the system curve, the watts per cubic feet per minute (CFM) of airflow are determined using the equations developed in this appendix. The power consumption of the fan at this operating condition, BE, is calculated by multiplying the Watts/CFM by the CFM at the operating point:

$$BE = \left(\frac{Watts}{CFM}\right) \times Q$$

where,

BE = circulating air fan electrical energy consumption (watts),
$Watts/CFM$ = determined by Equation 2 or Equation 3 in section J.1, and
Q = airflow (cfm).

The watts per CFM is given by the following equation:

$$\frac{Watts}{CFM} = m_0 + m_1 \times (P) + m_2 \times (P^2)$$

where,

Watts/CFM = blower electricity consumption in watts reported by manufacturer divided by the airflow in CFM at the same static pressure,
$m_{0,1,and\ 2}$ = coefficients derived from 2nd degree polynomial approximation, and
P = external static pressure (in.w.g.).

The coefficients derived are show in Tables 7-C.3.5 to 7-C.3.6 for non-weatherized gas furnaces (non-condensing).

Table 7-C.3.5 Coefficients for CFM equation for PSC motors (non-weatherized gas furnaces, non-condensing)

	Baseline			**Improved PSC**			**With Controls**		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2
2-ton	0.49	-0.20	0.19	0.44	-0.20	0.19	0.25	0.14	0.06
3-ton	0.52	-0.20	0.19	0.47	-0.20	0.19	0.27	0.14	0.06
4-ton	0.55	-0.20	0.19	0.49	-0.20	0.19	0.29	0.14	0.06
5-ton	0.57	-0.20	0.19	0.52	-0.20	0.19	0.31	0.14	0.06

Table 7-C.3.6 Coefficients for CFM equation for BPM motors (non-weatherized gas furnaces, non-condensing)

	Constant Torque, Single-Stage			**Constant Torque, Multi-Stage**			**Constant Airflow, Multi-Stage**			**Constant Airflow, Multi-Stage, Backward Curved Impeller**		
	m_0	m_1	m_0	m_1	m_2	m_2	m_0	m_1	m_2	m_0	m_1	m_2
2-ton	0.18	0.12	0.07	0.14	0.12	0.07	0.11	0.25	-0.01	0.09	0.25	-0.01
3-ton	0.19	0.12	0.07	0.15	0.12	0.07	0.12	0.25	-0.01	0.10	0.25	-0.01
4-ton	0.21	0.12	0.07	0.17	0.12	0.07	0.13	0.25	-0.01	0.11	0.25	-0.01
5-ton	0.23	0.12	0.07	0.18	0.12	0.07	0.15	0.25	-0.01	0.12	0.25	-0.01

7-C.3.3 Determination of Fan Curves for each Efficiency Level and Product Class

In order to generate the fan performance data used in the analysis DOE applied the following procedure:

STEP 1: Using the coefficients to generate for airflow (cfm) vs. pressure and watts/cfm vs. pressure curves at each airflow speed (heating, cooling, and continuous fan), DOE found the airflow cfm and watts per CFM at DOE's reference system curve external static pressure.

STEP 2: Using the BE equation above, DOE multiplied the airflow times the watt/cfm at each pressure from Step 1 to calculate *BE* at each airflow speed (heating, cooling, and continuous fan) in terms of DOE's reference system curve external static pressure.

STEP 3: Using the calculated maximum airflow CFM and BE values at DOE's reference system curve external static pressure, DOE was able to calculate Furnace Efficiency Rating (FER) values.

STEP 4: The constant curve fit parameter (m_0) in the pressure and watts/cfm vs. pressure curves was then adjusted using an adjustment multiplier in order to match the FER values derived in the engineering analysis.

Table 7-C.4.1 shows the airflow (cfm) vs. pressure coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level (EL). Figure 7-C.4.1 to Figure 7-C.4.4 shows the resulting curves at various pressures and operating modes.

Table 7-C.3.7 Coefficients for CFM equation for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton

	Heating (High)			**Heating (Low)**			**Cooling**			**Constant Circulation**		
EL	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	1133	49	-570	1028	49	-570	1318	49	-570	923	49	-570
1	1133	49	-570	1028	49	-570	1318	49	-570	923	49	-570
2	1071	267	-338	783	267	-338	1151	267	-338	633	267	-338
3	1283	-456	8	998	-456	8	1426	-456	8	856	-456	8
4	1283	-456	8	998	-456	8	1426	-456	8	856	-456	8
5	1095	99	-103	800	99	-103	1176	99	-103	647	99	-103
6	1095	99	-103	800	99	-103	1176	99	-103	647	99	-103

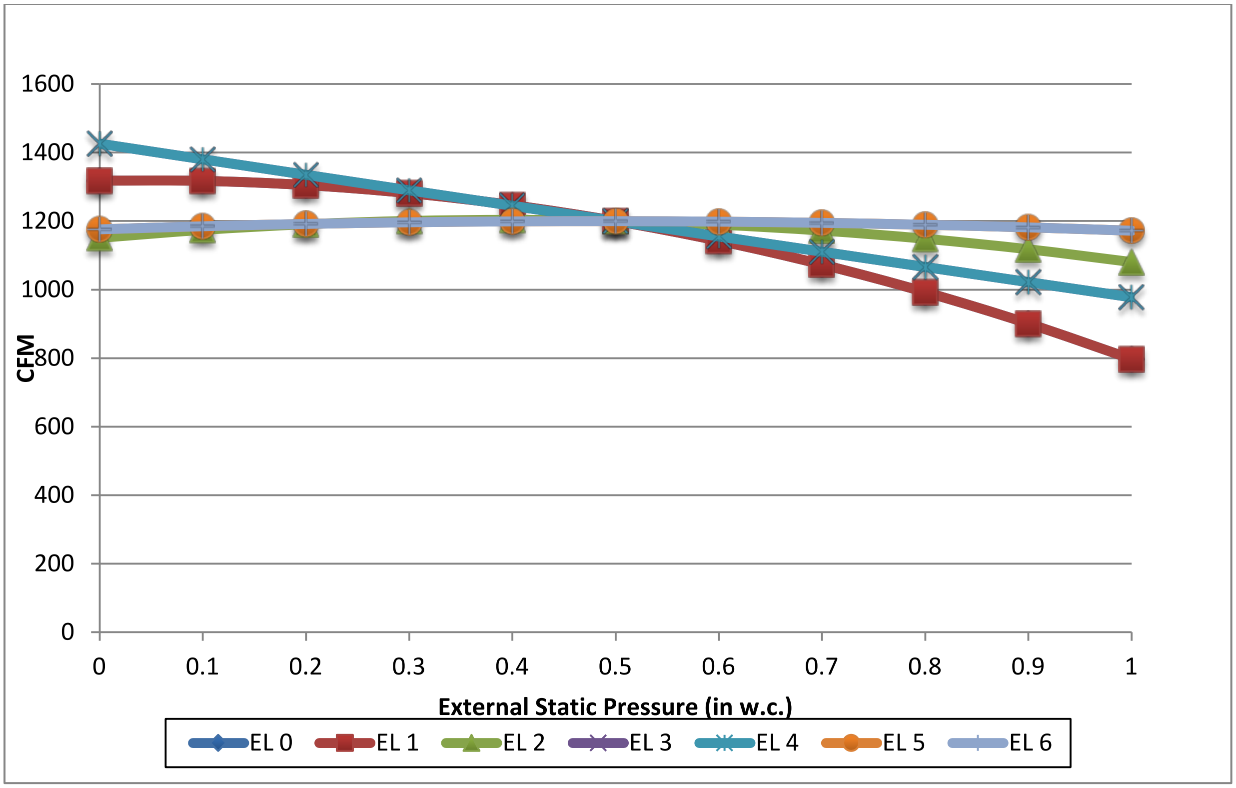

Figure 7-C.3.2 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)

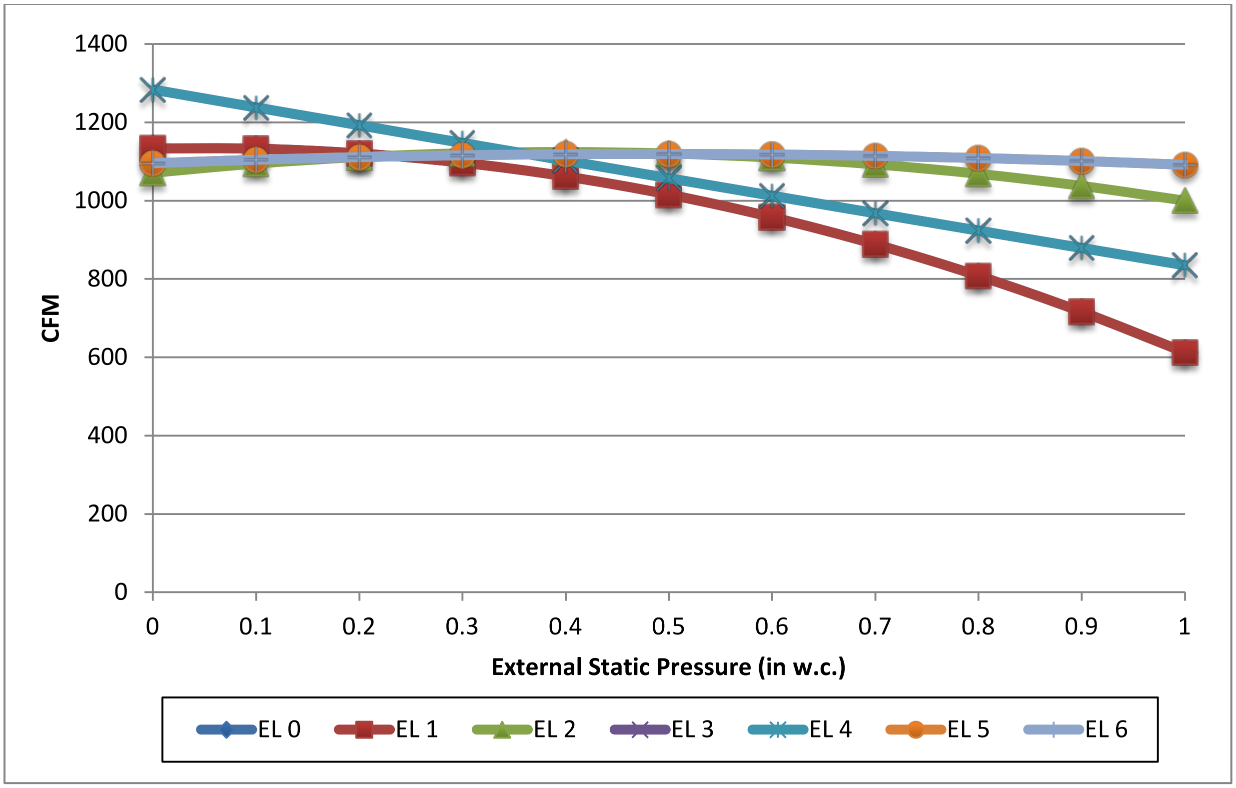

Figure 7-C.3.3 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (High Heating Mode)

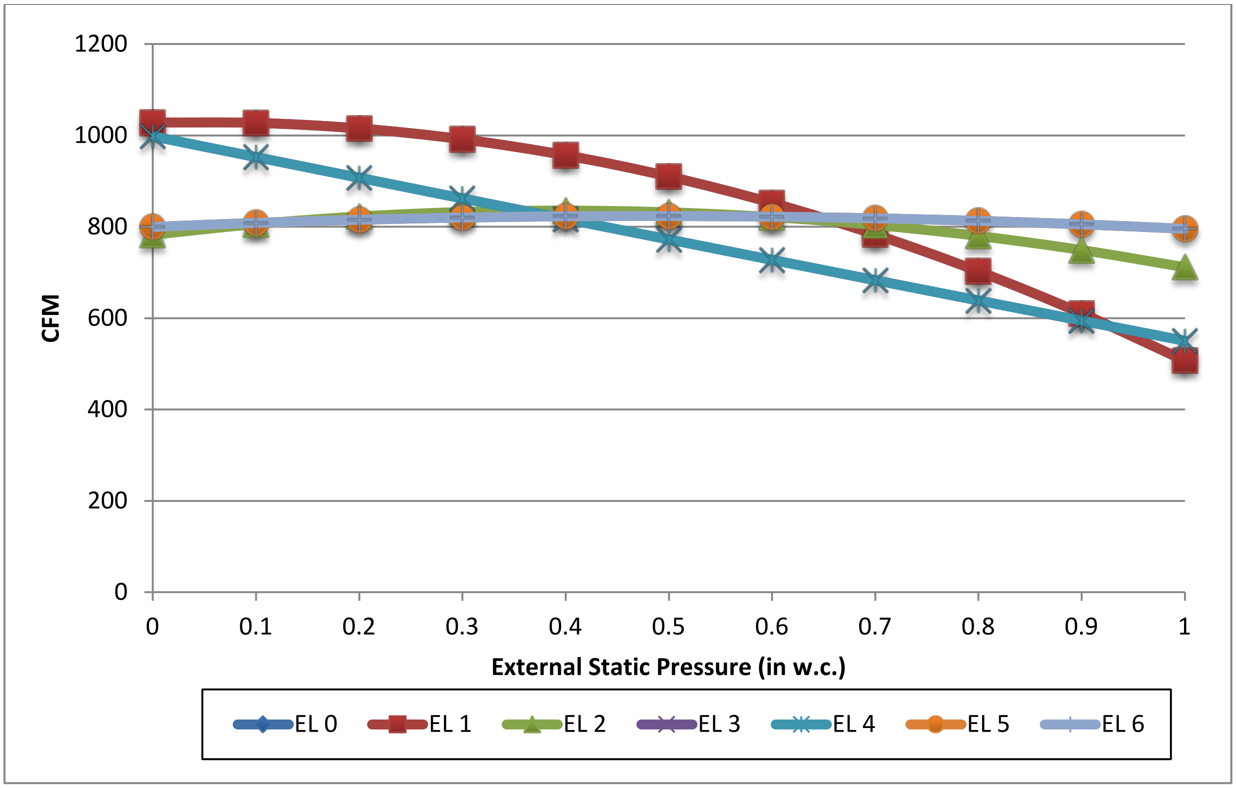

Figure 7-C.3.4 CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Low Heating Mode)

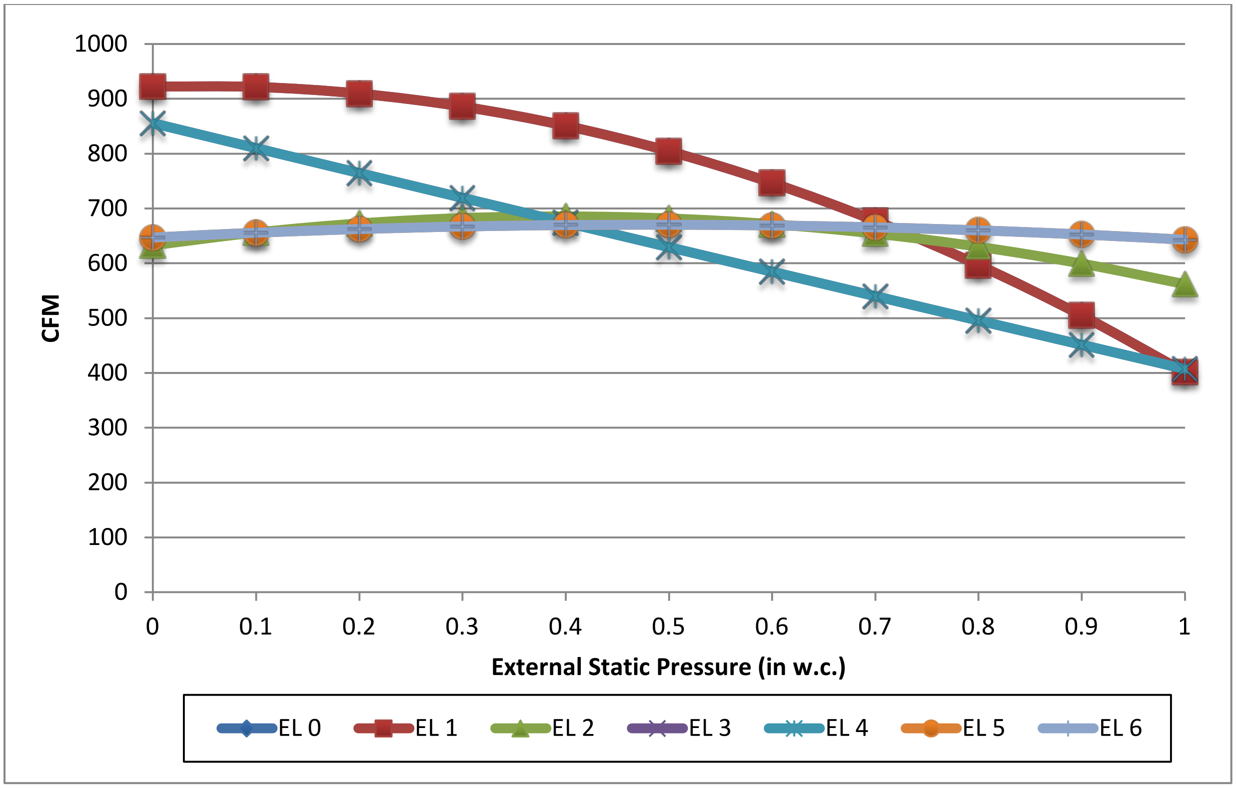

Figure 7-C.3.5 **CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Continuous Fan Mode)**

Table 7-C.4.2 shows the watts/cfm vs. pressure curves coefficients determined for non-weatherized (non-condensing) gas furnaces (3-ton) at each efficiency level. Figure 7-C.4.5 to Figure 7-C.4.8 shows the resulting curves at various pressures. Figure 7-C.4.9 to Figure 7-C.4.12 shows the resulting Watts vs. pressure curves.

Table 7-C.3.8 **Coefficients for Watts/CFM Equation for Non-Weatherized (Non-Condensing) Gas Furnaces, 3-Ton**

EL	**Heating (High)**			**Heating (Low)**			**Cooling**			**Constant Circulation**		
	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2	m_0	m_1	m_2
0	0.52	-0.20	0.19	0.52	-0.20	0.19	0.52	-0.20	0.19	0.52	-0.20	0.19
1	0.47	-0.20	0.19	0.47	-0.20	0.19	0.47	-0.20	0.19	0.47	-0.20	0.19
2	0.27	0.14	0.06	0.27	0.14	0.06	0.27	0.14	0.06	0.27	0.14	0.06
3	0.19	0.12	0.07	0.19	0.12	0.07	0.19	0.12	0.07	0.19	0.12	0.07
4	0.15	0.12	0.07	0.15	0.12	0.07	0.15	0.12	0.07	0.15	0.12	0.07
5	0.12	0.25	-0.01	0.12	0.25	-0.01	0.12	0.25	-0.01	0.12	0.25	-0.01
6	0.10	0.25	-0.01	0.10	0.25	-0.01	0.10	0.25	-0.01	0.10	0.25	-0.01

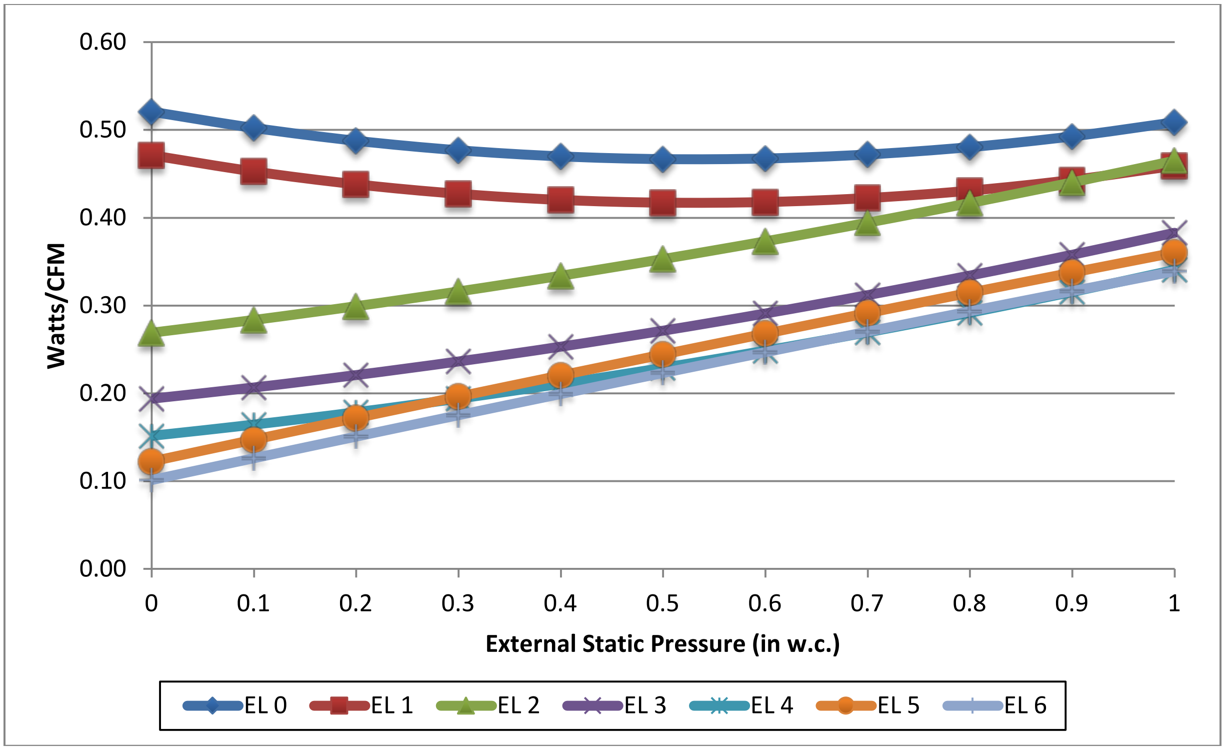

Figure 7-C.3.6 **Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)**

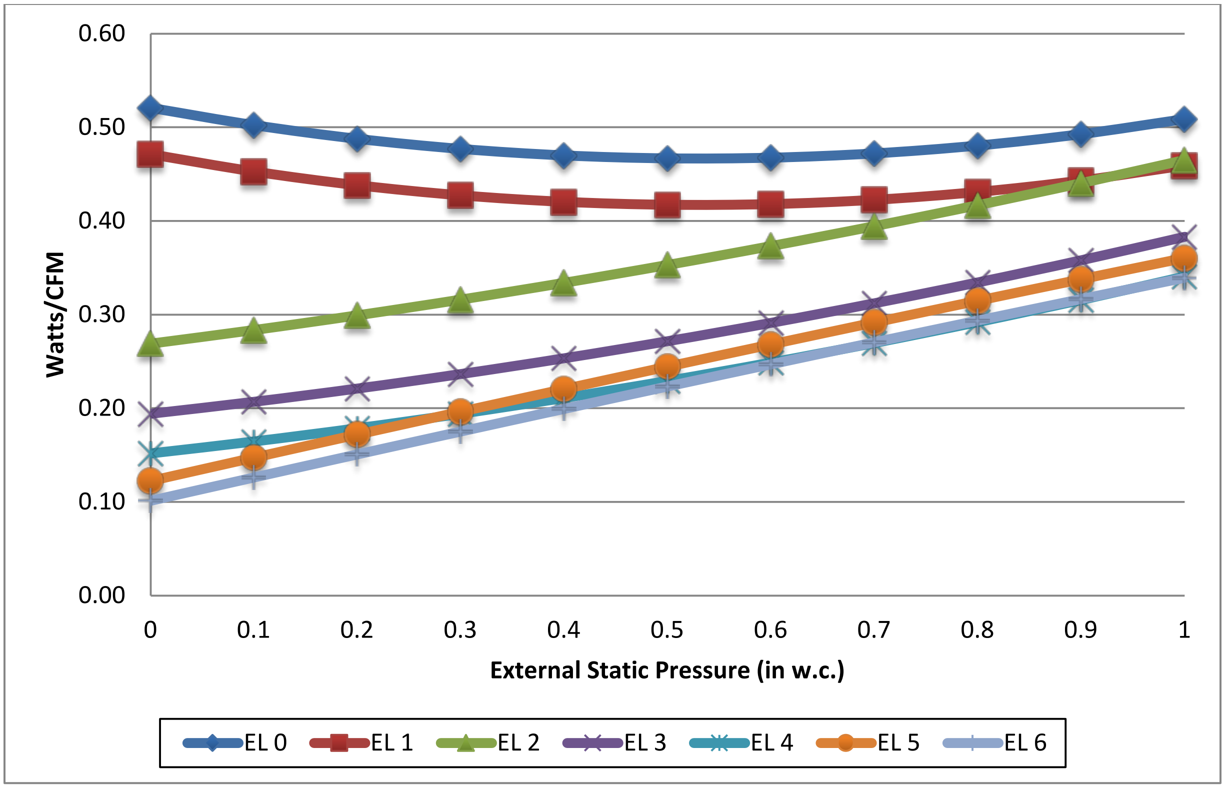

Figure 7-C.3.7 **Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (High Heating Mode)**

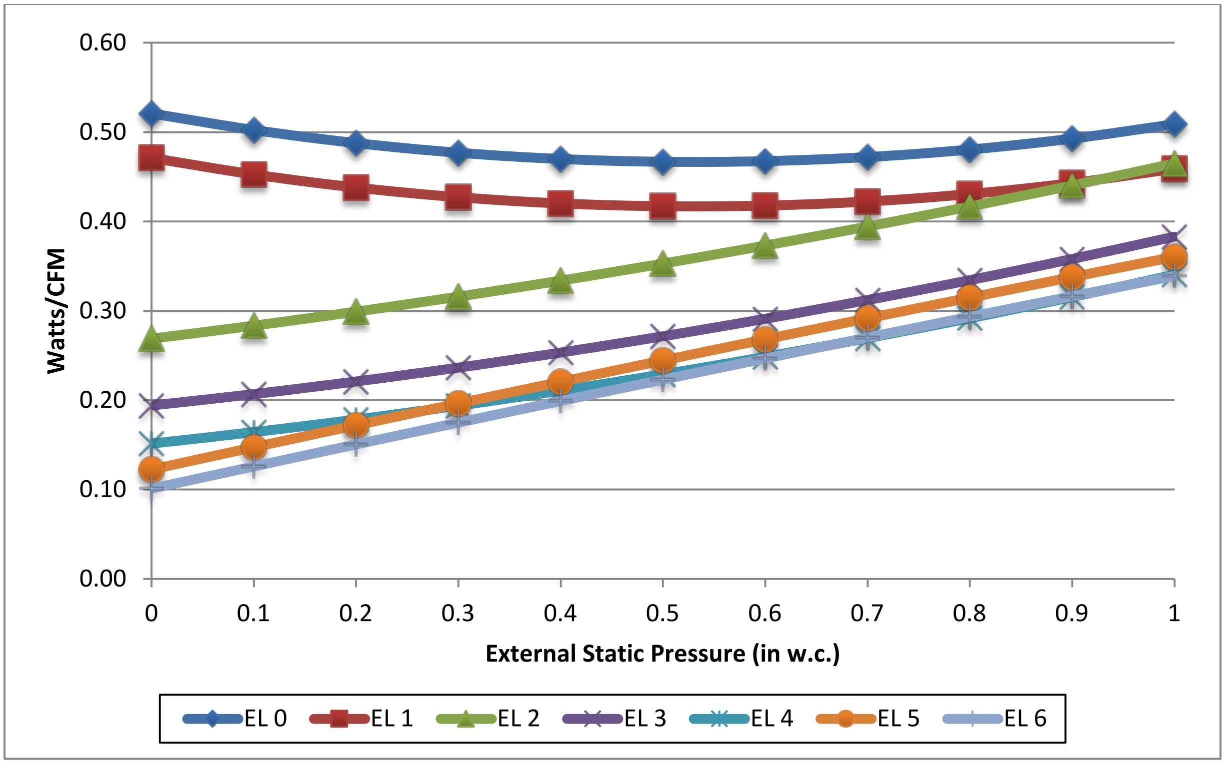

Figure 7-C.3.8 Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Low Heating Mode)

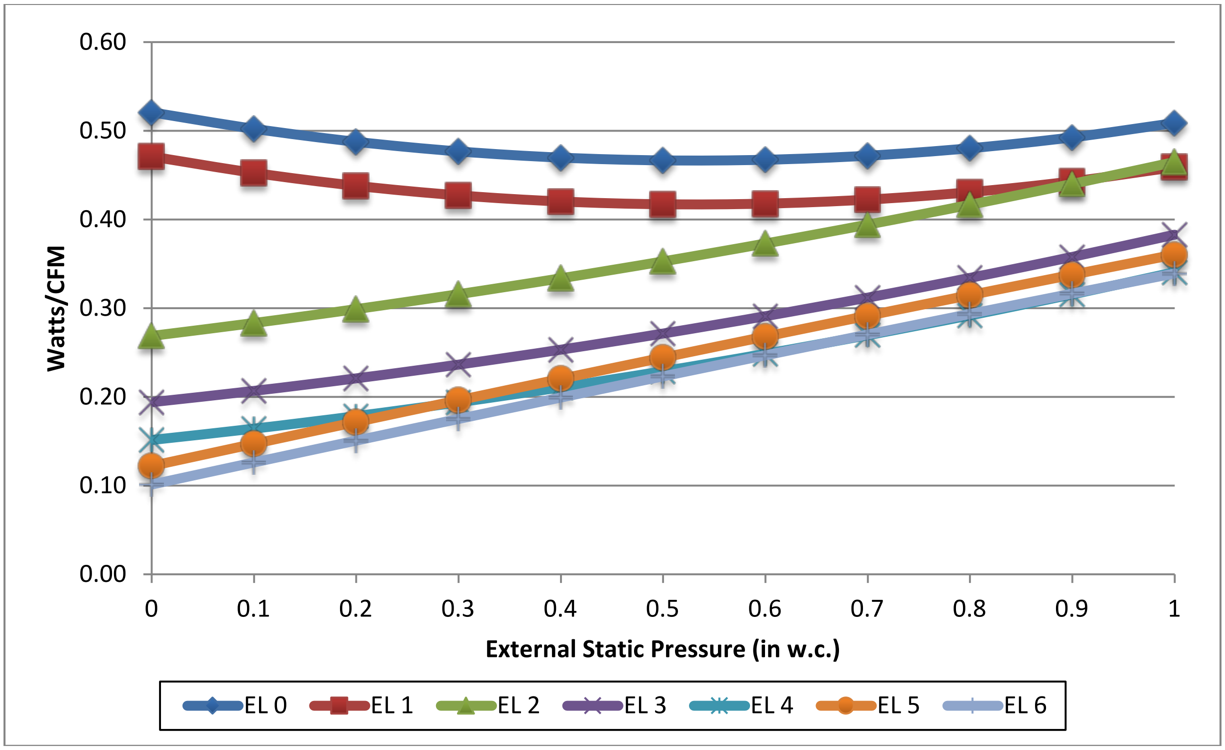

Figure 7-C.3.9 **Watt/CFM Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Continuous Fan Mode)**

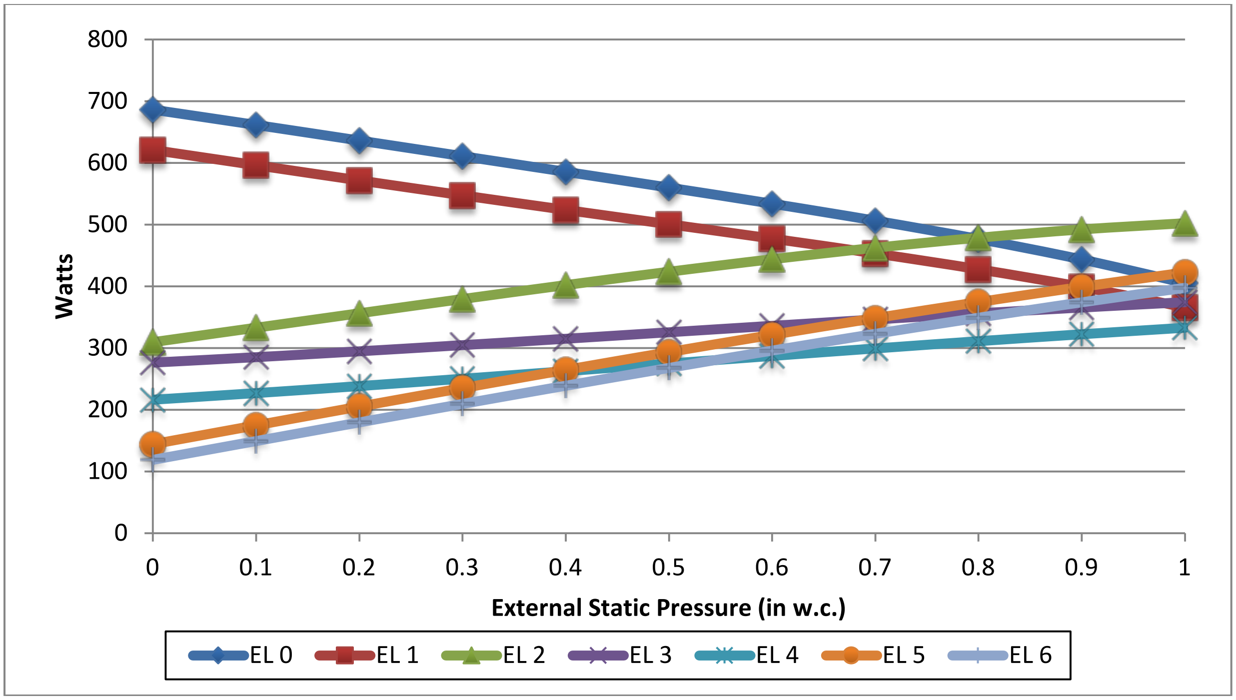

Figure 7-C.3.10 **Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Cooling Mode)**

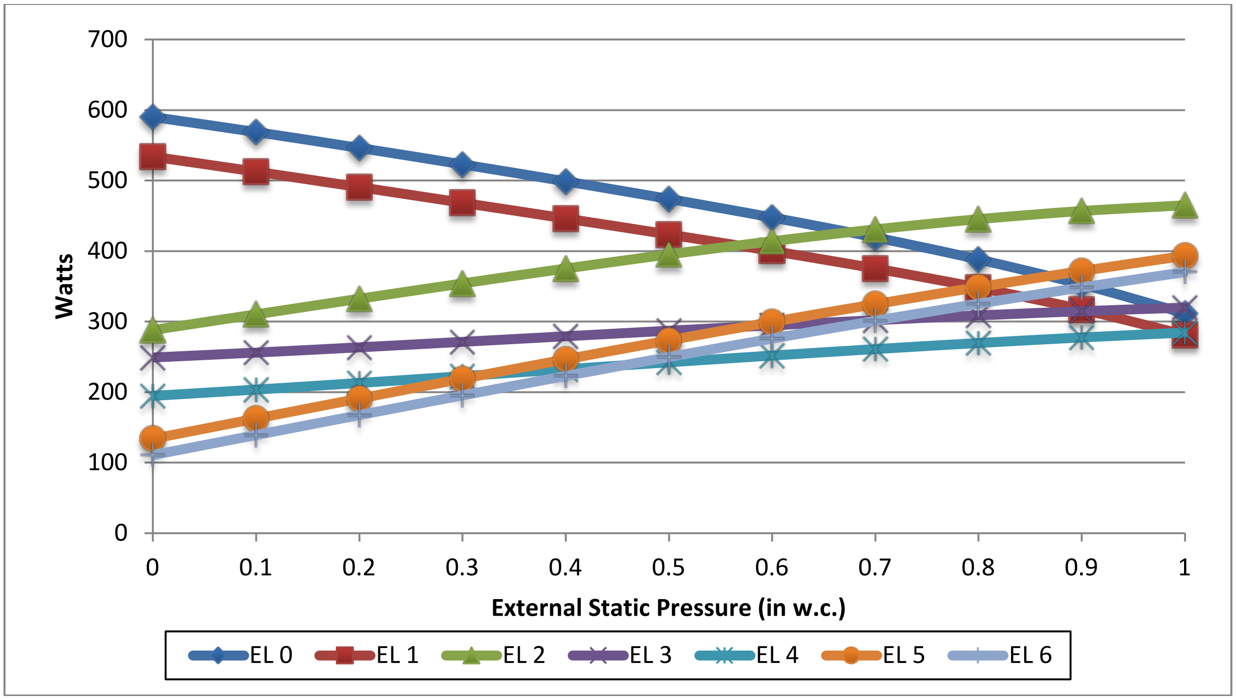

Figure 7-C.3.11 Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (High Heating Mode)

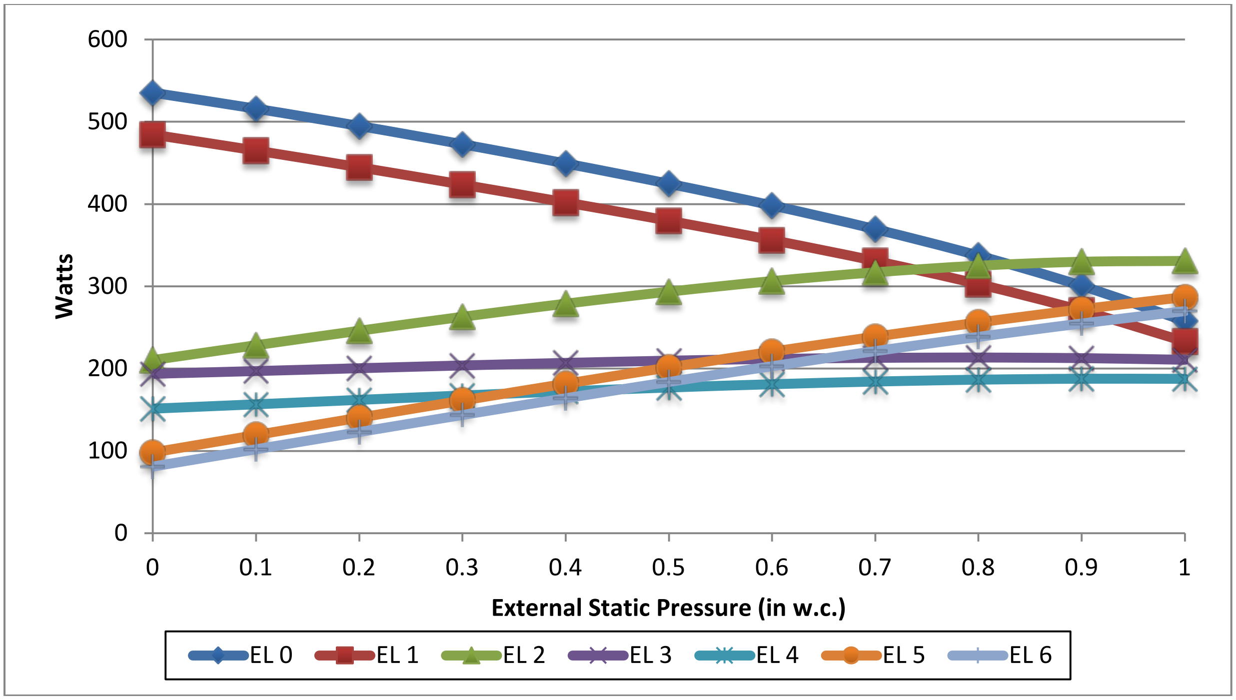

Figure 7-C.3.12 **Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Low Heating Mode)**

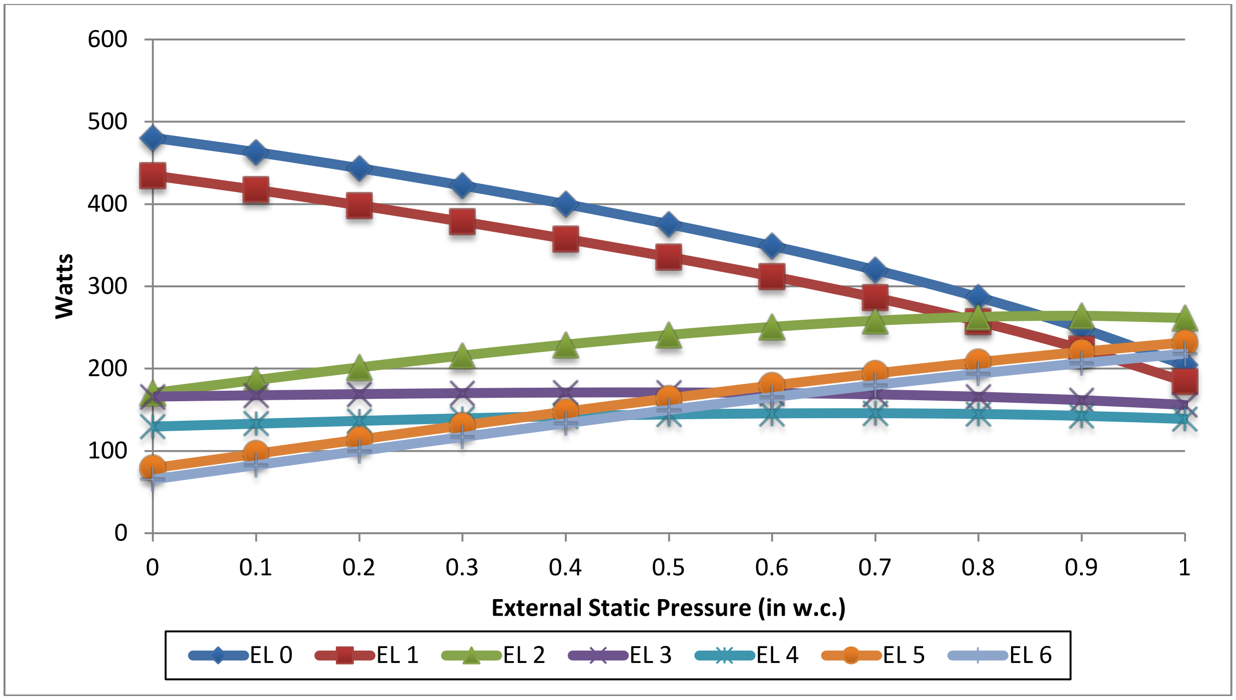

Figure 7-C.3.13 Resulting Watt vs. Pressure Curves for Non-Weatherized (Non-Condensing) Gas Furnace Fan, 3-Ton (Continuous Fan Mode)

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1. Michael R. Lindeburg, P., *Fans and Ductwork*. In *Mechanical Engineering Reference Manual for the PE Exam*, P. Michael R. Lindeburg, Editor. Tenth ed. 1997. Professional Publications, Inc.: Belmont, CA. p. 20-1, 20-26

2. American Society of Heating Refrigeration and Air-Conditioning Engineers, *ASHRAE 1997 Handbook - Fundamentals*. 1997. Atlanta, GA.p. 3.12.

APPENDIX 7-D. DERIVATION OF HOUSE HEATING LOAD FOR FURNACE FANS

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APPENDIX 7-D. DERIVATION OF HOUSE HEATING LOAD FOR FURNACE FANS

7-D.1 INTRODUCTION

The annual house-heating load (HHL) is the total amount of heat output from the furnace that the house needs during the heating season. This includes heat from the burner and heat from the blower and the blower motor.

7-D.2 HEATING LOAD CALCULATION

The Department determined HHL for each sampled housing unit, based on the burner operating hours (*BOH*) and the characteristics of the assigned existing furnace, using the following calculations:

$$HHL = \left(Q_{YR,RECS} \times AFUE_{ex} + 3.412 \times BE \times \left[BOH_{ex} + N \times \left(\frac{t^{+} - t^{-}}{3600} \right) \right] \right) \times Adj\_Factor$$

where:

$Q_{YR,RECS}$ = annual fuel consumption for heating based on RECS 2009 (kBtu/yr),
$AFUE_{ex}$ = AFUE of the existing furnace,
3.412 = constant to convert kW to kBtu/hr,
BE_{ex} = power consumption of the blower motor of the existing furnace (kW),
BOH_{ex} = as defined below (hr/yr),
N = number of cycles per hour,
HLH = heating load hours (hr),
t^{+} = off delay (seconds),
t^{-} = on delay (seconds), and
Adj_Factor = adjustment factor for the average heating degree days.

Burner operating hours (BOH_{ex}), the number of hours the existing furnace burner is on during a year, is a key variable in the calculation of HHL. The Department calculated BOH for the existing furnace as:

$$BOH_{ex} = \frac{Q_{YR,RECS}}{Q_{IN,ex}}$$

where:

BOH_{ex} = burner operating hours of existing household (hrs/yr),
$Q_{YR,RECS}$ = as defined above (kBtu/yr),[a]

---

[a] The value coming from RECS 2009 is adjusted in the case when there are multiple furnaces in the household (in this case $Q_{YR,RECS}$ is divided by the number of furnaces) and in the case when a secondary heating unit exists with the same fuel type (in this case $Q_{YR,RECS}$ is adjusted to exclude the secondary heating equipment).

$Q_{IN,ex}$ = input capacity of the existing furnace (kBtu/hr).

The power consumption of the blower motor depends on the steady-state operating conditions (the pressure and airflow) for the furnace. This calculation is explained in appendix 7-E.

DOE made adjustments to reflect the expectation that newly built housing units in 2019 will have a somewhat different heating load than the housing units in the RECS 2009 sub-sample. The adjustment involves multiplying the calculated HHL for each RECS 2009 housing unit by a building shell efficiency index derived from the National Energy Modeling System (NEMS) simulation performed for EIA's *AEO 2012*.[1] The building shell efficiency index sets the heating load value at 1.00 for an average home in 2005 (by type) in each census division. The values listed represent the change in heating load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows). This factor differs for new construction and replacement households. The value for households in 2019 is 0.86 for replacements and 0.87 for new construction, which means that the average new home in 2019 will require less heat energy to maintain indoor comfort.

DOE also made adjustments to the HHL calculated using RECS 2009 data to reflect historical average climate conditions. Table 7-D.2.1 shows the 2003-2012 average heating degree days (HDD) as well as the 2009 average HDD for the 30 geographical areas. The adjustment factors are calculated using the equation below and are almost all positive, which means that 2009 had warmer temperatures compared to the 10-year average[b].

$$Adj\_Factor_{average\_climate} = \frac{HDD_{10\_yr\_avg}}{HDD_{res\_stock\_2009}} \qquad \textbf{Eq. 7-D.2.1}$$

Where:

$HDD_{res\_stock\_2009}$ = HDD in 2009 for the specific census division or state where the housing unit is located, and

$HDD_{10\_yr\_avg}$ = 10-year average HDD (2003–2012) for the specific census division where the housing unit is located.

---

[b] The last 10-year average is used to normalize the HDD values, which is similar to what is done in AEO 2012.

Table 7-D.2.1 Heating Degree Day Adjustment Factors

Geographical Areas		Average HDD		Adjustment Factor
		2003-2012	2009	
1	CT, ME, NH, RI, VT	6497	6868	0.95
2	MA	6128	6438	0.95
3	NY	5720	6055	0.94
4	NJ	5059	5261	0.96
5	PA	5604	5842	0.96
6	IL	5955	6427	0.93
7	IN, OH	5625	5857	0.96
8	MI	6572	6995	0.94
9	WI	7281	7849	0.93
10	IA, MN, ND, SD	7761	8434	0.92
11	KS, NE	5379	5885	0.91
12	MO	4846	5186	0.93
13	VA	4178	4395	0.95
14	DE, DC, MD	4653	4909	0.95
15	GA	2748	2928	0.94
16	NC, SC	3126	3320	0.94
17	FL	679	666	1.02
18	AL, KY, MS	3201	3361	0.95
19	TN	3695	3856	0.96
20	AR, LA, OK	2668	2850	0.94
21	TX	1797	1856	0.97
22	CO	7030	7309	0.96
23	ID, MT, UT, WY	6895	7299	0.94
24	AZ	1929	1890	1.02
25	NV, NM	3921	4032	0.97
26	CA	2569	2562	1.00
27	OR, WA	5278	5516	0.96
28	AK	NA		0.96
29	HI	NA		1.00
30	WV	5021	5190	0.97

Note: RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. Data for Alaska and Hawaii was not available. The region 27 adjustment factor was used for Alaska, while region 26 adjustment factor was used for Hawaii.

For households in which it is clear that the fuel use for heating is associated solely with the use of furnace equipment as the primary or secondary heating equipment, DOE used the annual fuel consumption for heating the housing unit from RECS 2009. DOE adjusted the house heating load for households that used both a furnace (either as the primary or secondary heating equipment) and other heating equipment using the same fuel. RECS 2009 reports the percentage of heating energy consumption attributable to secondary products. DOE derived the house heating load applicable to the furnace by subtracting the estimated amount of heat provided by the other heating system. In the case when it was determined that a household had multiple furnaces, the house heating load was divided by the number of furnaces.

7-D.3 DERIVATION OF HEATING LOAD HOURS (HLH)

The heating load hours (HLH) is defined in Eq. M-2 as[3]:

$$HLH = \frac{24 * HDD}{65 - ODT}$$

where,

24 = number of hours in one day (h/d),
HDD = heating degree days, (d),
ODT = outdoor design temperature, (F°) and
65 = typical average outdoor temperature at which a furnace or boiler starts operating, (F°).

7-D.4 OUTDOOR TEMPERATURE DERIVATION

RECS 2009 provides data on heating and cooling degree-days but not air temperatures for each household in the sample. To derive the outdoor air temperatures for the households in the RECS sample, DOE developed an approach to assign a physical location to each RECS household. The following steps were performed:

1. DOE assembled weather data from 282 weather stations from NOAA that provide the heating and cooling degree-days at base temperature 65°F for year 2009 for these weather stations. The 2009 heating and cooling degree days match the period used to determine the degree-days in RECS 2009.
2. RECS reports both heating degree-days (HDD) and cooling degree-days (CDD) to base temperature 65°F for each housing record. DOE assigned each RECS household to one of the 282 weather stations by calculating which weather station (within the appropriate census region or large state) gave the best linear least squares fit of the RECS data to the weather data.

7-D.4.1 Imputation Method

To calculate the mean outdoor air temperature, DOE matched the RECS 2009 combinations (255 individual combinations of census divisions plus 4 large states, together with the HDD and CDD data) to U.S. weather data. DOE used the U.S. weather station closest (or with minimum "distance") from the RECS 2009 data combination. The following equation calculates the "distance" between the U.S. weather data and RECS 2009 data:

$$"\,Distance" = \sqrt{(HDD_2 - HDD_1)^2 + (CDD_2 - CDD_1)^2}$$

Where:

HDD_1 = heating degree days from U.S. weather data,

HDD_2 = heating degree days from RECS 2009 data,
CDD_1 = cooling degree days from U.S. weather data, and
CDD_2 = cooling degree days from RECS 2009 data.

Table 7-D.4.1 shows the imputation results for all RECS locations. Note that some weather station data matches with several of the RECS 2009 HDD & CDD combinations. Table 7-D.4.2 shows a subset of the data matches.

Table 7-D.4.1 Weather Station Data

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
AL	BIRMINGHAM	BHM	2605	1958
AL	HUNTSVILLE	HSV	2982	1863
AL	MOBILE	MOB	1594	2681
AL	MONTGOMERY	MGM	2137	2367
AL	MUSCLE SHOALS	MSL	2948	1773
AL	TUSCALOOSA	TCL	2349	2136
AK	ANCHORAGE	ANC	10335	2
AK	BARROW	BRW	18659	0
AK	BETHEL	BET	12530	0
AK	BETTLES	BTT	15465	29
AK	BIG DELTA	BIG	12918	70
AK	COLD BAY	CDB	9668	0
AK	CORDOVA	CDV	9511	0
AK	FAIRBANKS	FAI	13548	100
AK	GULKANA	GKN	13322	16
AK	HOMER	HOM	9817	0
AK	JUNEAU	JNU	8536	6
AK	KENAI	ENA	10423	0
AK	KETCHIKAN	KTN	7359	68
AK	KING SALMON	AKN	11088	0
AK	KODIAK	ADQ	8903	0
AK	KOTZEBUE	OTZ	15361	17
AK	MCGRATH	MCG	13642	43
AK	NOME	OME	14133	0
AK	NORTHWAY	ORT	15141	24
AK	ST PAUL ISLAND	SNP	11420	0
AK	SITKA	SIT	7309	4
AK	TALKEETNA	TKA	11085	28
AK	UNALAKLEET	UNK	13663	14

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
AK	VALDEZ	VWS	7074	23
AK	YAKUTAT	YAK	9295	1
AZ	DOUGLAS	DUG	2160	2204
AZ	FLAGSTAFF	FLG	6741	176
AZ	PHOENIX	PHX	807	4942
AZ	TUCSON	TUS	1268	3626
AZ	WINSLOW	INW	4233	1395
AZ	YUMA	NYL	671	4757
AR	EL DORADO	ELD	2539	2125
AR	FAYETTEVILLE	FYV	3957	1185
AR	FORT SMITH	FSM	3174	1906
AR	HARRISON	HRO	3811	1214
AR	LITTLE ROCK	LIT	2946	1943
AR	TEXARKANA	TXK	2573	2006
CA	BAKERSFIELD	BFL	1873	2644
CA	BLYTHE	BLH	968	4580
CA	EUREKA	EKA	5137	2
CA	FRESNO	FAT	2239	2390
CA	IMPERIAL	IPL	877	4419
CA	LOS ANGELES	LAX	1294	569
CA	MT SHASTA	MHS	5474	433
CA	PASO ROBLES	PRB	2676	1095
CA	RED BLUFF	RBL	2452	2122
CA	REDDING	RDD	2750	2086
CA	SACRAMENTO	SAC	2531	1357
CA	SAN DIEGO	SAN	1050	813
CA	SAN FRANCISCO	SFO	2614	220
CA	STOCKTON	SCK	2451	1468
CO	AKRON	AKO	6324	563
CO	ALAMOSA	ALS	8229	49
CO	COLORADO SPRIN	COS	6301	356
CO	DENVER	DEN	5988	541
CO	EAGLE	EGE	7593	124
CO	GRAND JUNCTION	GJT	5793	1168
CO	LA JUNTA	LHX	5129	1124
CO	PUEBLO	PUB	5427	818

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
CO	TRINIDAD	TAD	5323	719
CT	BRIDGEPORT	BDR	5484	669
CT	HARTFORD	BDL	6072	610
DE	WILMINGTON	ILG	4789	1031
DC	WASHINGTON	DCA	4124	1427
FL	DAYTONA BEACH	DAB	753	3321
FL	FT LAUDERDALE	FLL	118	4839
FL	FORT MYERS	FMY	294	4151
FL	GAINESVILLE	GNV	1181	2789
FL	JACKSONVILLE	JAX	1339	2772
FL	KEY WEST	EYW	108	5017
FL	MELBOURNE	MLB	526	3718
FL	MIAMI	MIA	109	4914
FL	ORLANDO	MCO	588	3620
FL	PENSACOLA	PNS	1443	2729
FL	TALLAHASSEE	TLH	1574	2802
FL	TAMPA	TPA	496	3876
FL	VERO BEACH	VRB	477	3604
FL	WEST PALM BEAC	PBI	239	4314
GA	ALBANY	ABY	1767	2686
GA	ATHENS	AHN	2882	1903
GA	ATLANTA	ATL	2813	1838
GA	AUGUSTA	AGS	2475	2068
GA	BRUNSWICK	BQK	1313	3320
GA	COLUMBUS	CSG	2183	2194
GA	MACON	MCN	2288	2133
GA	SAVANNAH	SAV	1739	2497
GA	WAYCROSS	AYS	1494	3059
HI	HILO-HAWAII	ITO	0	3050
HI	HONOLULU-OAHU	HNL	0	4816
HI	KAHULUI-MAUI	OGG	1	3746
HI	LIHUE-KAUAI	LIH	2	3611
ID	BOISE	BOI	5592	1199
ID	BURLEY	BYI	6697	397
ID	IDAHO FALLS	IDA	7936	239
ID	LEWISTON	LWS	5386	1008

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
ID	POCATELLO	PIH	7463	321
IL	CHICAGO	ORD	6417	585
IL	MOLINE	MLI	6250	636
IL	PEORIA	PIA	5841	752
IL	QUINCY	UIN	5460	849
IL	ROCKFORD	RFD	6738	433
IL	SPRINGFIELD	SPI	5234	933
IN	EVANSVILLE	EVV	4397	1283
IN	FORT WAYNE	FWA	6077	601
IN	INDIANAPOLIS	IND	5203	953
IN	SOUTH BEND	SBN	6426	545
IN	WEST LAFAYETTE	LAF	5436	826
IA	BURLINGTON	BRL	5687	810
IA	CEDAR RAPIDS	CID	6977	419
IA	DES MOINES	DSM	6124	898
IA	DUBUQUE	DBQ	7204	345
IA	MASON CITY	MCW	7856	338
IA	OTTUMWA	OTM	6317	588
IA	SIOUX CITY	SUX	6913	678
IA	SPENCER	SPW	7771	434
IA	WATERLOO	ALO	7253	448
KS	CHANUTE	CNU	4444	1324
KS	CONCORDIA	CNK	5558	1094
KS	DODGE CITY	DDC	4975	1257
KS	GARDEN CITY	GCK	5014	1154
KS	GOODLAND	GLD	6016	722
KS	RUSSELL	RSL	5298	1194
KS	SALINA	SLN	5012	1335
KS	TOPEKA	TOP	4968	1195
KS	WICHITA	ICT	4552	1506
KY	BOWLING GREEN	BWG	3808	1407
KY	JACKSON	JKL	4237	984
KY	LEXINGTON	LEX	4670	1020
KY	LOUISVILLE	SDF	4155	1316
KY	PADUCAH	PAH	4198	1239
LA	BATON ROUGE	BTR	1404	2985

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
LA	LAFAYETTE	LFT	1296	3086
LA	LAKE CHARLES	LCH	1380	2980
LA	MONROE	MLU	2118	2547
LA	NEW ORLEANS	MSY	1156	3221
LA	SHREVEPORT	SHV	2164	2449
ME	AUGUSTA	AUG	7487	276
ME	BANGOR	BGR	8098	246
ME	CARIBOU	CAR	9415	149
ME	HOULTON	HUL	9316	178
ME	PORTLAND	PWM	7107	294
MD	BALTIMORE	BWI	4745	1088
MD	SALISBURY	SBY	4345	1149
MA	BOSTON	BOS	5694	581
MA	CHATHAM	CHH	5820	380
MA	WORCESTER	ORH	6699	370
MI	ALPENA	APN	8343	161
MI	DETROIT	DTW	6224	588
MI	FLINT	FNT	7068	328
MI	GRAND RAPIDS	GRR	6580	444
MI	HANCOCK	CMX	9420	107
MI	HOUGHTON LAKE	HTL	8329	162
MI	JACKSON	JXN	6585	420
MI	LANSING	LAN	6830	372
MI	MARQUETTE	SAW	9379	121
MI	MUSKEGON	MKG	6719	371
MI	SAGINAW	MBS	6960	350
MI	SAULT ST MARIE	ANJ	8878	119
MI	TRAVERSE CITY	TVC	7695	253
MN	ALEXANDRIA	AXN	8922	340
MN	DULUTH	DLH	9517	118
MN	HIBBING	HIB	10159	64
MN	INT'L FALLS	INL	10648	72
MN	MINNEAPOLIS	MSP	7613	646
MN	ROCHESTER	RST	7884	321
MN	SAINT CLOUD	STC	8704	301
MS	GREENWOOD	GWO	2376	2250

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
MS	JACKSON	JAN	2223	2331
MS	MCCOMB	MCB	1833	2472
MS	MERIDIAN	MEI	2410	2141
MS	TUPELO	TUP	2842	1947
MO	COLUMBIA	COU	4999	958
MO	JOPLIN	JLN	4216	1382
MO	KANSAS CITY	MCI	5084	1093
MO	SAINT LOUIS	STL	4438	1457
MO	SPRINGFIELD	SGF	4596	1114
MT	BILLINGS	BIL	6948	627
MT	BUTTE	BTM	9212	45
MT	CUT BANK	CTB	8687	139
MT	GLASGOW	GGW	9203	470
MT	GREAT FALLS	GTF	7941	300
MT	HAVRE	HVR	8844	327
MT	HELENA	HLN	7704	444
MT	KALISPELL	FCA	5729	1492
MT	LEWISTOWN	LWT	8526	183
MT	MILES CITY	MLS	7700	716
MT	MISSOULA	MSO	7588	355
NE	GRAND ISLAND	GRI	6431	788
NE	LINCOLN	LNK	6159	912
NE	NORFOLK	OFK	6789	643
NE	NORTH PLATTE	LBF	6946	534
NE	OMAHA	OMA	6288	851
NE	SCOTTSBLUFF	BFF	6689	579
NE	VALENTINE	VTN	7279	527
NV	ELKO	EKO	6948	450
NV	ELY	ELY	7925	125
NV	LAS VEGAS	LAS	1882	3818
NV	LOVELOCK	LOL	5302	1189
NV	RENO	RNO	4948	1071
NV	TONOPAH	TPH	5298	874
NV	WINNEMUCCA	WMC	6236	611
NH	CONCORD	CON	7462	325
NH	LEBANON	LEB	7312	371

Station Location		Code	HDD (2009)	CDD (2009)
State	City			
NH	MT WASHINGTON	MWN	13555	5
NJ	ATLANTIC CITY	ACY	4693	994
NJ	NEWARK	EWR	4790	1021
NM	ALBUQUERQUE	ABQ	3823	1435
NM	CARLSBAD	CNM	2398	2376
NM	CLAYTON	CAO	4517	1143
NM	GALLUP	GUP	6134	442
NM	ROSWELL	ROW	3098	1961
NM	CLOVIS	CVN	3775	1286
NY	ALBANY	ALB	6644	433
NY	BINGHAMTON	BGM	7067	261
NY	BUFFALO	BUF	6651	361
NY	GLENS FALLS	GFL	7612	285
NY	MASSENA	MSS	7980	298
NY	NEW YORK	LGA	4647	1041
NY	ROCHESTER	ROC	6765	315
NY	SYRACUSE	SYR	6687	439
NY	UTICA	UCA	4660	1683
NY	WATERTOWN	ART	7707	298
NC	ASHEVILLE	AVL	4194	768
NC	CAPE HATTERAS	HAT	1308	3750
NC	CHARLOTTE	CLT	3346	1611
NC	GREENSBORO	GSO	3605	1510
NC	HICKORY	HKY	3593	1353
NC	NEW BERN	EWN	2769	1788
NC	RALEIGH DURHAM	RDU	3164	1865
NC	WILMINGTON	ILM	2521	1937
ND	BISMARCK	BIS	9130	332
ND	DEVIL'S LAKE	P11	10245	236
ND	DICKINSON	DIK	9456	197
ND	FARGO	FAR	9304	362
ND	GRAND FORKS	GFK	9928	269
ND	JAMESTOWN	JMS	9722	266
ND	MINOT	MOT	9559	314
ND	WILLISTON	ISN	9721	297
OH	AKRON CANTON	CAK	6131	497

Station Location		**Code**	**HDD (2009)**	**CDD (2009)**
State	**City**			
OH	CLEVELAND	CLE	5833	664
OH	COLUMBUS	CMH	5243	874
OH	CINCINNATI	CVG	4950	874
OH	DAYTON	DAY	5602	732
OH	FINDLAY	FDY	5901	698
OH	MANSFIELD	MFD	6214	468
OH	TOLEDO	TOL	6283	592
OH	YOUNGSTOWN	YNG	6239	443
OH	LANCASTER	LHQ	5205	791
OK	GAGE	GAG	4179	1707
OK	HOBART	HBR	3392	2034
OK	MCALESTER	MLC	3136	1845
OK	OKLAHOMA CITY	OKC	3519	1849
OK	PONCA CITY	PNC	3900	1702
OK	TULSA	TUL	3608	1885
OR	ASTORIA	AST	4871	39
OR	BAKER	BKE	7529	220
OR	BURNS	BNO	7604	266
OR	EUGENE	EUG	4999	331
OR	MEDFORD	MFR	4459	1043
OR	NORTH BEND	OTH	4830	8
OR	PENDLETON	PDT	5713	720
OR	PORTLAND	PDX	4357	635
OR	REDMOND	RDM	6737	313
OR	SALEM	SLE	4660	457
PA	ALLENTOWN	ABE	5725	622
PA	ALTOONA	AOO	6109	433
PA	BRADFORD	BFD	8059	74
PA	DU BOIS	DUJ	6753	254
PA	ERIE	ERI	6183	423
PA	HARRISBURG	CXY	5097	866
PA	PHILADELPHIA	PHL	4557	1219
PA	PITTSBURGH	PIT	5661	617
PA	SCRANTON	AVP	6121	450
PA	WILLIAMSPORT	IPT	5636	644
RI	PROVIDENCE	PVD	5717	579

Station Location		**Code**	**HDD (2009)**	**CDD (2009)**
State	**City**			
SC	CHARLESTON	CHS	1941	2390
SC	COLUMBIA	CAE	2561	2220
SC	FLORENCE	FLO	2541	2061
SC	GREENVILLE	GSP	3116	1735
SD	ABERDEEN	ABR	8872	329
SD	HURON	HON	8070	469
SD	PIERRE	PIR	7738	577
SD	RAPID CITY	RAP	7738	362
SD	SIOUX FALLS	FSD	7670	481
SD	WATERTOWN	ATY	8910	294
TN	BRISTOL	TRI	4267	930
TN	CHATTANOOGA	CHA	3168	1808
TN	CROSSVILLE	CSV	4100	940
TN	JACKSON	MKL	3379	1597
TN	KNOXVILLE	TYS	3643	1392
TN	MEMPHIS	MEM	2906	2091
TN	NASHVILLE	BNA	3615	1558
TX	ABILENE	ABI	2359	2494
TX	ALICE	ALI	738	4832
TX	AMARILLO	AMA	4034	1340
TX	AUSTIN	AUS	1722	3214
TX	BROWNSVILLE	BRO	525	4300
TX	COLLEGE STATIO	CLL	1404	3476
TX	CORPUS CHRISTI	CRP	811	4058
TX	DALHART	DHT	4395	1154
TX	DALLAS FT WORT	DFW	2097	2745
TX	DEL RIO	DRT	1252	3807
TX	EL PASO	ELP	2106	2783
TX	GALVESTON	GLS	907	3640
TX	HOUSTON	IAH	1267	3410
TX	LAREDO	LRD	602	5330
TX	LUBBOCK	LBB	3178	1965
TX	LUFKIN	LFK	1803	2839
TX	MCALLEN	MFE	393	5387
TX	MIDLAND ODESSA	MAF	2495	2445
TX	PALACIOS	PSX	1072	3564

Station Location		**Code**	**HDD (2009)**	**CDD (2009)**
State	**City**			
TX	CONROE	CXO	1700	2889
TX	SAN ANGELO	SJT	2020	2814
TX	SAN ANTONIO	SAT	1270	3598
TX	VICTORIA	VCT	1123	3608
TX	WACO	ACT	1927	3086
TX	WICHITA FALLS	SPS	2838	2394
UT	CEDAR CITY	CDC	6058	645
UT	SALT LAKE CITY	SLC	5716	1147
VT	BURLINGTON	BTV	7413	392
VT	MONTPELIER	MPV	7998	237
VA	LYNCHBURG	LYH	4433	1003
VA	NORFOLK	ORF	3330	1659
VA	RICHMOND	RIC	3781	1564
VA	ROANOKE	ROA	3931	1173
WA	BELLINGHAM	BLI	5568	115
WA	HOQUIAM	HQM	5471	51
WA	OLYMPIA	OLM	5614	178
WA	QUILLAYUTE	UIL	5869	44
WA	SEATTLE TACOMA	SEA	4879	319
WA	SPOKANE	GEG	6942	599
WA	WALLA WALLA	ALW	5062	1144
WA	WENATCHEE	EAT	6029	1120
WA	YAKIMA	YKM	6204	699
WV	BECKLEY	BKW	5325	404
WV	CHARLESTON	CRW	4443	960
WV	ELKINS	EKN	5993	284
WV	HUNTINGTON	HTS	4557	922
WV	MARTINSBURG	MRB	5046	854
WV	MORGANTOWN	MGW	4957	836
WV	PARKERSBURG	PKB	4910	850
WI	EAU CLAIRE	EAU	8208	333
WI	GREEN BAY	GRB	8005	275
WI	LACROSSE	LSE	7334	536
WI	MADISON	MSN	7343	368
WI	MILWAUKEE	MKE	6816	474
WI	WAUSAU	AUW	8337	277

Station Location		**Code**	**HDD (2009)**	**CDD (2009)**
State	**City**			
WY	CASPER	CPR	7858	225
WY	CHEYENNE	CYS	7390	203
WY	CODY	COD	7551	410
WY	LANDER	LND	7743	351
WY	ROCK SPRINGS	RKS	8204	230
WY	SHERIDAN	SHR	7844	287
WY	WORLAND	WRL	7757	467

Table 7-D.4.2 Subset of Data Matches (for the city of Boston, MA)

Location	DOE ID	HDD	CDD	Division
BOS	78	5928	630	2
BOS	82	5688	582	2
BOS	123	5507	630	2
BOS	127	6008	575	2
BOS	132	6045	601	2
BOS	362	6071	615	2
BOS	363	5839	617	2
BOS	404	5971	509	2
BOS	415	5594	622	2
BOS	446	5520	763	2
BOS	491	5984	581	2
BOS	529	6027	626	2
BOS	552	6027	570	2
BOS	615	6038	466	2
BOS	655	5706	578	2
BOS	699	5608	604	2
BOS	729	5973	583	2
BOS	809	6002	576	2
BOS	824	5737	570	2
BOS	853	5629	613	2
BOS	868	5615	602	2
BOS	938	6135	521	2
BOS	1069	5781	475	2
BOS	1235	5959	587	2
BOS	1273	5877	509	2
BOS	1352	6185	531	2
BOS	1353	5944	591	2
BOS	1367	5636	732	2
BOS	1402	5712	576	2
BOS	1481	6009	549	2
BOS	1637	6015	573	2
BOS	1732	5911	442	2
BOS	1876	6059	543	2
BOS	1921	5673	325	2
BOS	1993	5996	578	2
BOS	2026	5839	542	2
BOS	2047	5913	500	2
BOS	2062	5946	515	2
BOS	2134	5844	518	2
BOS	2144	6103	551	2
BOS	2215	5962	429	2
BOS	2249	5819	524	2

Location	DOE ID	HDD	CDD	Division
BOS	2274	6047	565	2
BOS	2301	5885	605	2
BOS	2307	5747	703	2
BOS	2429	6149	540	2
BOS	2495	5919	440	2
BOS	2521	5955	513	2
BOS	2566	5667	724	2
BOS	2638	5664	589	2
BOS	2675	5973	508	2
BOS	2733	5545	635	2
BOS	2770	5831	521	2
BOS	2829	5605	741	2
BOS	2837	5494	452	2
BOS	2867	5837	600	2
BOS	2894	5992	579	2
BOS	2956	5785	630	2
BOS	3004	5760	563	2
BOS	3011	5675	657	2
BOS	3166	6076	558	2
BOS	3311	5700	579	2
BOS	3321	5767	576	2
BOS	3326	5838	617	2
BOS	3419	5768	576	2
BOS	3422	6085	556	2
BOS	3424	6020	553	2
BOS	3449	5631	466	2
BOS	3498	6138	494	2
BOS	3513	6072	559	2
BOS	3593	5848	676	2
BOS	3621	5503	632	2
BOS	3667	6088	555	2
BOS	3786	6166	486	2
BOS	3805	5797	554	2
BOS	3823	5461	461	2
BOS	4106	6181	532	2
BOS	4152	6177	533	2
BOS	4153	5903	545	2
BOS	4191	5927	539	2
BOS	4212	5968	585	2
BOS	4216	5974	583	2
BOS	4247	5630	414	2
BOS	4259	5991	579	2
BOS	4305	6006	631	2

Location	DOE ID	HDD	CDD	Division
BOS	4433	5805	625	2
BOS	4516	5707	516	2
BOS	4517	5811	686	2
BOS	4567	5851	539	2
BOS	4635	5600	742	2
BOS	4685	6054	563	2
BOS	4737	5487	636	2
BOS	4841	5935	593	2
BOS	4842	5699	634	2
BOS	4899	5667	563	2
BOS	4919	5503	768	2
BOS	4921	5728	587	2
BOS	5053	5962	492	2
BOS	5090	5930	594	2
BOS	5122	5939	493	2
BOS	5214	5877	607	2
BOS	5233	5904	526	2
BOS	5434	5813	522	2
BOS	5443	5807	687	2
BOS	5532	6071	510	2
BOS	5534	5678	579	2
BOS	5552	5873	510	2
BOS	5558	5825	565	2
BOS	5596	5479	774	2
BOS	5668	5552	755	2
BOS	5678	5949	625	2
BOS	5697	5778	577	2
BOS	5712	5572	613	2
BOS	5724	5468	641	2
BOS	5730	5563	752	2
BOS	5757	5538	622	2
BOS	5775	6143	541	2
BOS	5814	5669	503	2
BOS	5846	5902	526	2
BOS	5851	5459	461	2
BOS	6009	5770	697	2
BOS	6034	5885	661	2
BOS	6143	6100	607	2
BOS	6158	6071	559	2
BOS	6169	6031	550	2
BOS	6183	5694	581	2
BOS	6187	5522	627	2
BOS	6247	5861	551	2

Location	DOE ID	HDD	CDD	Division
BOS	6290	5847	597	2
BOS	6332	5617	601	2
BOS	6340	5707	595	2
BOS	6398	6017	572	2
BOS	6492	6141	578	2
BOS	6504	5478	638	2
BOS	6517	6156	538	2
BOS	6549	5731	571	2
BOS	6712	6016	573	2
BOS	6737	5838	562	2
BOS	6745	6068	560	2
BOS	6934	5642	570	2
BOS	6965	5617	737	2
BOS	7006	6196	480	2
BOS	7015	6060	562	2
BOS	7084	5894	386	2
BOS	7088	5822	566	2
BOS	7103	5998	577	2
BOS	7123	5853	539	2
BOS	7143	5838	617	2
BOS	7265	5637	732	2
BOS	7322	5952	589	2
BOS	7329	5921	547	2
BOS	7428	6112	549	2
BOS	7474	6142	541	2
BOS	7481	5533	803	2
BOS	7485	6117	548	2
BOS	7626	5894	603	2
BOS	7667	6033	410	2
BOS	7748	5814	623	2
BOS	7779	5529	761	2
BOS	7827	5551	755	2
BOS	7852	5877	589	2
BOS	7885	5311	819	2
BOS	7980	5676	586	2
BOS	8026	5845	677	2
BOS	8068	5817	684	2
BOS	8085	5520	763	2
BOS	8111	5682	584	2
BOS	8159	6106	502	2
BOS	8164	6146	439	2
BOS	8184	5946	263	2
BOS	8285	6105	449	2

Location	DOE ID	HDD	CDD	Division
BOS	8290	6177	588	2
BOS	8346	5608	740	2
BOS	8461	5637	596	2
BOS	8549	5914	500	2
BOS	8550	5876	552	2
BOS	8551	5690	599	2
BOS	8552	6170	485	2
BOS	8556	6146	576	2
BOS	8624	6115	498	2
BOS	8674	5921	578	2
BOS	8677	6145	541	2
BOS	8701	5837	600	2
BOS	8806	5484	637	2
BOS	8908	6068	515	2
BOS	8922	5766	479	2
BOS	8926	5780	631	2
BOS	8981	5850	516	2
BOS	9062	6075	558	2
BOS	9077	6194	473	2
BOS	9128	6195	564	2
BOS	9248	5901	601	2
BOS	9360	6003	477	2
BOS	9369	5662	590	2
BOS	9449	5737	625	2
BOS	9578	5740	569	2
BOS	9606	6068	560	2
BOS	9674	6064	461	2
BOS	9713	5748	703	2
BOS	9797	6039	567	2
BOS	9832	5973	527	2
BOS	9904	5547	756	2
BOS	9926	5517	628	2
BOS	10007	5856	508	2
BOS	10009	5733	585	2
BOS	10037	5864	610	2
BOS	10094	6092	554	2
BOS	10337	5446	647	2
BOS	10437	5995	578	2
BOS	10510	6093	554	2
BOS	10513	5985	636	2
BOS	10609	5829	522	2
BOS	10633	5686	719	2
BOS	10642	6130	526	2

Location	DOE ID	HDD	CDD	Division
BOS	10683	5850	614	2
BOS	10694	6011	574	2
BOS	10729	5779	631	2
BOS	10789	5844	560	2
BOS	10835	6166	535	2
BOS	10894	5924	596	2
BOS	10910	5886	666	2
BOS	11052	5522	763	2
BOS	11114	5781	694	2
BOS	11163	6148	464	2
BOS	11393	5628	613	2
BOS	11420	5654	592	2
BOS	11424	5988	523	2
BOS	11446	6109	501	2
BOS	11524	5577	444	2
BOS	11534	6100	503	2
BOS	11613	5529	625	2
BOS	11643	5532	760	2
BOS	11664	5631	598	2
BOS	11665	5785	557	2
BOS	11676	6178	554	2
BOS	11690	5941	493	2
BOS	11713	6136	543	2
BOS	11735	5714	576	2
BOS	11736	5610	578	2
BOS	11797	5688	582	2
BOS	11897	6118	547	2
BOS	11932	5562	752	2
BOS	12033	6025	479	2

REFERENCES

1. Energy Information Administration, *Annual Energy Outlook 2012 with Projections to 2035*, 2012. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf>

APPENDIX 7-E. DETERMINATION OF FURNACE ENERGY USE IN THE LCC ANALYSIS

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7-E.1 INTRODUCTION

DOE accounted for the fact that more efficient furnace fans will tend to contribute less heat and thereby require additional furnace operation. Since the heating load of each sample housing unit is known, it is possible to estimate what the furnace energy consumption would be if more efficient fan equipment, rather than the baseline equipment, was used in each housing unit.

The furnace energy consumption of non-furnace components in the LCC analysis is determined using the 2007 ASHRAE SPC 103R "Method of Testing for Annual Fuel Efficiency of Residential Central Furnaces and Boilers".[1] This approach requires the calculation of the average annual fuel energy consumption (E_F), the average annual electrical energy consumption (E_{AE}), and the national average number of burner operating hours (BOH) of furnaces.

The following calculations describe the determination of E_F, E_{AE}, and BOH for gas- and oil-fired furnaces.

7-E.2 DETERMINATION OF AVERAGE ANNUAL FUEL ENERGY CONSUMPTION (E_F)

The average annual fuel consumption is calculated in Appendix C section 2 of the ASHRAE 103/2007 test procedure:[1]

$E_F = BOH_{SS} * (Q_{IN} - Q_P) + 8{,}760 * Q_P$, for single-stage furnaces,

$E_F = (BOH_H * Q_{IN}) + (BOH_R * Q_{IN,R}) + [8{,}760 - (BOH_H + BOH_R)] * Q_P$, for two-stage furnaces and

$E_F = (BOH_M * Q_{IN,M}) + (BOH_R * Q_{IN,R}) + [8{,}760 - (BOH_M + BOH_R)] * Q_P$, for continuous modulating[a1] furnaces

where,

BOH_{SS} = national average number of burner operating hours (see derivation in section 7-E.4),

BOH_H = national average number of burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = national average number of burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section7-E.4),

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[a] In this Technical Support Documentation, "continuous modulating" term is used instead of "step-modulating". Both terms are interchangeable used in the literature.

BOH_M = national average number of burner operating hours at the modulating operating mode for continuous modulating furnaces (see derivation in section 7-E.4),
Q_{IN} = steady-state nameplate input rate in Btu/h for single-stage furnaces or steady-state nameplate maximum input rate in Btu/h for two-stage and continuous modulating furnaces,
$Q_{IN,R}$ = steady-state reduced fuel input rate,
$Q_{IN,M}$ = steady-state modulating fuel input rate, and
Q_P = pilot flame fuel input rate in Btu/h.

Q_{IN} is based on the baseline value for each product class. We set $Q_{IN,R}$ to be 69% of Q_{IN} for non-condensing two-stage equipment, 67% for condensing two-stage equipment, and 40% for continuous modulation equipment, where this value represents the average ratio $Q_{IN}/Q_{IN,R}$ as derived using manufacturer product literature and AHRI March 2013 Directory data for all listed two-stage furnace models.[2]

From the test procedure,[1] $Q_{IN,M}$ is calculated using $Q_{OUT,M}$ and $Effy_{SS,M}$ (as defined in section 11.4.8.10 or 11.5.8.8 in the ASHRAE SPC 103/2007 test procedure).[1] Q_P is zero for all product classes, except for the baseline manufactured-home gas furnace and gas boiler.

7-E.3 DETERMINATION OF AVERAGE ANNUAL ELECTRICAL ENERGY CONSUMPTION (E_{AE})

Using the ASHRAE SPC 103/2007 test procedure,[1] the average annual auxiliary electrical energy consumption is calculated in Appendix C section 3:

$$E_{AE} = BOH_{SS}\,(y_P * PE + y_{IG} * PE_{IG} + y * BE),$$ for single-stage furnaces,

and

$$E_{AE} = BOH_R\,(y_{P,R} * PE_R + y_{IG,R} * PE_{IG,R} + y_R * BE_R) + BOH_{H\ or\ M}\,(y_P * PE_H + y_{IG} * PE_{IG,H} + y * BE_H)$$[b][2], for two-stage and continuous modulating furnaces,

where

BOH_{SS} = as defined in section 7-E.4,
BOH_H = as defined in section 7-E.4,
BOH_M = as defined in section 7-E.4
BOH_R = as defined in section 7-E.4
y_P = ratio of induced or forced draft blower on-time to average burner on-time,
$y_{P,R}$ = ratio of induced or forced draft blower on-time to average burner on-time, measured at the reduced fuel input rate,

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[b] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

PE = burner (or draft inducer) electrical power input at full-load steady-state operation in kW,
PE_R = burner (or draft inducer) electrical power input at full-load steady-state operation in kW**,** measured at the reduced fuel input rate,
PE_H = burner (or draft inducer) electrical power input at full-load steady-state operation in kW, measured at the maximum fuel input rate,
y_{IG} = ratio of burner interrupted-ignition device on-time to average burner on-time,
$y_{IG,R}$ = ratio of burner interrupted-ignition device on-time to average burner on-time, measured at the reduced fuel input rate,
PE_{IG} = electrical input rate to the interrupted ignition device on the burner,
$PE_{IG,R}$ = electrical input rate to the interrupted ignition device on the burner, measured at the reduced fuel input rate,
$PE_{IG,H}$ = electrical input rate to the interrupted ignition device on the burner, measured at the maximum fuel input rate,
y = ratio of blower or pump on-time to burner on-time,
y_R = ratio of blower or pump on-time to burner on-time, measured at the reduced fuel input rate,
BE = circulating-air fan or water pump electrical energy input rate in kW,
BE_R = circulating-air fan or water pump electrical energy input rate in kW, measured at the reduced fuel input rate, and
BE_H = circulating-air fan or water pump electrical energy input rate in kW**,** measured at the maximum fuel input rate.

The values y_P and $y_{P,R}$ are calculated using t_P (post-purge time). For this calculation, DOE took t_P to be 5 seconds for furnaces, which is less than or 30 seconds and is therefore set equal to 0 seconds, according to Appendix C section 1 of the ASHRAE SPC 103/2007. DOE calculated the values y and $y_{P,R}$ using t^+ (blower or pump on-delay) and t^- (blower or pump off-delay). For furnaces, $t^+ = 2$ min and $t^- = 0.5$ min, which are values obtained for the generic furnace models. For gas furnaces, PE is equal to 75 W for non-condensing furnaces and 90 W for condensing furnaces. For oil furnaces, PE is set to 220 W. [6] For design options which include modulating controls, we set PE_R and PE_H to have the same values as PE, since it is assumed that there is no inducer modulation. For gas furnaces, PE_{IG}, $PE_{IG,R}$, and $PE_{IG,H}$ are set equal to 400 W.[7] For oil furnaces, PE_{IG} is equal to 45 watts for oil equipment without interrupted ignition, and 25 watts with oil equipment with interrupted ignition.[8] For design options which include modulating controls, we set $PE_{IG,R}$ and $PE_{IG,H}$ to have the same values as PE_{IG}, since it is assumed that there is no ignition modulation.

7-E.4 DETERMINATION OF NATIONAL AVERAGE NUMBER OF BURNER OPERATING HOURS (BOH_{SS})

From the ASHRAE SPC103/2007 test procedure,[1] the national average number of burner operating hours for furnaces and boilers is calculated in Appendix C section 1:

$BOH_{SS} = 2080 * 0.77 * A * (Q_{OUT} / (1 + \alpha)) - 2080 * B$, for single-stage furnaces,

$BOH_H = X_H * (2080) * (0.77) * A_H * (Q_{OUT} / (1 + \alpha)) - 2080 * B_H$, for two-stage furnaces at the maximum operating mode,

$BOH_R = X_R * (2080) * (0.77) * A_R * (Q_{OUT} / (1 + \alpha)) - 2080 * B_R$, for two-stage and continuous modulating furnaces operating at the reduced operating mode,

and

$BOH_M = X_H * (2080) * (0.77) * A_M * (Q_{OUT} / (1 + \alpha)) - 2080 * B_M$, for continuous modulating furnaces operating at the modulating operating mode,

where

2080 = national average heating load hours,
0.77 = adjustment factor to adjust the calculated design heating requirements and heating load hours to the actual heating load experienced by the heating system,
A = $100{,}000/ [341300(y_P * PE + y_{IG,R} *PE_{IG,R} + y * BE) + (Q_{IN} - Q_P) * Effy_{HS}]$[c][3],
A_H = $100{,}000/ [341300(y_P * PE_H + y_{IG,R} *PE_{IG,R} + y * BE_H) + (Q_{IN} - Q_P) * Effy_{U,H}]$[a],
A_R = $100{,}000/ [341300(y_{P,R} * PE_R + y_{IG,R} *PE_{IG,R} + y_R * BE_R) + (Q_{IN,R} - Q_P) * Effy_{U,R}]$[a],
A_M = $100{,}000/ [341300(y_P * PE_H + y_{IG,R} *PE_{IG,R} + y * BE_H) + (Q_{IN,M} - Q_P) * Effy_{U,M}]$[a],
B = $2 * (Q_P) * (Effy_{HS}) * (A) / 100{,}000$,
B_H = $2 * (Q_P) * (Effy_{U,H}) * (A_H) / 100{,}000$,
B_R = $2 * (Q_P) * (Effy_{U,R}) * (A_R) / 100{,}000$,
B_M = $2 * (Q_P) * (Effy_{U,M}) * (A_M) / 100{,}000$,
Q_{OUT} = maximum fuel input rate heating capacity,
α = oversize factor set to 0.7,
X_H = fraction of heating load at maximum fuel input rate operating mode,
X_R = fraction of heating load at reduced fuel input rate operating mode ($1-X_H$),
Q_{IN} = as defined in above,
$Q_{IN,R}$ = as defined in above,
$Q_{IN,M}$ = as defined in above,
Q_P = as defined in above,
y_P = as defined in above,
$y_{P,R}$ = as defined in above,
PE = as defined in above,
PE_R = as defined in above,
PE_H = as defined in above,
y_{IG} = as defined in above,
$y_{IG,R}$ = as defined in above,
PE_{IG} = as defined in above,
$PE_{IG,R}$ = as defined in above,
$PE_{IG,H}$ = as defined in above,

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[c] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

y = as defined in section above,
y_R = as defined in section above,
BE = as defined in section above,
BE_R = as defined in section above,
BE_H = as defined in section above,
$Effy_{HS}$ = ratio of the average length of the heating season in hours to the average heating load hours,
$Effy_{U,H}$ = average part load efficiency at the maximum fuel input rate,
$Effy_{U,R}$ = average part load efficiency at the reduced fuel input rate, and
$Effy_{U,M}$ = average part load efficiency at the modulating fuel input rate.

The modified equations used in the LCC spreadsheet are as follows (Note that the maximum value for BOH is set to 8760):

$BOH_{SS} = A * HHL - 2080 * B$, for single-stage furnaces,

$BOH_H = X_H * A_H * HHL - 2080 * B_H$, for two-stage furnaces at the maximum operating mode,

$BOH_R = X_R * A_R * HHL - 2080 * B_R$, for two-stage and continuous modulating furnaces operating at the reduced operating mode,

and

$BOH_M = X_H * A_M * HHL - 2080 * B_M$, for continuous modulating furnaces operating at the modulating operating mode,

To calculate factors A, A_H, A_R, A_M, B, B_H, B_R, and B_M, DOE calculated y_P, $y_{P,R}$, PE, PE_R, PE_H, y_{IG}, $y_{IG,R}$, PE_{IG}, $PE_{IG,R}$, $PE_{IG,H}$, y, y_R, BE, BE_R, BE_H, PE, y_{IG}, PE_{IG}, y, BE, Q_{IN}, and Q_P y_P , as described in section 7-E.3 of this appendix. Based on a Canadian Study not all heat from the electrical components is useful heat,[4] so DOE adjusted the electrical component heat output by 94 percent. For factor B, if $Q_P = 0$, then $B = 0$, which is true for all cases except for the baseline manufactured-home gas furnace and the baseline gas boiler. We calculated $Effy_{HS}$, heating seasonal efficiency, as defined in sections 11.2.11, 11.3.11.3, 11.4.11.3, and 11.5.11.3 in ASHRAE SPC 103/2007 test procedure.[1] For $Q_P = 0$, $Effy_{HS}$ is equal to the annual fuel utilization efficiency (*AFUE*). For $Q_P > 0$, $Effy_{HS}$ is calculated using $Effy_{SS}$ (as defined in section 11.2.8.1[1]). $Effy_{SS}$ is calculated using Q_{OUT} (as defined below), K (factor that adjusts the jacket losses, where K = 1.7 for non-weatherized furnaces and Lj (jacket loss, where Lj = 1 is the default value as described in section 11.2.8.1[1])

Q_{OUT} for all product classes is calculated using the following equations based on AHRI Directory data for Non-Weatherized Gas Furnaces:[2]

$Q_{OUT} = Q_{IN} (0.7247 * \text{AFUE} + 0.22346)$, for non-condensing equipment, and

$Q_{OUT} = Q_{IN}$ (0.8127 * AFUE + 0.17557), for condensing equipment.

DOE calculated X_H by using T_C (balance-point temperature as defined in section 11.4.8.4 of ASHRAE SPC 103/2007 test procedure[1]), α (the oversize factor, as calculated in Equation 11), Q_{OUT}, and $Q_{OUT,R}$ (reduced fuel input rate heating capacity). $Q_{OUT,R}$ is set equal to 69% Q_{OUT} for non-condensing equipment and 67% Q_{OUT} for condensing equipment, as derived using manufacturer product literature and AHRI Directory data for all listed two-stage furnace models.[2] X_R is set equal to 1-X_H. $Effy_{U,H} = Effy_{U,R}$ and therefore using the equation in section 11.5.11.3 of ASHRAE SPC 103/2007 test procedure is equal to $Effy_{SS}$. $Effy_{U,M}$ is calculated using the equation in section 11.4.9.2.3 of ASHRAE SPC 103/2007 test procedure.[1]

7-E.5 DETERMINATION OF IMPACT ON FURNACE ENERGY USE WITH MORE EFFICIENT FURNACE FANS

DOE accounted for the fact that more efficient furnace fans will tend to contribute less heat and thereby require additional furnace operation. Since the heating load of each sample housing unit is known, it is possible to estimate what the furnace energy consumption would be if more efficient fan equipment, rather than the baseline equipment, was used in each housing unit.

DOE calculated the furnace fuel consumption (*FuelUse*) for each furnace fan efficiency level using the following formula based on the current American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) test procedure SPC 103-2007 section C [d]:

$$FuelUse = BOH \times Q_{IN}\text{, for single-stage furnace, and}$$

$$FuelUse = (BOH_H * Q_{IN}) + (BOH_R * Q_{IN,R})\text{, for two-stage furnaces}$$

Where:

BOH = steady-state burner operating hours (hr),

Q_{IN} = input capacity of existing furnace (kBtu/h,).

BOH_H = burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section 7-E.4), and

$Q_{IN,R}$ = reduced fuel input rate.

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[d] For natural draft equipment this formula is modified to include the pilot light consumption.

Recall from above that BOH is calculated using BE (furnace fan electrical energy input rate), which is equal to the furnace fan power during the heating operation calculated for each furnace fan efficiency level.

DOE also calculated the non-furnace fan furnace electricity consumption (i.e., the electricity used by the induce draft blower and the electricity used by the ignitor) for each furnace fan efficiency level using the following formula:

$ElecUse_{non\text{-}furnac\_fan} = BOH_{ss} (y_P{*}PE + y_{IG}\ {*}PE_{IG})$,[e] for single-stage furnace, and

$ElecUse_{non\text{-}furnac\_fan} = BOH_R (y_{P,R}{*}PE_R + y_{IG,R}\ {*}PE_{IG,R}) + BOH_H (y_P{*}PE_H + y_{IG}\ {*}PE_{IG,H})$[f2], for two-stage

Where:

BOH = steady-state burner operating hours (hr),

y_P = ratio of induced-draft blower on-time to burner on-time,

PE = power consumption of the draft-inducer blower-motor (kW),

y_{IG} = ratio of ignitor on-time to burner on-time, and

PE_{IG} = power consumption of the ignitor (kW).

BOH_H = burner operating hours at the maximum operating mode for two-stage furnaces (see derivation in section 7-E.4),

BOH_R = burner operating hours at the reduced operating mode for two-stage or continuous modulating furnaces (see derivation in section 7-E.4), and

$y_{P,H}$ = ratio of induced-draft blower on-time to burner on-time, measured at the maximum fuel input rate,

PE_H = power consumption of the draft-inducer blower-motor (kW), measured at the maximum fuel input rate,

$y_{IG,H}$ = ratio of ignitor on-time to burner on-time, measured at the maximum fuel input rate, and

$PE_{IG,H}$ = power consumption of the ignitor (kW) measured at the maximum fuel input rate.

$y_{P,R}$ = ratio of induced-draft blower on-time to burner on-time, measured at the reduced fuel input rate,

PE_R = power consumption of the draft-inducer blower-motor (kW), measured at the reduced fuel input rate,

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[e] For two-stage equipment this formula includes parameters for the operation at full, modulating, and reduced load.

[f] The ASHRAE test procedure does not deal with ignitor energy consumption. The ratio of ignitor on-time to burner on-time and the ignitor power consumption variables come from the DOE test procedure.[3]

$y_{IG,R}$ = ratio of ignitor on-time to burner on-time, measured at the reduced fuel input rate, and

$PE_{IG,R}$ = power consumption of the ignitor (kW) measured at the reduced fuel input rate.

Once the heating load of each sample housing unit is known, it is possible to estimate what the energy consumption would be if more efficient furnace fan equipment, rather than the baseline equipment, were used in each housing unit.

The ratio of blower on-time to burner on-time and the ratio of induced draft blower on-time to burner on-time are from the current ASHRAE test procedure SPC 103-2007[1] using delay times (pre-purge, post-purge, on-delay, and off-delay) derived from DOE's 2007 Furnace and Boiler Final Rule.[5] The ratio of ignitor on-time to burner on-time comes from the DOE test procedure and the ignition time derived from the 2007 final rule. The delay times are defined as follows: pre-purge and post-purge times are the lengths of time the draft inducer operates before and after a firing cycle. On-delay is the amount of time the blower waits to begin operating after the burner starts firing. Off-delay is the time the blower keeps operating after the burner turns off. Ignition time is the length of time the hot surface ignitor is on before gas is sent to the burner. The average values for the delay and ignition times are shown in the next table.

Table 7-E.5.1 Average Values for Delay and Ignition Times

Pre-Purge	Post-Purge	On-Delay	Off-Delay	Ignition
15 seconds	5 seconds	30 seconds	120 seconds	37 seconds

A common value for the power consumption of the draft inducer, PE, for basic non-condensing model furnaces is 75 W, and the average value is about 75 W, so DOE selected 75 W for all the non-condensing models. DOE found no correlation between the PE and input capacity or between PE and airflow capacity. For condensing furnaces, DOE used a PE of 90 W, which closely matches the mean for that group.

7-E.6 ASSIGNING FURNACE EQUIPMENT CHARACTERISTICS TO SAMPLE HOUSEHOLDS

To estimate the heating load of each sample housing unit, DOE represented the existing furnace by assigning an input capacity, airflow capacity, and AFUE to the furnace in the RECS sample housing units.

7-E.6.1 Input Capacity of Existing and New Equipment

DOE assigned an input capacity for the existing furnace of each housing unit based on an algorithm that correlates the housing unit size and outdoor design temperature with the distribution of input capacity of furnaces. DOE assumed that, for the new furnace installation, the input capacity would remain the same. The following steps describe the assignment process for furnaces:

1) DOE ranked all the RECS housing units in ascending order by size (heating square foot) multiplied by a scaling factor to account for the outdoor design temperature (see equation below) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.
2) DOE constructed percentile tables by input capacity of furnaces based on the historical shipment information and number of models in AHRI Directory.
3) After selecting a housing unit from the RECS database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.
4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the correlation was not perfect. DOE used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.
5) Using the percentile from Step 4, DOE looked up the input capacity from the input capacity percentile table in Step 2.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household. Using this data, DOE then developed a scaling factor to be applied to the home heating square footage and equal to:

$$SF_{design,h} = (65 - T_{design,\,h}) / (65 - 42)$$

Where:

$SF_{design,h}$ = heating design scaling factor, and
$T_{design,\,h}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for heating.

The design scaling factor is used as a proxy to represent lower heating loads for the same household area in cooler climates and supports the allocation of the sizes across observations, but that the total relative allocation of sizes is unaffected. The end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential furnaces by input capacity. Table 7-E.6.1shows the distribution of input capacities for the most commonly available input capacity bins for non-weatherized gas furnaces based on the 2012 AHRI Residential Furnace Directory.[2] See the LCC spreadsheet, worksheet “Furnace & AC Spec” for the distributions of input capacities for other product classes.

Table 7-E.6.1 Distribution of Input Capacities for Non-Weatherized Gas Furnaces

	Non-Condensing		Condensing	
Input Capacity *kBtu/h*	2012 AHRI Directory Fraction of Models *%*	Cumulative Fraction of Models *%*	2012 AHRI Directory Fraction of Models *%*	Cumulative Fraction of Models *%*
40	10.9	10.9	10.9	10.9
50	3.3	14.2	1.8	12.7
60	17.6	31.8	17.1	29.8
70	5.4	37.2	6.7	36.5
80	18.5	55.7	20.4	56.9
90	1.8	57.5	7.5	64.4
100	17.4	75.0	16.0	80.4
110	6.5	81.5	6.7	87.1
120	9.1	90.6	10.5	97.6
130	3.4	94.0	2.2	99.8
140	3.4	97.5	0.2	100.0
150	2.0	99.5	0.0	100.0
160	0.5	10.9	0.0	100.0

7-E.6.2 Airflow Size of Existing Equipment

DOE classified furnaces by nominal maximum airflow in cfm at 0.5 in. w.g. of external static pressure. DOE assigned the airflow capacity of existing furnaces for housing units that had air conditioners in a manner similar to how it assigned furnace input capacity. Larger air conditioners go to larger housing units, according to the distribution of sizes of air conditioners sold the year the air conditioner was installed in that housing unit. DOE used the air conditioner nominal size of two, three, four, or five tons to set the airflow capacity with a ratio of 400 cfm per ton of cooling. The steps were:

1) DOE ranked all the RECS housing units in ascending order by size (cooling square foot) multiplied by a scaling factor to account for the outdoor design temperature (see equation below) and calculated the percentile rank of each housing unit using the statistical weight of each of the sample records.

2) Based on historical shipment information of residential central air conditioners by capacity, DOE constructed the airflow capacity percentiles table for air conditioners. (See Table 7-E.6.2). Since there are no available shipment data on the airflow capacity of furnaces, DOE used the airflow capacity of residential central air conditioners as a proxy.

3) After selecting a housing unit from the RECS database during each Monte Carlo iteration, DOE noted the size of the selected housing unit and determined the percentile rank from Step 1.

4) To avoid a one-to-one deterministic relation between the housing unit size and input capacity, DOE added a random term to the percentile identified in Step 3 so that the

correlation was not perfect. DOE used a normal distribution to characterize the random term. The random term has a mean of zero and a standard deviation of 8 percent.

5) Using the percentile from Step 4, DOE looked up the airflow from the airflow percentile table in Step 2. DOE selected an input capacity and airflow combination with the identified airflow capacity, based on commonly available models. If no input capacity and airflow combination with the identified airflow capacity was available, DOE selected the input capacity and airflow combination with the same input capacity and the closest airflow capacity as a substitute.

DOE used ASHRAE design data to develop estimates of the average 1 percent design dry bulb temperature for each household. Using these data, DOE then developed a scaling factor to be applied to the home cooling square footage and equal to:

$$SF_{design,c} = (T_{design,\,c} - 65) / (95 - 65)$$

Where:

$SF_{design,c}$ = cooling design scaling factor, and
$T_{design,\,c}$ = average 1 percent ASHRAE design dry bulb temperature (°F) for cooling.

It is noted that the design scaling factor is used as a proxy to represent lower cooling loads for the same household area in warmer climates and supports the allocation of the sizes across observations, but that the total relative allocation of sizes is unaffected. This end result was a distribution of sizes assigned to the weighted RECS samples that matches the distribution of sizes for shipments of residential furnaces.

7-E.6.3 AFUE of Existing Equipment

DOE assigned the AFUE of existing furnaces based on the equipment age of the existing furnace as given by RECS and historical shipments by efficiency. The following steps describe this process:

1) After DOE selected a housing unit from the RECS database during each Monte Carlo iteration, DOE randomly assigned a percentile value and extracted the furnace age information from RECS. Using the extracted furnace age, DOE assigned an installation year from the installation year range for the applicable RECS equipment age bin.
2) Based on the historical furnace shipment information sorted by AFUE, DOE constructed percentile tables by AFUE shipments of furnaces for 2009 and prior years. AHRI shipments data for non-weatherized gas furnaces indicate that housing units in the northern region receive more efficient furnaces. Therefore, DOE developed two historical AFUE shipment distributions—one for the northern region and one for the southern region—for non-weatherized gas furnaces.

3) DOE determined the AFUE by looking it up from the AFUE percentile table from Step (2) corresponding to the age of the existing equipment in the housing unit and whether the housing unit was located in the northern or southern regions. See the LCC spreadsheet, worksheet "Furnace & AC Spec" for the distributions of input capacities for other product classes.

7-E.6.4 AFUE of New Equipment

DOE assigned the AFUE of new furnaces based on distribution of AFUE of furnaces equipment and the RECS household location standards in 2019 for furnaces (e.g. minimum efficiency of 80% AFUE nationally for households with a non-weatherized gas furnace). Table 7-E.6.2 shows the distribution of AFUE for the most commonly available AFUE bins for non-weatherized gas furnaces based on the March 2013 AHRI Residential Furnace Directory.[2] See the LCC spreadsheet, worksheet "Furnace & AC Spec" for the distributions of AFUE for other product classes.

Table 7-E.6.2 Distribution of AFUE for Non-Weatherized Gas Furnaces

	Non-Condensing		Condensing	
AFUE %	2013 AHRI Directory Fraction of Models %	Cumulative Fraction of Models %	2013 AHRI Directory Fraction of Models %	Cumulative Fraction of Models %
80	100.0	100.0	0.0	0.0
81-89	0.0	100.0	0.0	0.0
90	0.0	100.0	3.1	3.1
91	0.0	100.0	3.1	6.1
92	0.0	100.0	17.7	23.9
93	0.0	100.0	4.3	28.2
94	0.0	100.0	2.2	30.4
95	0.0	100.0	25.9	56.2
96	0.0	100.0	28.0	84.3
97	0.0	100.0	12.1	96.4
98	0.0	100.0	3.6	100.0

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APPENDIX 7-F. DETERMINATION OF CENTRAL AIR CONDITIONER ENERGY USE IN THE LCC ANALYSIS

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APPENDIX 7-F. DETERMINATION OF CENTRAL AIR CONDITIONERS ENERGY USE IN THE LCC ANALYSIS

7-F.1 INTRODUCTION

DOE accounted for the fact that more efficient furnace fans will tend to contribute less heat and thereby require less cooling operation by the central air conditioner. Since the cooling load of each sample housing unit is known, it is possible to estimate what the air conditioner energy consumption would be if more efficient fan equipment, rather than the baseline equipment, were used in each housing unit.

7-F.2 DETERMINATION OF NON-FURNACE FAN COOLING ENERGY USE

DOE calculated the non-furnace fan cooling energy using the following formula:

$$CoolingEnergyUse_{non-furnace\_fan} = COH \times Power_{non-furnace\_fan}$$

Where:

COH = as defined in section 7-F.2.1,

$Power_{non\text{-}furnace\_fan}$ = power consumption of all non-furnace fan components of the central air conditioner (kW).

7-F.2.1 Determination Cooling Operating Hours

The cooling operating hours are calculated using the following formula:

$$COH = \frac{HCL}{CoolingCapacity} \times Adj\_Factor_{motor}$$

Where:

COH = cooling operating hours, hour/year,

HCL = house cooling load, MMBtu/year,

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h (see section 7-F.2.2.1), and

Adj_Factor_{motor} = adjustment factor to account for impact of motor heat on cooling operating hours.

The house cooling load (HCL) assumes that the household has a default furnace fan motor power output of 365 watts per 1000 CFM (used in the CAC test procedure). To properly account for increased or decreased cooling operating hours due to the higher or lower motor power output for different furnace fan efficiencies, DOE used the following equation to determine the adjustment factor:

$$Adj\_Factor_{motor} = \frac{1}{(1 + 3.412 \times \frac{\frac{365}{1000} * CFM - FFPcooling}{CoolingCapacity})}$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output used for calculating SEER, watts,

CFM = nominal cooling load CFM measured at 400 CFM per AC ton, cu. ft. per min,

$FFP_{cooling}$ = furnace fan power during the cooling operation, kW, and

$CoolingCapacity$ = cooling capacity of air conditioner, Btu/h.

The house cooling load is derived using the EIA's RECS 2009[1] cooling energy use data for the sample households as follows:

$$HCL = \frac{CoolingEnergyUseRECS \times SEER_{ex}}{CoolingCapacity_{ex}} \times Adj\_Factor$$

$CoolingEnergyUseRECS$ = annual electricity consumption for cooling based on RECS 2009 (kBtu/yr),

$SEER_{ex}$ = SEER of the existing central air conditioner (See Table 7-F.2.3),

Adj_Factor = adjustment factors (discussed below).

DOE made adjustments to the house cooling load to reflect the expectation that newly built housing units in 2019 will have a somewhat different house cooling load than the housing units in the RECS 2009 sub-sample. Similar to furnace fan energy use calculation above, the building shell efficiency index sets the cooling load value at 1.00 for an average home in 2009 (by type) in each census division. DOE developed adjustment factors to represent the change in cooling load based on the difference in physical size and shell attributes for homes in the future (which takes into account physical size difference and efficiency gains from better insulation and windows). This factor differs for new construction and replacement households. The value for households in 2019 is 0.94 for replacements and 1.01 for new construction.

DOE also made adjustments to the HCL calculated using RECS 2009 data to reflect historical average climate conditions. Table 7-F.2.1 shows the 2003-2012 average cooling degree days (CDD) as well as the 2009 average CDD for the 30 geographical areas. The adjustment factors are calculated using the equation below.

$$Adj\_Factor_{average\_c\lim ate} = \frac{CDD_{10\_yr\_avg}}{CDD_{res\_stock\_2005}}$$

Where:

$CDD_{res\_stock\_2009}$ = CDD in 2009 for the specific region where the housing unit is located, and
$CDD_{10\_yr\_avg}$ = 10-year average CDD (2003–2012) based on NOAA data[2] for the specific region where the housing unit is located.

Table 7-F.2.1 Cooling Degree Day Adjustment Factors

Geographical Areas		Average CDD		Adjustment Factor
		2003-2012	2009	
1	CT, ME, NH, RI, VT	489	348	1.41
2	MA	525	377	1.39
3	NY	737	509	1.45
4	NJ	934	689	1.36
5	PA	764	570	1.34
6	IL	935	630	1.48
7	IN, OH	878	655	1.34
8	MI	626	384	1.63
9	WI	558	324	1.72
10	IA, MN, ND, SD	646	402	1.61
11	KS, NE	1335	961	1.39
12	MO	1347	987	1.36
13	VA	1205	1025	1.18
14	DE, DC, MD	1119	930	1.20
15	GA	1831	1693	1.08
16	NC, SC	1647	1503	1.10
17	FL	3549	3611	0.98
18	AL, KY, MS	1807	1616	1.12
19	TN	1516	1301	1.17
20	AR, LA, OK	2291	2049	1.12
21	TX	2876	2799	1.03
22	CO	357	208	1.72
23	ID, MT, UT, WY	583	487	1.20
24	AZ	3177	3198	0.99
25	NV, NM	1707	1662	1.03
26	CA	933	978	0.95
27	OR, WA	232	271	0.86
28	AK	NA	NA	0.86
29	HI	NA	NA	0.95
30	WV	856	678	1.26

Note: RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. Data for Alaska and Hawaii was not available. The region 27 adjustment factor was used for Alaska, while region 26 adjustment factor was used for Hawaii.

DOE is calculating multi-stage cooling the same way as single-stage equipment (i.e., at the highest cooling mode only) and therefore used the same number of operating hours, since:

1) Multi-stage heating is not necessarily associated with multi-stage cooling equipment (e.g. multi-stage cooling is much less common than multi-stage furnace equipment); and

2) SEER already captures cases when multi-stage heating and cooling equipment are matched.

For households in which it is clear that the electricity use for cooling is associated solely with the use of central air conditioning equipment, DOE used the annual electricity consumption for cooling the household from RECS 2009. DOE adjusted the house cooling load for households that used both a central air conditioner and a room air conditioner. RECS 2009 reports the percentage of cooling energy consumption attributable to room air conditioners. DOE derived the house cooling load applicable to the central air conditioner by subtracting the estimated amount of cooling provided by the other cooling system.

7-F.2.1.1 Existing Space-Cooling Efficiency ($SEER_{ex}$)

To estimate annual space-cooling energy consumption data at the baseline and higher efficiency levels, DOE relies on the cooling and heating energy calculated for the stock households and the historic space-cooling efficiency levels of the stock equipment, $SEER_{res\_stock}$. The space-cooling efficiency of stock equipment is related to the vintage of the equipment. In the 2009 RECS database, the age of the equipment is reported in terms of age groups and not the specific vintage year. The six age groups are “less than 2 years old,” “2 to 4 years old,” “5 to 9 years old,” “10 to 14 years old,” “15 to 19 years old,” and “20 years or older.” The data also include one additional age category: “as old as the home.” In RECS the years of construction of each residence for older homes are also reported in age bands, though the specific year of construction is indicated for the newer homes. DOE assumed that the age of the central air conditioner system, within a given age group in the general population, would be approximately uniformly distributed throughout the range of the age band. For example, for the central air conditioner systems in the “less than 2 years old” age group, it was assumed that 50 percent of heat pumps were 1 year old and the other 50 percent were 2 years old. A similar technique was used in ascertaining the probable vintage year of the home and the equipment when the equipment was reported to be the age of the home.

Once the age group into which the household equipment falls was established, DOE estimated the vintage of the equipment for each household in each age group by random assignment using the uniform age distribution assumption for each age group and the known 2009 survey year. For the 20-year and older age group, all equipment was assumed to be between 20 and 29 years old with the actual vintage assigned using a uniform distribution. The resulting vintage distribution of the residential air conditioners and heat pumps in the overall sample is shown in the table below.

DOE estimated the stock cooling SEER for each household using equipment vintage and average shipped efficiency for each vintage year. The latter was developed from AHRI data[3] and is shown in the table below.

Table 7-F.2.2 Average Annual Shipped Space-Cooling Efficiency

Year	Central A/C *SEER*	Split HP *SEER*	Packaged A/C *SEER*	Packaged HP *SEER*
1976	7.16	6.84	6.57	6.94
1977	7.18	6.95	6.95	6.73
1978	7.42	7.26	6.99	7.18
1979	7.45	7.32	7.54	7.41
1980	7.51	7.47	7.72	7.65
1981	7.73	7.71	7.79	7.67
1982	8.25	7.94	8.30	7.85
1983	8.39	8.23	8.15	8.00
1984	8.65	8.42	8.39	8.34
1985	8.78	8.53	8.66	8.43
1986	8.84	8.70	8.83	8.69
1987	8.90	8.87	9.00	8.94
1988	9.05	9.06	9.06	9.05
1989	9.18	9.20	9.27	9.22
1990	9.24	9.43	9.34	9.31
1991	9.43	9.75	9.47	9.60
1992	10.49	10.61	10.05	10.26
1993	10.54	10.85	10.38	10.63
1994	10.59	10.92	10.43	10.72
1995	10.66	10.95	10.46	10.78
1996	10.65	10.97	10.50	10.80
1997	10.63	10.96	10.46	10.74
1998	10.24	10.54	10.17	10.38
1999	10.88	11.24	10.73	11.20
2000	10.97	11.24	10.77	11.18
2001	11.08	11.32	10.98	11.23
2002	11.07	11.33	11.06	11.25
2003	11.24	11.51	11.06	11.25
2004	11.34	11.61	11.12	11.30
2005	11.35	11.72	11.13	11.37
2006	13.16	13.45	12.39	12.74
2007	13.72	13.86	12.83	13.16
2008	13.77	13.99	13.02	13.41
2009	13.90	14.25	13.41	13.73

7-F.2.2 Determination of Power Consumption of non-Furnace Fan Components of the Central Air Conditioner

DOE determined the power consumption of all non-furnace fan components of the central air conditioner as follows.

$$Powerofnon_{FanComponents} = \left(\frac{CoolingCapacity}{SEER} - \frac{365}{1000} * CFM\right)$$

Where:

$\frac{365}{1000} * CFM$ = default central air conditioner blower output, watts,

CFM = nominal cooling load CFM measured at 400 CFM per AC ton, cfm (see Table 7-F.2.4 labeled airflow rating),

$SEER$ = SEER of central air conditioner in 2019, Btu/h/W, and

CoolingCapacity = cooling capacity of air conditioner, Btu/h (see Table 7-F.2.4).

7-F.2.2.1 Cooling CFM and Cooling Capacity of 0the Central Air Conditioner in 2019

As described in appendix 7-E (section 7-E.6.2), DOE determined the distribution of airflow for furnaces based on shipments of central air conditioner equipment by cooling capacity. Table 7-F.2.3 shows the distribution of cooling capacity bins that match to cooling airflow based on 12,000 Btu/h for every 400 CFM.

Table 7-F.2.3 Distribution of Airflow for Furnaces

Airflow Rating ***cfm***	**Cooling Capacity** ***btu/h***	**2007-2012 AHRI Shipments** ***%***	**Cumulative Fraction** ***%***
600	18,000	9.6	9.6
800	24,000	19.7	29.2
1000	30,000	16.5	45.7
1200	36,000	22.4	68.1
1400	42,000	8.7	76.8
1600	48,000	12.4	89.2
2000	60,000	10.8	100.0

7-F.2.2.2 Central Air Conditioner SEER in 2019

DOE used the SEER efficiency distributions developed in the 2011 Central Air Conditioning, Heat Pump, and Furnace Final Rule,[4] as well as central air conditioner standards that will take effect before 2019. Table 7-F.2.4 shows the distribution of SEER used in the analysis. DOE assumed that all central air conditioners with SEER levels above 15 SEER are associated with ECM furnace fan design option only.

Table 7-F.2.4 Distribution of SEER in 2019 by CAC Region and CAC Type

North				South			
Coil Only		Blower Coil		Coil Only		Blower Coil	
SEER	***Frac.***	***SEER***	***Frac.***	***SEER***	***Frac.***	***SEER***	***Frac.***
13	24.6%	13	18.5%	14	76.9%	14	57.7%
13.5	48.2%	13.5	36.2%	14.5	7.4%	14.5	5.6%
14	4.1%	14	3.1%	15	5.9%	15	4.4%
14.5	7.4%	14.5	5.6%	15.5	2.1%	15.5	1.5%
15	5.9%	15	4.4%	16	7.2%	16	5.4%
15.5	2.1%	15.5	1.5%	16.5	0.5%	16.5	0.4%
16	7.2%	16	5.4%			17	10.0%
16.5	0.5%	16.5	0.4%			18	7.0%
		17	10.0%			19	3.0%
		18	7.0%			20	2.0%
		19	3.0%			21	2.0%
		20	2.0%			22	1.0%
		21	2.0%				
		22	1.0%				

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APPENDIX 7-G. REDUCED SET OF FURNACE FAN MODELS AND CHARACTERISTICS

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APPENDIX 7-G. REDUCED SET OF FURNACE FAN MODELS AND CHARACTERISTICS

7-G.1 INTRODUCTION

This appendix presents the approach for developing a reduced set of furnace fan models and the resulting furnace characteristics.

7-G.2 REDUCED SET OF FURNACE FAN MODELS DATABASE

7-G.2.1 Purpose

The Reduced Set of Furnace Models was developed to identify actual unique furnace models which represent units with different design characteristics and to expand the AHRI directory data for each unique furnace model by adding information provided in the manufacturers' product literature. One application of the reduced set was to develop furnace fan curves which were used in the life-cycle cost (LCC) analysis.

The March 2013 AHRI Directory[1] lists more than 6,000 non-weatherized gas furnace models. Many models represent essentially identical units which differ only in brand name. The database of furnace models described here (referred to as the reduced set of furnace models or simply the reduced set) represents non-repetitive furnace models only. After examining the AHRI Directory database, the Department determined that about 1,400 models may be considered sufficiently different to be listed as unique models. Similar approach was used to develop the reduced set of other furnace fan product classes. See the LCC spreadsheet (“Models Directory” worksheet) for a complete listing of models used for each furnace fan product class.

Once the reduced set was identified, the Department examined the manufacturer’s product literature and added additional data including the airflow at different static pressures, power for the blower, blower motor type, blower wheel dimensions, furnace dimensions, low fire heating input and output capacity for modulating furnaces, and delay times.

7-G.2.2 Data Set Development Background

In 2002, DOE began to develop a database of product specifications (such as different design characteristics) for residential furnaces currently sold in the U.S. A preliminary version of the reduced set database was completed at the end of 2002 and released with the ANOPR.[2] In 2005, during the NOPR phase of the rulemaking, an update version of the database was published[3] and a final version was published in 2007.[4] This current version updates the past version of the data as well as adds additional furnace fan product classes.

7-G.3 DECODING OF MANUFACTURER MODEL NUMBERS

The Department used manufacturer model numbers, among other furnace characteristics, to determine nominal airflow capacity. Manufacturers often code furnace specifications into their model numbers. This appendix illuminates the coding of different manufacturer model numbers.

An Amana model number is shown as an example of how manufacturers code furnace characteristics. Table 7-G.3.1 shows the Amana model number "GUID045CA30." The first row of the table shows the model number broken into eight cells. The fifth, sixth, and seventh characters of the model number are grouped together. The tenth and eleventh characters are grouped together. The second row gives an explanation for each character or group of characters. Row three deciphers the character or group. Deciphering the model number shows that this Amana furnace model is an upflow gas furnace with induced draft, a nominal output of 45K Btuh, that it is not NO_x certified, and has a nominal airflow capability appropriate for a three-ton air conditioner.

Table 7-G.3.1 Example Furnace Model Number Description

G	**U**	**I**	**D**	**045**	**C**	**A**	**30**
Product Type	Supply Type	Furnace Type	Model Features	Nominal Input (kBtu/h)	Design Series	Additional Features	Nominal AC Size
G: Gas Furnace	U: Upflow	I: Induced Draft (80%)	D: Air Command 80 SV (Category I Venting)	045	C: Third Series	A: Standard Unit (not NOx certified)	30: 3 Tons

All manufacturers have similar coding schemes for their furnace model numbers. Table 7-G.3.2 to Table 7-G.3.16 show model numbers from the major manufacturers and an explanation of their conventions.

Table 7-G.3.2 Amana Model Number Description

A	**M**	**S**	**8**	**070**	**3**	**A**	**N**	**A**
Brand	Air Flow Direction	Description	AFUE	Nominal Input (kBtu/h)	Max CFM @0.5" ESP	Cabinet Width	NOx	Revision
A = Amana B = Distinctions G = Goodman	M: Upflow/ Horizontal D: Dedicated Downflow C: Downflow/ Horizontal H: Hi Air Flow	S: Single-Stage/ Multi-Speed V:Two-Stage/ Variable-Speed	8: 80% 9: 90%	045 070 090 115 140	3:1,200 4:1,600 5:2,000	A:14" B:17.5" C:21" D:24.5"	N:Natural Gas X:Low NOx	A: Initial Revision B: First Revision C: Second Revision

Table 7-G.3.3 Armstrong Model Number Description

G	1N	80	A	H	100	D	20	B		1A
Product Family	Furnace Type	Nominal AFUE	Series	Configuration	Heating Input x 1000 (btu/h)	Motor Type	Nominal Maximum CFM x 100	Cabinet Width	Low NOx Model	Revision
G=Gas Furnace	1N = Single-Stage Heat, Non-Direct Vent 1D = Single-Stage Heat, Direct Vent 2D = Two-Stage Heat, Direct Vent	80 AFUE 93 AFUE 95 AFUE	A Series B Series	H = Horizontal U = Upflow T = Upflow/ Horizontal R = Downflow/ Horixontal	50 75 100 125 150	D = Direct Drive	12=1200 14=1400 16=1600 20=2000	A = 13-1/2 B = 17 C = 20-1/2	L = Low NOx Model	1A

Table 7-G.3.4 Carrier Model Number Description

58DLA	045	100	08
Furnace Series Configuration/Type	Input Capacity (kBtu/h)	Series Number	Nominal Cooling Size (Airflow) (400 CFM per 12,000 btu/h)
58DLA = Deluxe 4-Way Multipoise 58DLX = Low NOx version 58CVA = Variable Speed 4-Way Multipoise 58CVX = Low NOx version 58CTA = Two-Stage 4-Way Multipoise 58CTX = Low NOx version	045 = 44,000 070 = 66,000 090 = 88,000 110 = 110,000 135 = 132,000 155 = 154,000	100 Series	08 = 800 CFM 12 = 1200 CFM 14 = 1400 CFM 16 = 1600 CFM 20 = 2000 CFM 22 = 2200 CFM

Table 7-G.3.5 Ducane Model Number Description

MGPA	075	B	4	B
Furnace Family	Input Capacity (kBtu/h)	Series	Nominal Cooling Capacity (tons)	Revision
MGPA = Fits-All 80 AFUE FPBB = Horizontal 80 AFUE DPGB = Downflow 80 AFUE CMPB = Fits-All 92 AFUE (Downflow) CMPU = Fits-All 92 AFUE (Upflow) CMPV = Fits-All 92 AFUE variable speed	050 075 100 125	A B C U	3 4 5	B

Table 7-G.3.6 ECR International (Olsen) Model Number Description

GTM	50
Furnace Family	Input Capacity (kBtu/h)
GTM = Med Efficiency Gas Furnace (80% AFUE) GTH = High Efficiency Gas Furnace (95% AFUE)	50 70 85 100

Table 7-G.3.7 Goodman Model Number Description

GMNT	**040**	**3**
Unit Type	Input Capacity (Btu/h)	Nominal Cooling Capacity (tons)
GMNT = Multi-position gas furnace	040 = 40,000 Btu/h 060 = 60,000 Btu/h 080 = 80,000 Btu/h 100 = 100,000 Btu/h 120 = 120,000 Btu/h	3 = 3 tons 4 = 4 tons 5 = 5 tons

Table 7-G.3.8 ICP Model Number Description

N	**9**	**MP**	**2**	**075**	**F**	**12**	**A**	**#**
Brand Identifier	Model Identifier	Installation Configuration	Major Design Feature	Heating Input (btu/h)	Cabinet Width (inches)	Cooling Airflow	Marketing Digit	Engineering Rev.
N = Non-Brand Specific (Generic) T = Tempstar	8 = Non-Condensing 9 = Condensing	MP = Multiposition UP = Upflow DN = Downflow UH = Uplfow/ Horizontal HZ = Horizontal DH = Downflow/ Horizontal	1 = One pipe 2 = Two pipe D = 1 or 1 pipe L = Low Nox N = Single-Stage P = PVC Vent T = Two-Stage V = Variable Speed	050 075 080 100 125	B = 15.5" J = 22.8" F = 19.1" L = 24.5"	08 = 800 12 = 1200 14 = 1400 16 = 1600 20 = 2000	Denotes minor change	Denotes minor change

Table 7-G.3.9 Lennox Model Number Description

G	**40**	**UH**	**24**	**A**	**045**	**X**
Unit Type	Series	Configuration	Nominal Add-On Cooling Capacity	Cabinet Width	Heating Input (btu/h)	CA emission requirements
G = Gas Furnace	40 = Merit Series 80% 50 = Elite 80% 60 = Two-Stage 80%	UH = Upflow/Horizontal DF = Downflow/Horizontal	24 = 2 Tons 36 = 3 Tons 48 = 4 Tons 60 = 5 Tons	A = 14-1/2 B = 17-1/2 C = 21 D = 24-1/2	045 = 44,000 070 = 66,000 090 = 88,000 110 = 110,000 135 = 132,000 155 = 154,000	X = meets California NOx standards

Table 7-G.3.10 Nordyne Model Number Description

G	**6**	**R**	**A**	**144**	**C**	**20**	**C**
Furnace Fuel Type	Design Series	Furnace Type	Furnace Configuration	Heating Input (btu/h)	Certification Type	Nominal CFM	Cabinet Width
G, FG, KG, L = Gas	6 or 1	R = Residential T = Residential, Two-Stage	A = Upflow C = Upflow, Condensing K = Downflow L = Downflow, condensing	045 = 45,000 060 = 60,000 072 = 72,000 096 = 96,000 120 = 120,000 144 = 144,000	C = US/Canada N = NOx US	08 = 800 CFM 12 = 1200 CFM V = Variable Speed	A = 14-1/4 B = 19-3/4 C = 22-1/2

Table 7-G.3.11 Rheem Non-Condensing Model Number Description

R	G	P	J	07	E	A	U	E	R
Brand Identifier	Fuel Type	Non-Condensing Furnace Type	Design Series	Heating Input (kbtu/h)	Ignition Type	Variations	Blower Size	Cooling Designation (CFM)	Natural Gas Fuel Code
R = Rheem U = Ruud W = Weatherking	G = Natural Gas	D = Upflow L = Downflow P = Upflow/ Horizontal	J = Acclaim A = Acclaim II K = Criterion II Plus 2 N = Classic Series L = Criterion II Plus 2 LXE	04 = 45 05 = 50 06 = 67.5 07 = 75 10 = 100 12 = 125 15 = 150	E = Electric Ignition N = Electric Ignition - NOx Model	A = Standard B= Wide Cabinet	U = 11x6 M = 11x7 R = 11x10	S = 500-1200 E = 1100-1300 G = 1450-1750 J = 1900-2075	R = US A = Canada

Table 7-G.3.12 Rheem Condensing Model Number Description

R	G	T	J	07	E	M	A	E	S
Brand Identifier	Fuel Type	Condensing Furnace Type	Design Series	Heating Input (kbtu/h)	Ignition Type	Blower Size	Variations	Cooling Designation (CFM)	Natural Gas Fuel Code
R = Rheem U = Ruud W = Weatherking	G = Natural Gas	T = Downflow/ Horizontal R = Upflow M = Upflow Modulating	J = Classic 90 A = Classic 90 Plus D = Classic 90 Plus Modulating	04 = 45 06 = 60 07 = 75 09 = 90 10 = 105 12 = 120	E = Electric Ignition N = Electric Ignition - (Low NOx)	M = 11x7 R = 11x10 Z = 12x11 Y = 12x7	A = Standard B= Wide Cabinet C = Single/Multi Zone	E = 1100-1300 G = 1500-1700 J = 1900-2100 K = 600-1200 M = 1200-2000	S = US B = Canada

Table 7-G.3.13 Texas Furnace Model Number Description

ABA	040	NH	3	R
Furnace Family	Heating Input (kbtu/h)	Series	Nominal Cooling Capacity (tons)	Version
ABA = 80 Plus CSA = 90 Plus (Downflow) VSA = 90 Plus (Upflow)	040 060 080 100 120 140	NH	2 3 4 5 6	R = Standard RX = Low Nox RH = High Altitude

Table 7-G.3.14 Thermo-Pride Furnace Model Number Description

MHA	50	N
Furnace Family	Heating Input (kbtu/h)	Furnace Fuel Type
MHA1 = Comfort 80+% Mid-Efficiency Gas Fired Furnace MHA = Comfort 80+% Mid-Efficiency Gas Fired Furnace CHX1 or CDX1 = Premiere Series Two-Stage Gas Fired Furnace CHB1 or CDB1 = 90+% High-Efficiency Gas Fired Furnace	50 75 100 125	N = Natural Gas P = Propane

Table 7-G.3.15 Trane/American Standard Model Number Description

T	**U**	**Y**	**080**	**R**	**9**	**V3**	**V**	**0**
Brand Identifier	Furnace Configuration	Type	Heating Input (Kbtu/h)	Major Design Change	Power Supply and Fuel	Airflow Capacity for Cooling (400 CFM/Ton)	Minor Design Change or	Service Digit
T = Trane A = American Standard	U = Upflow/ Horizontal D = Downflow/ Horizontal	C = Condensing D = Induced Draft E = Electronic Ignition X = Direct Vent Condensing Y = Direct Vent Condensing Variable Speed	040 060 080 100 120 140	C = Single-Stage R = Two-Stage All other = Standard system	115 Volt/ Natural Gas	3 = 3 Tons V3 = 1½-3 Tons, Variable Speed Motor (ICM) V4 = 2 - 4 Tons, Variable Speed Motor (ICM) V5 = 3 - 5 Tons, Variable Speed Motor (ICM)	H = Upflow/ Horizontal V = Variable Speed Motor	0

Table 7-G.3.16 York Furnace Model Number Description

P4	**HU**	**A**	**12**	**N**	**032**	**01**
Series	Furnace Configuration	Cabinet Size Width	Design Series		Output Capacity (kbtu/h)	Revision
P4	HU = Upflow Horizontal	A = 14-1/2 B = 17-1/2 C = 21 D = 24-1/2	12 = 1200 CFM 16 = 1600 CFM 20 = 2000 CFM	N L = Low NOx	032 048 064 080 100 115 130	01 = first revision 02 = second revision

7-G.4 REDUCED FURNACE MODEL CHARACTERISTICS

Input capacity for furnaces and boilers is an essential component used in the LCC analysis. The basic methodology for obtaining the generic input capacities involves using the reduced set of models for each product class and then using a histogram of input capacities to pick the input capacities which are the most common. Figure 7-G.4.1 and Figure 7-G.4.2 shows the number of non-weatherized gas furnace models by input capacity for non-weatherized gas furnaces. A similar approach was used for other furnace fan product classes (See LCC spreadsheet “Furnace and AC Specs” worksheet for all the input capacity and AFUE distributions).

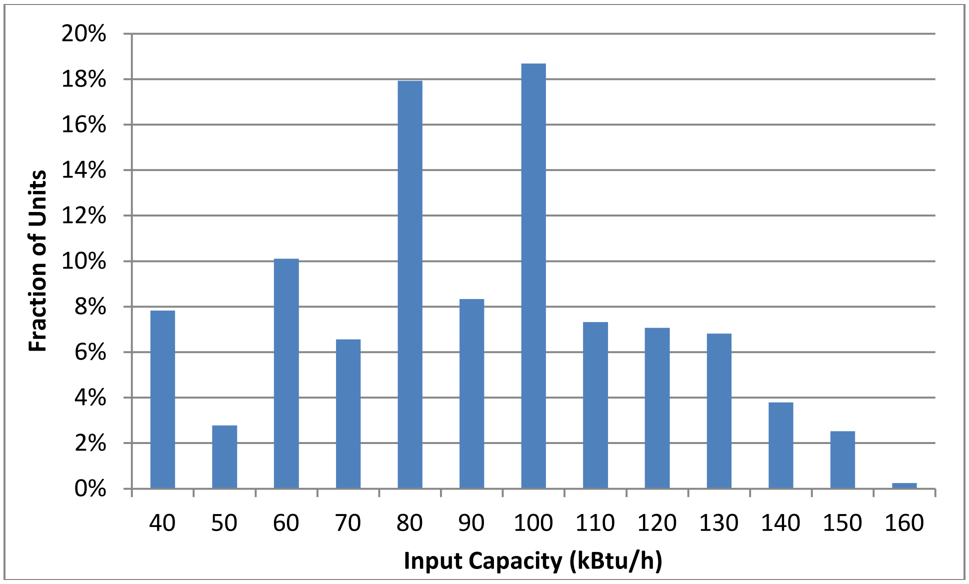

Figure 7-G.4.1 Number of Non-Weatherized Gas Furnace (Non-Condensing) Models by Input Capacity

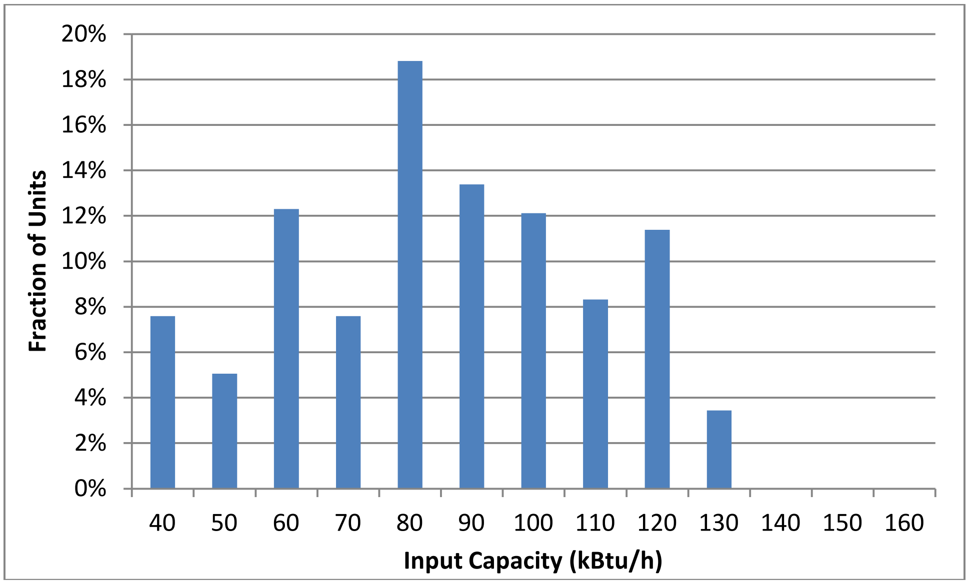

Figure 7-G.4.2 Number of Non-Weatherized Gas Furnace (Condensing) Models by Input Capacity

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

The effect of amended standards on individual customers usually includes a reduction in operating cost and an increase in purchase cost. This chapter describes two metrics used in the analysis to determine the economic impact of standards on individual residential consumers.

- Life-cycle cost (LCC) is the total customer cost over the life of an appliance or product, including purchase costs and operating costs (which in turn include maintenance, repair, and energy costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance or product.
- Payback period (PBP) measures the amount of time it takes customers to recover the assumed higher purchase price of more energy-efficient products through reduced operating costs.

The U.S. Department of Energy (DOE) conducted the LCC and PBP analysis using a spreadsheet model developed in Microsoft Excel. When combined with Crystal Ball (a commercially available software program), the LCC and PBP model generates a Monte Carlo simulation to perform the analysis by incorporating uncertainty and variability considerations in certain of the key parameters as discussed further in section 8.1.1.

Inputs to the LCC and PBP analysis of furnace fan products are discussed in sections 8.2 and 8.3 respectively. Results for each metric are presented in section 8.4. Key variables and calculations are presented for each metric. The calculations discussed here were performed with a series of Microsoft Excel spreadsheets that are accessible over the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans.html).

Details of the spreadsheets and instructions for using them are discussed in appendix 8-A.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

In recognition of the fact that each building using furnace fans is unique, variability and uncertainty are analyzed by performing the LCC and PBP calculations detailed here for a representative sample of individual households and commercial buildings. The results are expressed as the number of buildings experiencing economic impacts of different magnitudes. The LCC and PBP model was developed using Microsoft Excel spreadsheets combined with Crystal Ball. The LCC and PBP analysis explicitly model both the uncertainty and the variability in the model's inputs using Monte Carlo simulation and probability distributions (see appendix 8-B).

The LCC analysis used the estimated energy use for each furnace fan unit as described in the energy use analysis in chapter 7. Energy use of furnace fans is sensitive to climate and therefore varies by location within the United States. Aside from energy use, other important factors influencing the LCC and PBP analysis include energy prices, installation costs, product distribution markups, and sales taxes. The LCC spreadsheets explicitly modeled both the uncertainty and the variability in the model's inputs.

As mentioned previously, DOE generated LCC and PBP results as probability distributions using a simulation based on Monte Carlo analysis methods, in which certain key inputs to the analysis consist of probability distributions rather than single-point values. Therefore, the outcomes of the Monte Carlo analysis can also be expressed as probability distributions. As a result, the Monte Carlo analysis produces a range of LCC and PBP results. A distinct advantage of this type of approach is that DOE can identify the percentage of customers achieving LCC savings or attaining certain PBP values due to an increased efficiency level, in addition to the average LCC savings or average PBP for that efficiency level.

The LCC and PBP results are displayed as distributions of impacts compared to a market base case. As described in chapter 7, the market base case efficiency level is for 2019 and is defined as a mix of furnace fan efficiency levels reflecting the expected distribution of efficiency levels by product class.

8.1.2 Overview of Life-Cycle Cost and Payback Period Analysis Inputs

The LCC is the total customer cost over the life of the product, including purchase price (including retail markups, sales taxes, and installation costs) and operating cost (including repair costs, maintenance costs, and energy cost). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. The PBP is the increase in purchase cost of a higher efficiency product divided by the change in annual operating cost of the product. It represents the number of years that it will take the customer to recover the increased purchase cost through decreased operating costs. In the calculation of PBP, future costs are not discounted.

Inputs to the LCC and PBP analysis are categorized as: (1) inputs for establishing the purchase cost, otherwise known as the total installed cost; and (2) inputs for calculating the operating cost (*i.e.*, energy, maintenance, and repair costs).

The primary inputs for establishing the total installed cost are:

- *Baseline manufacturer selling price*: The baseline manufacturer selling price (MSP) is the price charged by the manufacturer to a wholesaler for product meeting existing minimum efficiency (or baseline) standards. The MSP includes a markup that converts the cost of production (*i.e.*, the manufacturer cost) to a MSP.
- *Standard-level manufacturer selling price increase*: The standard-level MSP is the incremental change in MSP associated with producing product at each of the higher standard levels.
- *Markups and sales tax*: Markups and sales tax are the wholesaler and contractor margins and state and local retail sales taxes associated with converting the MSP to a customer price.

- *Installation cost*: Installation cost is the cost to the customer of installing the product. The installation cost represents all costs required to install the product but does not include the marked-up customer product price. The installation cost includes labor, overhead, and any miscellaneous materials and parts.

The primary inputs for calculating the operating cost are:

- *Product energy consumption*: The product energy consumption is the site energy use associated with the use of the furnace fan units to provide space conditioning to the building.
- *Energy Prices*: Electricity, natural gas, liquid petroleum gas (LPG), and fuel oil prices are determined using average monthly energy prices.
- *Electricity, natural gas, and fuel oil price trends*: The Energy Information Administration's (EIA's) *Annual Energy Outlook 2012* (*AEO 2012*)[1] is used to forecast electricity prices into the future. For the results presented in this chapter, DOE used the *AEO 2012* reference case to forecast future energy prices.
- *Maintenance costs*: The labor and material costs associated with maintaining the operation of the.
- *Repair costs*: The labor and material costs associated with repairing or replacing components that have failed.
- *Lifetime*: The age at which the furnace housing the furnace fan is retired from service.
- *Discount rate*: The rate at which future costs and savings are discounted to establish their present value.

Figure 8.1.1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP.

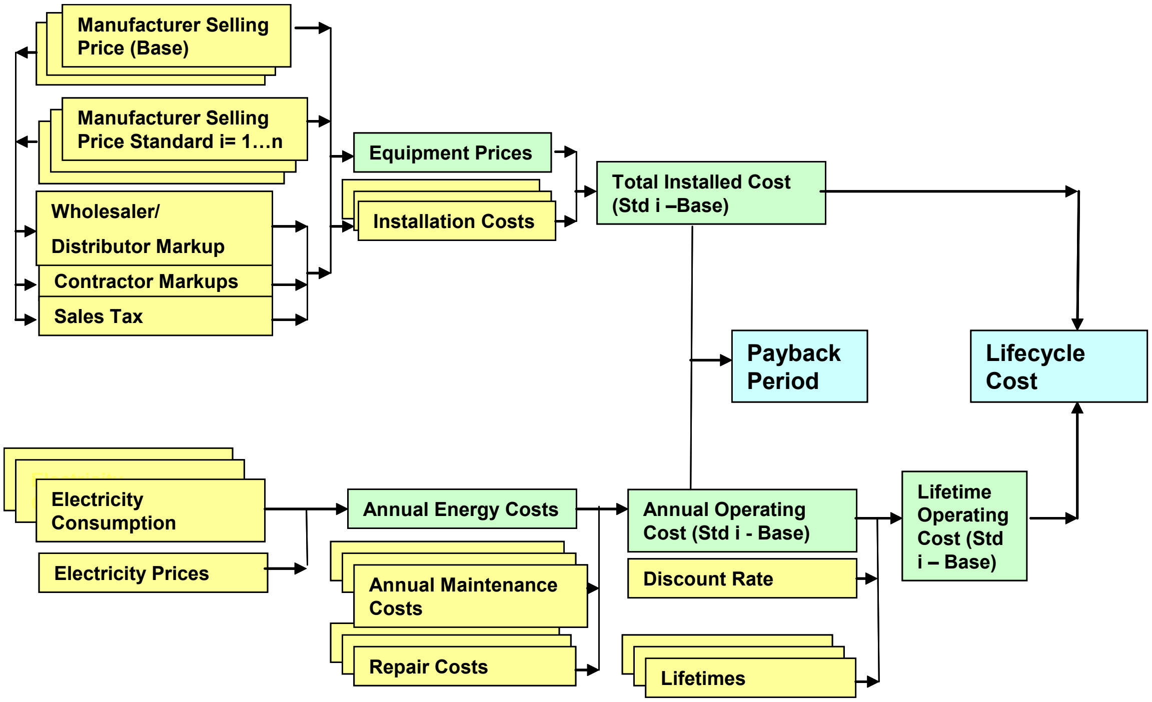

Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.1 provides descriptions of the various inputs to the calculation of the LCC and PBP. As noted earlier, most of the inputs are characterized by probability distributions that capture variability in the input variables.

Table 8.1.1 Summary of Inputs and Key Assumptions Used in the LCC and PBP Analysis

Inputs	Description
Affecting Installed Costs	
Product Price	Derived MSP for furnace fan units at different heating and air conditioning input capacities (from the engineering analysis) and multiplied by wholesaler markups and contractor markups plus sales tax (from markups analysis). Used the probability distribution for the different markups to describe their variability.
Installation Cost	Includes installation labor derived from *RS Means Residential Cost Data 2012*.[2] Overhead and materials costs and profits are assumed to be included in the contractor's markup. Thus, the total installed cost equals the consumer product price (manufacturer cost multiplied by the various markups plus sales tax) plus the installation cost.
Affecting Operating Costs	
Annual Energy Use	See chapter 7.
Energy Efficiency	The fan efficiency ratio (FER) is the efficiency descriptor for furnace fans. Furnace and air conditioning test procedure algorithms as well as furnace fan performance characteristics are used to determine the annual energy consumption associated with a particular standard level.
Energy Prices	Costs were calculated for RECS 2009 households from monthly marginal

	average electricity and natural gas, LPG, or fuel oil prices in each of 30 states and groups of states in RECS 2009.[a] Residential prices were escalated by the *AEO 2012* forecasts to estimate future electricity prices. Escalation was performed at the census division level and aggregated to the regions used in the study.
Maintenance Cost	The cost associated with maintaining the operation of the product (*e.g.*, checking blower). Annual maintenance cost does not change as a function of MSP.
Repair Cost	Estimated the annualized repair cost for baseline efficiency furnace product, based on costs of major repair (such as motor replacement), from a variety of published sources. It is assumed that repair costs would vary for higher efficiency levels.
Affecting Present Value of Annual Operating Cost Savings	
Product Lifetime	Used the probability distribution of lifetimes developed for furnaces.
Discount Rate	Mean real discount rates ranging from 0 percent to 10.7 percent for various classes of residential customers based on Federal Reserve Board's *Survey of Consumer Finances*. Probability distributions are used for the discount rates.
Date Standard Becomes Effective	2019 (5 years after expected publication of the final rule)

All of the inputs depicted in Figure 8.1.1 and summarized in Table 8.1.1 are discussed in sections 8.2 and 8.3.

8.1.3 Use of Residential Energy Consumption Survey in Life-Cycle Cost and Payback Period Analysis

The LCC and PBP calculations detailed here are for a representative sample of individual households. All furnace equipment is assumed to be for residential buildings.

The Energy Information Administration's 2009 Residential Energy Consumption Survey (2009 RECS)[3] serves as the basis for determining the representative sample. The 2009 RECS is based on a sample of 12,083 households that were surveyed for information on their housing units, energy consumption and expenditures, stock of energy-consuming appliances, and energy-related behavior. Information was also collected on certain demographic and economic characteristics of household members. The information collected represents all households nationwide—approximately 113.6 million. The RECS consists of three parts:

- Personal interviews with households for information about energy used, how it is used, energy-using appliances, structural features, energy efficiency measures, and demographic characteristics of the household.

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[a] RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. See Appendix 7-A for more details.

- Telephone interviews with rental agents for households that have any of their energy use included in their rent. This information augments information collected from those households that may not be knowledgeable about the fuels used for space heating or water heating.
- Mail questionnaires sent to energy suppliers (after obtaining permission from households) to collect the actual billing data on energy consumption and expenditures.

Of the 12,083 households surveyed in the 2009 RECS, 4,839 households representing 40.0% of the housing population have a gas furnace (non-weatherized or weatherized), 1,849 representing 15.3% of the housing population have an electric furnace, 156 representing 1.3% of the housing population have a manufactured home gas furnace, 293 representing 2.4% of the housing population have an oil-fired furnace, and 149 representing 1.2% of the housing population have a manufactured home electric furnace. Using the households in RECS that utilize each type of furnace, an LCC and PBP analysis is performed on a household-by-household basis. Each RECS household has an associated household weight representing the number of similar households in the nation.

Of the inputs necessary for the LCC and PBP analysis, there are three inputs that are based on data from the 2009 RECS: (1) space-conditioning annual energy consumption, (2) product efficiency, and (3) average electricity price. Each household in RECS with a furnace has a unique value for the space-conditioning annual energy consumption, the average electricity price, and the marginal electricity price. In other words, the annual energy consumption and average electricity price associated with a particular RECS household are not uncertain and are, therefore, not expressed with probability distributions. Although those three input variables are not uncertain, they are extremely variable. Due to the large number of households considered in the LCC and PBP analysis (almost 5,000 for gas furnaces), the range of annual energy use, average electricity price, and marginal electricity price is quite large. Thus, although these three input variables are not uncertain for any particular household, their variability across all households contributes significantly to the range of LCCs and PBPs calculated for any particular standard level.

8.2 LIFE-CYCLE COST ANALYSIS INPUTS

Life-cycle cost is the total customer cost over the life of a product, including purchase cost and operating costs (which are composed of energy costs, maintenance costs, and repair costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the product. Life-cycle cost is defined by the following equation:

$$LCC = IC + \sum_{t=1}^{N} OC_t / (1+r)^t \qquad \textbf{Eq. 8.2.1}$$

Where:

LCC = life-cycle cost (\$),
IC = total installed cost (\$),

$\sum$ = sum over the lifetime, from year 1 to year N, where N = lifetime of product (years),
OC = operating cost (\$),
r = discount rate, and
t = year for which operating cost is being determined.

DOE expresses all the costs in 2012\$. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. In the LCC analysis, the year of product purchase is assumed to be 2019, the effective date of the energy conservation standards for furnace fans.

8.2.1 Total Installed Cost Inputs

The total installed cost to the consumer is defined by the following equation:

$$IC = EQP + INST \qquad \textbf{Eq. 8.2.2}$$

Where:

EQP = product price (\$) (*i.e.*, customer price for the product only), and
$INST$ = installation cost (\$) (*i.e.*, the cost for labor and materials).

The product price is based on the distribution channel through which the customer purchases the product. As discussed in chapter 6, DOE defined one major distribution channel for new units to describe how the product passes from the manufacturer to the customer: the manufacturer sells the product to a wholesaler or distributor, who sells to a mechanical contractor hired by a general contractor. The general contractor purchases and installs the product on behalf of the customer and adds its markup to the mechanical contractor's price. Replacement products follow the same distribution channel, except that there is no general contractor. Instead, the mechanical contractor takes on the general contractor's function.

The remainder of this section provides information about the variables DOE used to calculate the total installed cost for furnace fan products.

8.2.1.1 Manufacturer Costs

DOE developed the manufacturer costs for furnace fans as described in chapter 5, Engineering Analysis. The manufacturer costs at each efficiency level for the representative characteristics of 1200 CFM furnace fan size and 70 kBtu/h input capacity (120 kBtu/h input capacity for oil furnaces) are shown in Table 8.2.1.

Table 8.2.1 Manufacturer Production Cost for Furnace Fans by Efficiency Level

Efficiency Level		Non-Weatherized Gas and Weatherized Gas Furnace Fans		Electric Furnace/Modular Blower Fans		Oil Furnace Fans	
		Total Cost (2012$)	Incremental Cost (2012$)	Total Cost (2012$)	Incremental Cost (2012$)	Total Cost (2012$)	Incremental Cost (2012$)
0	Baseline PSC	$81.11	-	$81.11	-	$99.24	-
1	Improved PSC	$86.90	$5.79	$86.90	$5.79	$108.04	$8.80
2	Inverter-driven PSC	$111.11	$30.00	$111.11	$30.00	$141.53	$42.29
3	Constant-torque BPM motor	$113.71	$32.60	$113.71	$32.60	$146.17	$46.93
4	Constant-torque BPM motor + multi-stage	$147.70	$66.59	$118.61	$37.50	$181.93	$82.69
5	Constant-airflow BPM motor + multi-stage	$212.00	$130.89	$182.92	$101.81	$269.18	$169.94
6	Constant-airflow BPM motor + multi-stage + backward-curved impeller	$229.56	$148.45	$200.47	$119.36	$287.05	$187.81

In order to capture variations in manufacturer production costs, DOE derived manufactured cost adders for different furnace fan size and input capacity.

8.2.1.2 Markups

For a given distribution channel, the overall markup is the value determined by multiplying all the associated markups and the applicable sales tax together to arrive at a single overall distribution chain markup value. The overall markup is multiplied times the baseline or standard-compliant manufacturer cost to arrive at the price paid by the customer. Because there are baseline and incremental markups associated with the wholesaler and mechanical contractor, the overall markup is also divided into a baseline markup (*i.e.*, a markup used to convert the baseline manufacturer price into a customer price) and an incremental markup (*i.e.*, a markup used to convert a standard-compliant manufacturer cost increase due to an efficiency increase into an incremental customer price). Markups can differ depending on whether the product is being purchased for a new construction installation or is being purchased to replace an existing product. DOE developed the overall baseline markups and incremental markups for both new construction and replacement applications as a part of the markups analysis (chapter 6 of the TSD).

Based on the percentages of the market attributed to each distribution channel, Table 8.2.2 and Table 8.2.3 display the weighted-average overall markups and their associated components for the baseline and incremental markups, respectively.

Table 8.2.2 Summary of National Average Markups on Non-Manufactured Home Furnace Fans

	Baseline Markup	Incremental Markup
Manufacturer	1.19 to 1.35 (see Table 6.3.1 in chapter 6)	
Wholesaler	1.37	1.10
Mechanical Contractor (new construction/replacement)	1.43/1.54	1.15/1.23
General Contractor (new construction only)	1.47	1.34
Sales Tax (replacement only)	1.07	1.07

Table 8.2.3 Summary of National Average Markups on Manufactured Home Furnace Fans

	Baseline Markup	Incremental Markup
Manufacturer	1.15 to 1.25 (see Table 6.3.1 in chapter 6)	
Wholesaler (replacement only)	1.37	1.10
Mechanical Contractor (replacement only)	1.54	1.23
Manufactured Home Manufacturer (new construction only)	1.41	1.28
Manufactured Home Dealer (new construction only)	1.30	1.17
Sales Tax (replacement only)	1.07	1.07

Because the relative importance of new construction and replacements in total shipments varies among the product classes, the total markup varies as well (Table 8.2.4).

Table 8.2.4 Overall Markup for Furnace Fans by Product Class

Product Class	Baseline Markup	Incremental Markup
Non-Weatherized, Non-Condensing Gas Furnaces	3.18	2.00
Non-Weatherized, Condensing Gas Furnaces	3.11	1.96
Weatherized Gas Furnace	3.08	1.95
Oil Furnace	3.09	1.96
Electric Furnace / Modular Blower	2.84	1.80
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	2.55	1.84
Manufactured Home Non-Weatherized, Condensing Gas Furnaces	2.54	1.83
Manufactured Home Electric Furnace /Modular Blower	2.32	1.69

8.2.1.3 Total Consumer Price

DOE derived the consumer product price for the efficiency levels above the baseline by taking the product of the baseline manufacturer cost and the baseline overall markup (including the sales tax) and adding to it the product of the incremental manufacturer cost and the incremental overall markup (including the sales tax). Markups and the sales tax all can take on a variety of values, depending on location, so the resulting total installed cost for a particular efficiency level is represented by a distribution of values.

Table 8.2.5 presents the average consumer product price for each furnace product class at each efficiency level examined.

Table 8.2.5 Average Consumer Price for Furnace Fans Used in HVAC Products (2012$)

	Efficiency Level						
Key Product Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**
	Baseline PSC	Improved PSC	Inverter -driven PSC	Constant -torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward -curved impeller
Non-weatherized, Non-condensing Gas Furnace Fan	$294	$306	$354	$365	$433	$572	$607
Non-weatherized, Condensing Gas Furnace Fan	$285	$296	$343	$353	$420	$557	$592
Weatherized Gas Furnace Fan	$281	$292	$339	$349	$415	$550	$584
Oil Furnace Fan	$333	$350	$416	$428	$498	$693	$728
Electric Furnace / Modular Blower Fan	$199	$209	$253	$252	$260	$372	$404
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	$211	$222	$267	$272	$335	$455	$488
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	$223	$234	$278	$286	$348	$474	$506
Manufactured Home Electric Furnace / Modular Blower Fan	$155	$165	$206	$203	$211	$313	$343

8.2.1.4 Future Product Prices

In DOE's 2011 central air conditioning, heat pump, and furnace standards rulemaking,[4] it derived a forecast of future furnace prices based on an analysis of the historic trend in the producer price index (PPI) for furnaces. DOE believes that using the same trend for furnace fans would not be appropriate, however, as the fan does not make up a major part of the total cost of a furnace. Because the fan motor is the most important component of the furnace fan, DOE believes that historic prices of electric motors provide a more reasonable basis for considering trends in the price of furnace fans.

DOE obtained historical PPI data for fractional horsepower motorsmanufacturing spanning the time period 1967-2012 from the Bureau of Labor Statistics' (BLS).[b] The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for fractional horsepower motors and generators manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index (see Figure 8.2.1).

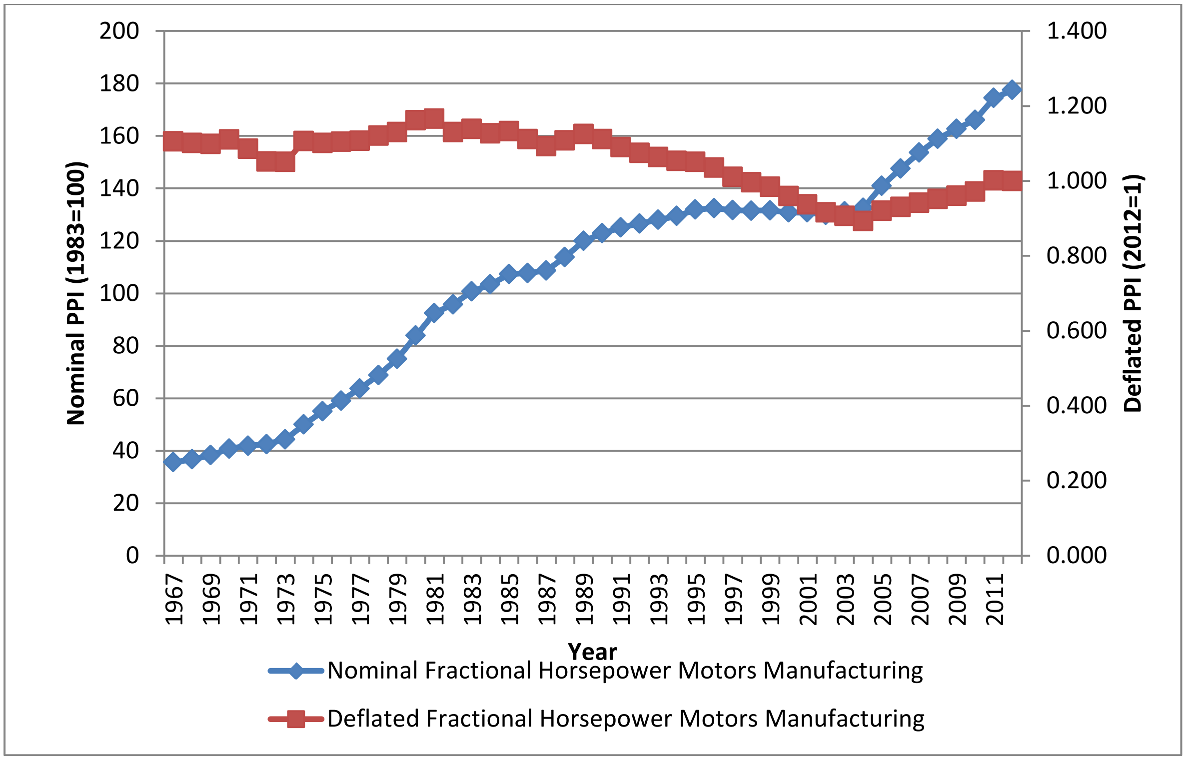

Figure 8.2.1 Historical Nominal and Deflated Producer Price Indexes for Fractional Horsepower Motors Manufacturing

From the mid-1960s to 1989, the deflated price index for electric motors was roughly flat. From 1989 to 2004, the deflated price index for fractional horsepower electric motors was decreasing. Since then, the index has risen, primarily due to rising prices of copper and steel products that are used in motors. The rising prices for copper and steel products were primarily a result of strong demand from China and other emerging economies. Given the slowdown in global economic activity in recent years, DOE believes that the extent to which the trends of the past five years will continue is very uncertain. DOE performed an exponential fit on the deflated price index for electric motors, but the R^2 was relatively low (0.5). DOE also considered the experience curve approach, in which an experience rate parameter is derived using two historical data series on price and cumulative production, but the time series for historical shipments was not long enough for a robust analysis.

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[b] Series ID PCU3353123353121; http://www.bls.gov/ppi/

Given the above considerations, DOE decided to use constant prices as the default price assumption to project future motor prices. Thus, projected prices for the LCC and PBP analysis are equal to the 2012 values for each efficiency level in each product class.

8.2.1.5 Installation Cost

Because furnace fans are installed in furnaces in the factory, there is generally no additional installation cost at the home. However, furnace fans that employ a constant-airflow brushless permanent magnet (BPM) design may require additional installation costs. DOE assumed that all constant-airflow BPM furnace fan installations will require extra labor at startup to check and adjust airflow.

DOE's analysis of installation costs accounts for regional differences in labor costs. DOE estimated the installation costs using a variety of sources, including RS Means 2012 Residential Cost Data[2] , manufacturer literature, and information from expert consultants. For a detailed discussion of the development of installation costs, see appendix 8-D, Installation, Repair, and Maintenance Cost Calculations.

8.2.1.6 Total Installed Cost

The total installed cost is the sum of the product price and the installation cost. MSPs, markups, and sales taxes all can take on a variety of values, depending on location, so the resulting total installed cost for a particular efficiency level will not be a single-point value, but rather a distribution of values. Table 8.2.6 presents the average total installed cost for each furnace product class at each efficiency level examined.

Table 8.2.6 Average Total Installed Cost for Furnace Fans Used in HVAC Products (2012$)

	Efficiency Level						
Key Product Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**
	Baseline PSC	Improved PSC	Inverter -driven PSC	Constant -torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward -curved impeller
Non-Weatherized, Non-Condensing Gas Furnace Fan	$343	$354	$403	$414	$496	$662	$697
Non-Weatherized, Condensing Gas Furnace Fan	$339	$351	$398	$408	$490	$658	$692
Weatherized Gas Furnace Fan	$329	$340	$387	$397	$476	$636	$670
Oil Furnace Fan	$387	$404	$470	$482	$570	$798	$833
Electric Furnace / Modular Blower Fan	$241	$252	$295	$294	$315	$450	$482
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fan	$254	$265	$310	$315	$391	$537	$569
Manufactured Home Non-Weatherized, Condensing Gas Furnace Fan	$271	$282	$326	$334	$410	$564	$597
Manufactured Home Electric Furnace / Modular Blower Fan	$192	$202	$243	$241	$259	$382	$412

8.2.2 Operating Cost Inputs

DOE defined the operating cost by the following equation:

$$OC = EC + RC + MC \qquad \textbf{Eq. 8.2.3}$$

Where:

OC = operating cost ($),
EC = energy cost associated with operating the product ($),
RC = repair cost associated with component failure ($), and

MC = annual maintenance cost for maintaining product operation (\$).

The remainder of this section provides information about the variables that DOE used to calculate the operating cost for furnace fans. The annual energy costs of the product are computed from energy consumption per unit for the baseline and standard-compliant cases (efficiency level 2, 3, and so on), combined with the energy prices. Product lifetime, discount rate, and compliance date of the standard are required for determining the operating cost and for establishing the operating cost present value.

8.2.2.1 Annual Energy Use Savings

For each key product class, DOE calculated the annual energy use savings for each sample household at each efficiency level as described in chapter 7. DOE accounted for additional energy use required for space heating due to more-efficient furnace fans, as well as reductions in energy use required for air conditioning.

DOE considered the possibility that some consumers may use a higher efficiency furnace fan more than a baseline furnace fan, thereby negating some or all of the energy savings from the more efficient fan. Such change in behavior when operating costs decline is known as a rebound effect.

DOE reviewed an evaluation report from Wisconsin[5] that indicates that a considerable number of homeowners who purchase constant-airflow BPM furnaces significantly increase the frequency with which they operate their furnace fan subsequent to the installation of the constant-airflow BPM furnace. To estimate a rebound effect that would apply to the national household sample, DOE calculated a separate rebound effect for each product class and efficiency level based on the increase of constant circulation fan use that can be expected for constant-airflow BPM furnaces. See chapter 10 for further details.

The take-back in energy consumption associated with the rebound effect provides consumers with increased value (*e.g.,* enhanced comfort associated with use of constant circulation). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect, as measured in the LCC analysis, are the same.

8.2.2.2 Energy Prices

DOE derived average monthly energy prices for a number of geographic areas in the United States using the latest data from EIA and monthly energy price factors that it developed. DOE assigned an appropriate price to each household in the sample, depending on its location.

EIA Data. DOE derived 2011 annual electricity prices from EIA Form 826 data.[6] The EIA Form 826 data include energy prices by State. DOE calculated annual electricity prices for each region by averaging monthly energy prices by State to get State electricity prices. For areas with more than one State, DOE weighted each State's average price by its number of households in 2019. Table 8.2.7 shows the electricity prices by region. (See appendix 8-C for more details)

DOE obtained the data for natural gas prices from EIA's Natural Gas Navigator,[7] which includes monthly natural gas prices by State for residential, commercial, and industrial customers. For areas with more than one State, DOE weighted each State's average price by its number of households in 2019. Table 8.2.8 shows the natural gas prices by region. (See appendix 8-C for more details)

Table 8.2.7 Average Residential Electricity Prices in 2011

	Geographic Area	**2012$/kWh**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$0.171
2	Massachusetts	$0.151
3	New York	$0.186
4	New Jersey	$0.166
5	Pennsylvania	$0.137
6	Illinois	$0.121
7	Indiana, Ohio	$0.112
8	Michigan	$0.134
9	Wisconsin	$0.134
10	Iowa, Minnesota, North Dakota, South Dakota	$0.108
11	Kansas, Nebraska	$0.103
12	Missouri	$0.099
13	Virginia	$0.109
14	Delaware, District of Columbia, Maryland	$0.138
15	Georgia	$0.112
16	North Carolina, South Carolina	$0.108
17	Florida	$0.119
18	Alabama, Kentucky, Mississippi	$0.105
19	Tennessee	$0.101
20	Arkansas, Louisiana, Oklahoma	$0.094
21	Texas	$0.115
22	Colorado	$0.114
23	Idaho, Montana, Utah, Wyoming	$0.091
24	Arizona	$0.111
25	Nevada, New Mexico	$0.116
26	California	$0.155
27	Oregon, Washington	$0.090
28	Alaska	$0.180
29	Hawaii	$0.354
30	West Virginia	$0.097

Table 8.2.8 Average Residential Natural Gas Prices in 2011

	Geographic Area	2012$/MMBtu
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$15.87
2	Massachusetts	$14.05
3	New York	$15.69
4	New Jersey	$12.53
5	Pennsylvania	$14.60
6	Illinois	$10.86
7	Indiana, Ohio	$13.04
8	Michigan	$11.64
9	Wisconsin	$10.79
10	Iowa, Minnesota, North Dakota, South Dakota	$10.27
11	Kansas, Nebraska	$12.12
12	Missouri	$16.58
13	Virginia	$15.21
14	Delaware, District of Columbia, Maryland	$14.95
15	Georgia	$19.25
16	North Carolina, South Carolina	$16.34
17	Florida	$19.74
18	Alabama, Kentucky, Mississippi	$14.46
19	Tennessee	$12.98
20	Arkansas, Louisiana, Oklahoma	$14.56
21	Texas	$12.89
22	Colorado	$9.68
23	Idaho, Montana, Utah, Wyoming	$9.13
24	Arizona	$17.29
25	Nevada, New Mexico	$11.18
26	California	$10.17
27	Oregon, Washington	$12.96
28	Alaska	$8.98
29	Hawaii	$55.28
30	West Virginia	$12.84

DOE collected 2011 average LPG prices from EIA's 2011 State Energy Consumption, Price, and Expenditures Estimates (SEDS).[8] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one State, DOE weighted each State's average price by its number of households. See Table 8.2.9. Appendix 8-C includes more details.

Table 8.2.9 Average Residential LPG Prices in 2011

	Geographic Area	**2012$/MMBtu**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$35.85
2	Massachusetts	$38.37
3	New York	$34.92
4	New Jersey	$36.65
5	Pennsylvania	$31.92
6	Illinois	$24.35
7	Indiana, Ohio	$26.15
8	Michigan	$24.30
9	Wisconsin	$23.12
10	Iowa, Minnesota, North Dakota, South Dakota	$24.35
11	Kansas, Nebraska	$24.29
12	Missouri	$23.89
13	Virginia	$27.78
14	Delaware, District of Columbia, Maryland	$36.63
15	Georgia	$28.74
16	North Carolina, South Carolina	$30.27
17	Florida	$41.59
18	Alabama, Kentucky, Mississippi	$29.80
19	Tennessee	$30.17
20	Arkansas, Louisiana, Oklahoma	$28.08
21	Texas	$31.13
22	Colorado	$27.01
23	Idaho, Montana, Utah, Wyoming	$27.46
24	Arizona	$35.95
25	Nevada, New Mexico	$33.21
26	California	$34.70
27	Oregon, Washington	$29.70
28	Alaska	$39.26
29	Hawaii	$65.33
30	West Virginia	$29.50

DOE collected 2011 average fuel oil prices from EIA's SEDS. [8] SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one State, DOE weighted each State's average price by its number of households. See Table 8.2.10. Appendix 8-C includes more details.

Table 8.2.10 Average Residential Fuel Oil Prices in 2011

	Geographic Area	**2012$/MMBtu**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$25.65
2	Massachusetts	$25.71
3	New York	$26.12
4	New Jersey	$26.71
5	Pennsylvania	$26.43
6	Illinois	$27.72
7	Indiana, Ohio	$27.67
8	Michigan	$27.66
9	Wisconsin	$27.41
10	Iowa, Minnesota, North Dakota, South Dakota	$27.72
11	Kansas, Nebraska	$27.66
12	Missouri	$27.20
13	Virginia	$27.41
14	Delaware, District of Columbia, Maryland	$26.26
15	Georgia	$27.14
16	North Carolina, South Carolina	$27.53
17	Florida	$27.66
18	Alabama, Kentucky, Mississippi	$26.22
19	Tennessee	$27.93
20	Arkansas, Louisiana, Oklahoma	$26.00
21	Texas	$25.69
22	Colorado	$25.39
23	Idaho, Montana, Utah, Wyoming	$25.81
24	Arizona	$28.64
25	Nevada, New Mexico	$27.29
26	California	$28.96
27	Oregon, Washington	$27.99
28	Alaska	$26.87
29	Hawaii	$27.95
30	West Virginia	$27.66

Monthly Prices. To determine monthly prices for use in the analysis, DOE developed monthly energy price factors for each fuel based on long-term price data. See appendix 8-C, for a description of the method. DOE multiplied the annual prices shown in the previous tables by the monthly price factors for each fuel to derive prices for each month.

Electricity and Natural Gas Marginal Prices. Electricity and natural gas prices were adjusted using seasonal marginal price factors to come up with monthly marginal electricity and natural gas prices. For a detailed discussion of the development of marginal energy price factors, see appendix 8-C.

Household Energy Price Adjustment Factor. RECS 2009 reports the total annual consumption and expenditure of each energy use type. From this data DOE determined average energy prices per geographical area. To take into account that household energy prices vary inside a geographical area, DOE developed an adjustment factor based on the reported average energy price in RECS 2009 divided by the average energy price of the geographical region. This factor was then multiplied times the monthly marginal energy prices (for natural gas and electricity) or the monthly price developed above to come up with the household energy price. Appendix 8-C includes more details.

8.2.2.3 Energy Price Trends

To arrive at prices in future years, DOE multiplied the prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2012.*[1] Figure 8.2.2 shows the national residential electricity price trend. To estimate the trend after 2035, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2020–2035 for electricity, natural gas, and LPG.

DOE used *AEO 2012* Reference Case scenarios[c] for the nine census divisions. DOE applied the projected energy price for each of the nine census divisions to each household in the sample based on the household's location. Appendix 8-C includes more details.

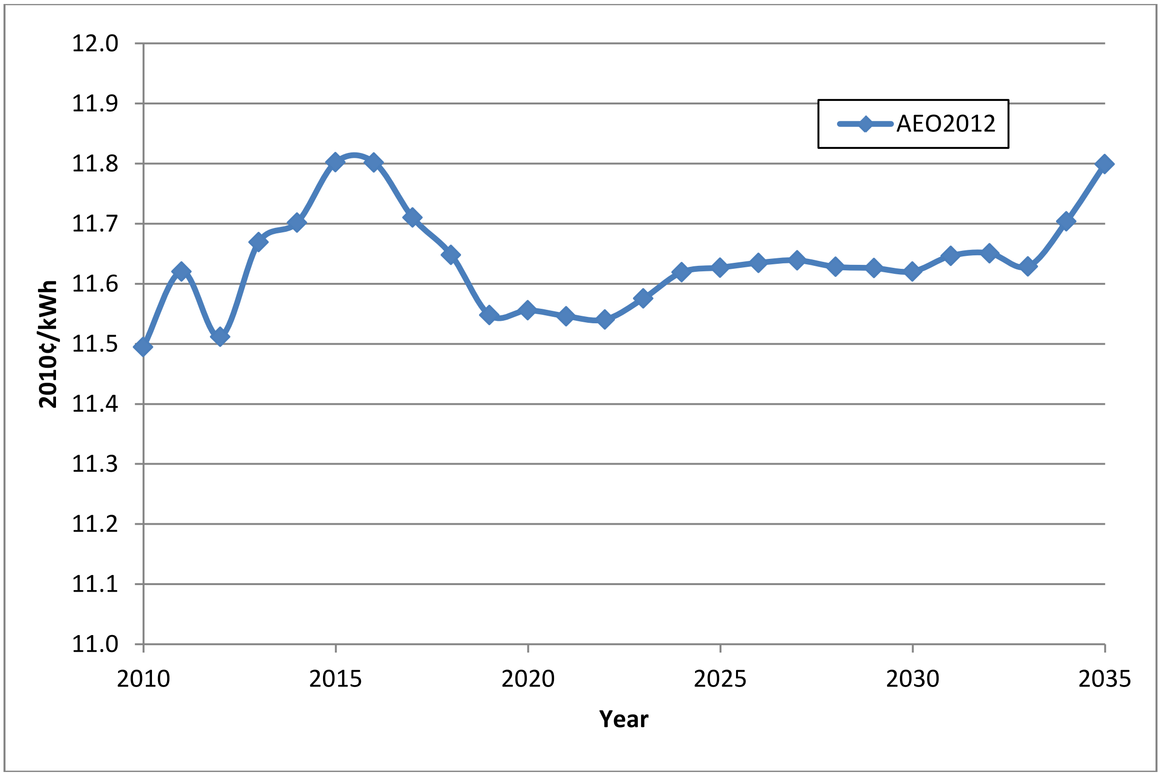

Figure 8.2.2 Projected Electricity Price

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[c] The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. DOE conducted sensitivity analyses using alternative economic growth scenario assumptions (see appendix 8-G).

8.2.2.4 Repair Cost

The repair cost is the cost to the consumer for replacing or repairing components in the furnace fan that have failed. DOE included motor replacement as a repair cost for a fraction of furnace fans. To estimate rates of motor failure, DOE developed a distribution of fan motor lifetime (expressed in operating hours) by motor size using data from DOE's analysis for small electric motors and manufacturer literature.[9] DOE then paired these data with the calculated number of annual operating hours for each sample furnace fan. Motor costs were based on costs developed in the engineering analysis and the replacement markups developed in the markup analysis. DOE assumed that the motor cost does not apply if motor failure occurs during the furnace warranty period (assumed to be at least one year and 5 or more years for a fraction of installations).

The repair costs at each considered efficiency level were based on *2012 RS Means Facilities Maintenance and Repair Data*[10] and a consultant report. DOE accounts for regional differences in labor costs. For a detailed discussion of the development of repair costs, see appendix 8-D, Installation, Repair, and Maintenance Cost Calculations.

Table 8.2.11 shows the annualized repair cost estimates for each product class.

Table 8.2.11 Annualized Repair Cost for Furnace Fans Used in HVAC Products (2012$)

Key Product Class	Efficiency Level						
	0	1	2	3	4	5	6
	Baseline PSC	Improved PSC	Inverter-driven PSC	Constant-torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + BC impeller
Non-weatherized, Non-condensing Gas Furnace Fan	$5.96	$6.09	$6.77	$6.93	$9.06	$12.13	$12.60
Non-weatherized, Condensing Gas Furnace Fan	$5.89	$6.02	$6.68	$6.83	$9.41	$12.68	$13.16
Weatherized Gas Furnace Fan	$6.42	$6.57	$7.29	$7.42	$9.41	$12.63	$13.15
Oil Furnace Fan	$4.91	$5.06	$5.75	$5.93	$8.46	$11.76	$12.14
Electric Furnace / Modular Blower Fan	$5.10	$5.23	$5.91	$5.89	$6.74	$9.45	$9.91
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	$3.86	$3.95	$4.47	$4.61	$6.57	$9.02	$9.38
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	$3.72	$3.81	$4.30	$4.44	$6.48	$8.93	$9.28
Manufactured Home Electric Furnace / Modular Blower Fan	$3.72	$3.82	$4.39	$4.38	$5.08	$7.33	$7.71

8.2.2.5 Maintenance Cost

The maintenance cost is the routine cost to the consumer of maintaining equipment operation. The regular furnace maintenance generally includes checking the furnace fan. DOE assumes that this maintenance cost is the same at all efficiency levels.

Labor hours and costs for annual maintenance were estimated using RS Means data. The frequency with which the maintenance occurs was derived from a consumer survey[11] on the frequency with which owners of different types of furnaces perform maintenance. For a detailed discussion of the development of maintenance costs, see appendix 8-D.

8.2.2.6 Lifetime

DOE defines lifetime as the age when a product is retired from service. Furnace fan lifetimes are considered to be equivalent to furnace lifetimes, so DOE modeled furnace fan lifetime based on estimated furnace lifetimes, which were developed for the recent furnace standards rulemaking.[d] In that analysis, DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of furnace lifetimes. For a detailed discussion of the development of furnace fan lifetime, see appendix 8-E, Furnace Fan Lifetime Determination.

Table 8.2.12 shows the minimum, median, and average lifetime, as well as the Weibull distribution parameters alpha and beta for each product class. DOE assumed that the lifetime of a furnace (and fan) is the same at different fan efficiency levels.

Table 8.2.12 Lifetime Parameters for Furnace Fans

Product Class	**Weibull Parameters**				
	Minimum *years*	**Median** *years*	**Average** *years*	**Alpha (scale)**	**Beta (shape)**
Gas and Electric Furnace Fans	1	22.6	23.6	26.68	2.218
Oil-Fired Furnace Fans	1	26.3	26.5	29.67	3.019

8.2.2.7 Discount Rates

The discount rate is the rate at which future expenditures are discounted to establish their present value. The appropriate discount rate to be used in the DOE analysis should equal the opportunity cost of funds used to purchase efficient appliances. The opportunity cost of funds in this case may include interest payments (on debt), interest returns (on assets), and forgone liquidity (on insured accounts).

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[d] http://www1.eere.energy.gov/buildings/appliance_standards/residential/residential_furnaces_cac_hp_direct_final_rule.html

Discount Rates for Replacement Products Purchased by Existing Households

DOE's approach involved identifying all possible debt or asset classes that might approximate the opportunity cost of funds used to purchase efficient appliances. These are shown in Table 8.2.13.

As a way of weighting the debt or asset classes, DOE estimated the average percentage shares of the various types of debt and equity using data from the Federal Reserve Board's *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.[12] DOE derived the mean percentages of each source of financing throughout the 7 years surveyed. These long-term averages are seen as most appropriate for use in the analysis.

Table 8.2.13 Types of Household Debt and Equity by Percentage Shares (%)

Type of Debt or Equity	**1989**	**1992**	**1995**	**1998**	**2001**	**2004**	**2007**	**2010**	**Mean**
Home equity loan	4.3	4.5	2.7	2.8	2.8	4.4	4.6	4.4	3.8
Credit card	1.6	2.1	2.6	2.2	1.7	2.0	2.4	2.1	2.1
Other installment loan	2.8	1.7	1.4	1.7	1.1	1.3	1.1	1.3	1.6
Other residential loan	4.4	6.9	5.2	4.3	3.1	5.8	7.1	7.3	5.5
Other line of credit	1.1	0.6	0.4	0.2	0.3	0.5	0.3	0.8	0.5
Checking account	5.8	4.7	4.9	3.9	3.6	4.2	3.4	4.3	4.4
Savings or money market account	19.2	18.8	14.0	12.8	14.2	15.1	13.0	16.2	15.4
Certificate of deposit	14.5	11.7	9.4	7.0	5.4	5.9	6.5	6.7	8.4
Savings bond	2.2	1.7	2.2	1.1	1.2	0.9	0.7	0.6	1.3
Bonds	13.8	12.3	10.5	7.0	7.9	8.4	6.7	7.3	9.2
Stocks	22.4	24.0	25.9	36.9	37.5	28.0	28.6	23.4	28.3
Mutual funds	8.0	11.1	20.9	20.1	21.3	23.4	25.5	25.6	19.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.

DOE then estimated return or interest rates associated with each type of equity and debt. The source for interest rates for loans, credit cards, and lines of credit was the Federal Reserve Board's Survey of Consumer Finances (SCF) for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010. Table 8.2.14 shows the average nominal rates in each year and the inflation factors used to calculate real rates. DOE calculated effective interest rates for home equity loans in a similar manner as for mortgage rates, because interest on both such loans is tax deductible. Table 8.2.15 shows the average effective real rates in each year and the mean rate across years. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2019.

Table 8.2.14 Average Nominal Interest Rates for Household Debt

Type of Debt	1989, %	1992, %	1995, %	1998, %	2001, %	2004, %	2007, %	2010, %	Mean, %
Home equity loan	11.5	9.6	9.6	9.8	8.7	5.7	7.9	6.0	8.6
Credit card*	-	-	14.2	14.5	14.2	11.7	12.6	13.9	13.5
Other installment loan	9.0	7.8	9.3	7.8	8.7	7.4	10.4	10.4	8.8
Other residential loan	8.8	7.6	7.7	7.7	7.5	6.0	6.3	6.0	7.2
Other line of credit	14.8	12.7	12.4	11.9	14.7	8.8	12.7	10.6	12.4
Inflation rate	4.82	3.01	2.83	1.56	2.85	2.66	2.85	1.64	

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, 2007 and 2010.
* No data on interest rates available for credit cards in 1989 or 1992.

Table 8.2.15 Average Real Effective Interest Rates for Household Debt

Type of Debt	1989, %	1992, %	1995, %	1998, %	2001, %	2004, %	2007, %	2010, %	Mean, %
Home equity loan	3.8	4.3	4.4	5.8	3.8	1.9	2.1	3.1	3.8
Credit card*	-	-	11.0	12.7	11.1	9.1	3.3	12.1	11.0
Other installment loan	4.9	5.8	7.0	6.6	6.1	5.4	9.7	9.0	6.7
Other residential loan	4.0	4.7	4.8	6.0	4.6	3.3	3.4	4.3	4.4
Other line of credit	9.6	9.4	9.3	10.2	11.7	6.0	9.7	8.8	9.4

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.
* No data on interest rates available for credit cards in 1989 or 1992.

No similar rate data are available from the SCF for classes of assets, so the Department derived that information from national historical data. The interest rates associated with certificates of deposit,[13] savings bonds,[14] and bonds (AAA corporate bonds)[15] were collected from Federal Reserve Board time-series data for 1977–2012. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts came from Cost of Savings Index data covering 1984–2012.[16] The rates for stocks are the annual returns on the Standard and Poor's 500 for 1977–2012.[17] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year for 1977–2012. DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.16. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2019.

Table 8.2.16 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Nominal Rate %	Average Real Rate %
Checking account	-	0.0
Savings and money market accounts	5.0	2.0
Certificate of deposit	6.0	1.9
Savings bond	7.3	3.2
Bonds	8.1	3.9
Stocks	11.9	7.7
Mutual funds	10.4	6.2

Table 8.2.17 summarizes the shares and mean real effective rates of each type of equity or debt. The average rate across all types of household debt and equity, weighted by the percentages of each type, is 5.0 percent.

Table 8.2.17 Average Shares and Rates for Household Debt and Equity

Type of Debt or Equity	Average Percentage of Household Debt plus Equity %*	Mean Effective Real Rate %**
Home equity loan	3.8	3.8
Credit card	2.1	11.0
Other installment loan	1.6	6.7
Other residential loan	5.5	4.4
Other line of credit	0.5	9.4
Checking account	4.4	0.0
Savings and money market account	15.4	2.0
Certificate of deposit	8.4	1.9
Savings bond	1.3	3.2
Bonds	9.2	3.9
Stocks	28.3	7.7
Mutual funds	19.5	6.2
Total/weighted-average discount rate	100.0	5.0

* Not including primary mortgage or retirement accounts.

** Adjusted for inflation and, for home equity loans, tax deduction of interest.

DOE developed a normal probability distribution of rates for each debt or asset type by using the mean value and standard deviation from the distribution. To account for variation among households, DOE sampled a rate for each household from the distributions for the appropriate asset class. Appendix 8-F presents the probability distributions for each class that DOE used in the LCC and PBP analysis.

Discount Rates for Products Installed in New Housing

DOE estimated discount rates for new-housing appliances using the effective real (after-inflation) mortgage rate for homebuyers. This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[e] For example, a 6% nominal mortgage rate has an effective nominal rate of 4.5% for a household at the 25% marginal tax rate. When adjusted for an inflation rate of 2%, the effective real rate becomes 2.45%.

The data sources DOE used for mortgage interest rates were the SCF in 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010. Using the appropriate SCF data for each year, DOE adjusted the mortgage interest rate for each relevant household in the SCF for mortgage tax deduction and inflation (see Table 8.2.18). In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

The average nominal mortgage rate carried by homeowners in these 6 years was 7.9%. As the mortgage rates carried by households in these years were established over a range of time, DOE believes they are representative of rates that may apply when amended standards take effect. After adjusting for inflation and interest tax deduction, effective real interest rates on mortgages across the six surveys averaged 3.0%.

Table 8.2.18 Data Used to Calculate Real Effective Mortgage Rates

Year	Mortgage Interest Rates in Selected Years %			
	Average Nominal Interest Rate	**Inflation Rate[18]**	**Marginal Tax Rate Applicable to Mortgage Interest[19]**	**Average Real Effective Interest Rate**
1989	9.7	4.82	24.1	2.4
1992	9.1	3.01	23.2	3.9
1995	8.2	2.83	24.2	3.3
1998	7.9	1.56	25.0	4.3
2001	7.6	2.85	24.2	2.8
2004	6.2	2.66	20.9	2.2
2007	6.3	2.85	20.6	2.1
2010	5.7	1.64	20.0	2.9
Average	7.6			**3.0**

To account for variation among households, DOE sampled a rate for each household in the RECS samples from a distribution of mortgage rates. DOE developed the distribution based on the SCF data. Appendix 8-F presents the probability distribution that DOE used in the LCC and PBP analysis.

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[e] Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1.

8.2.2.8 Compliance Date of Standard

Pursuant to 42 U.S.C. 6295(m), the compliance date of any new energy efficiency standard for furnace fans is 5 years after the final rule is published. Consistent with its published regulatory agenda, DOE assumed that the final rule would be issued at the end of 2013 and that, therefore, the new standards would require compliance beginning in 2019. DOE calculated the LCC and PBP for all consumers as if they each would purchase a new furnace fan in 2019.

8.2.2.9 Base Case Distribution of Efficiency Levels

Based on data provided by AHRI, BPM motor fan market share has increased from about 10 percent in 2005 to about 25 percent in 2011.[20] Based on this data and input from manufacturers,[21] DOE estimated a 35 percent share for BPM fans in 2019 out of the overall market for furnace fans.[f]

To estimate the market share for the different furnace fan product classes of BPM fans in 2019, DOE developed data on the share of models in each product class that are of the different BPM designs.[g] DOE believes that the current shares of models are a reasonable indication of where the market may be in several years.

For the permanent split capacitor (PSC) fan efficiency levels, DOE based the 2019 market shares on the current availability of models and FER calculations of some of these models. Based on FER calculations of PSC motors DOE tested or of models it had sufficient manufacturer product literature to calculate an FER value, 40 percent are at the baseline level and 60 percent are at the improved PSC level. There are currently no models of inverter-driven PSC, so DOE assumed zero market share.

To take into account differences between replacement and new construction markets, DOE made separate estimates of the BPM fan market shares in replacements and new homes using data from a Canadian survey in 2003.[22] The survey indicated that the market share of BPM fans in replacement applications was 3.7 times higher than the share in new homes.

Table 8.2.19 shows the market shares that were used in the LCC and PBP analysis for non-weatherized gas furnaces. The market shares used for the other key product classes may be found in the sheet "Base Case Fan Efficiency" in the furnace fan LCC spreadsheet.

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[f] AHRI stated that BPM market share would be from 35 percent to 45 percent by 2018, while Goodman estimated the BPM market share to be 30 percent in 2018.

[g] DOE used the AHRI Directory of Certified Furnace Equipment as well as manufacturer product literature.

Table 8.2.19 Base Case Market Shares (2019) by Efficiency Level for Fans in Non-Weatherized Gas Furnaces

Efficiency Level	Non-Condensing		Condensing	
	Replacements (%)	New Homes (%)	Replacements (%)	New Homes (%)
Baseline PSC	28%	46%	20%	43%
Improved PSC	42%	46%	30%	43%
Inverter-driven PSC	0%	0%	0%	0%
Constant-torque BPM motor	13%	4%	8%	2%
Constant-torque BPM motor + multi-stage	3%	1%	7%	2%
Constant-airflow BPM motor + multi-stage	14%	4%	35%	9%
Constant-airflow BPM motor + multi-stage + backward-curved impeller	0%	0%	0%	0%

8.2.2.10 Avoiding Double-Counting Savings Accounted for in Air Conditioner Standards Rulemaking

The fan electricity used for cooling operation or heat pump heating operation is part of the SEER and HSPF ratings for air conditioners and heat pumps. In the recent HVAC rulemaking,[4] the standard adopted by DOE accounted for savings from higher-efficiency central air conditioners (CAC) and heat pumps (HP) (above SEER 14) that incorporate a constant-airflow BPM fan. DOE has taken steps to avoid also counting those energy savings in this rulemaking for furnace fans.

DOE used the same base case efficiency distribution of CAC and HP efficiencies in this analysis as it used in the HVAC rulemaking. In the household sample, those households assigned a CAC or HP at 15 SEER or above would already have a constant-airflow BPM fan. This situation is reflected in the base case efficiency distribution used for furnace fans. Since the energy savings from the considered fan efficiency levels are measured relative to the base case efficiencies, any savings reported here are over and above those counted in the CAC and HP rulemaking.

8.3 PAYBACK PERIOD INPUTS

The PBP is the amount of time it takes the customer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in first year annual operating expenditures.

The equation for PBP is:

$PBP = \Delta IC / \Delta OC$ **Eq. 8.3.1**

Where:

PBP = payback period in years,
Δ IC = difference in the total installed cost between the more efficient standard-level equipment (efficiency levels 2, 3, etc.) and the baseline efficiency equipment, and
ΔOC = difference in first year annual operating costs.

Payback periods are expressed in years. Payback periods can be greater than the life of the equipment if the increased total installed cost of the more efficient equipment is not recovered fast enough in reduced operating costs.

DOE also calculates a rebuttable PBP, which is the time it takes the consumer to recover the assumed higher purchase cost of more energy-efficient equipment as a result of lower energy costs. Numerically, the rebuttable PBP is the ratio of the increase in purchase cost (i.e., from a less efficient design to a more efficient design) to the decrease in annual energy expenditures; that is, the difference in first year annual energy cost as calculated from the DOE test procedure. The calculation excludes repair costs and maintenance costs.

The data inputs to PBP are the total installed cost of the equipment to the customer for each efficiency level and the annual (first year) operating costs for each efficiency level. The inputs to the total installed cost are the equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost (or, in the case of rebuttable PBP, only the annual energy cost). The PBP uses the same inputs as the LCC analysis, except that electricity price trends and discount rates are not required. Since the PBP is a "simple" payback, the required electricity cost is only for the year in which a new efficient standard is to take effect—in this case, 2019.

8.4 LCC AND PBP RESULTS

As discussed previously, DOE's approach for conducting the LCC and PBP analysis relied on developing samples of households that use each of the products. DOE used a Monte Carlo simulation technique to perform the LCC and PBP calculations on the households in the sample. For each set of sample households using the equipment in each product class, DOE calculated the average LCC and LCC savings and the median and average PBP for each of the efficiency levels. These efficiency levels are also referred to as candidate standard levels (CSLs).

DOE calculated LCC savings and PBPs relative to the base case equipment that it assigned to the households. In some cases, DOE assigned base case equipment that is more efficient than the baseline and some of the CSLs. For that reason, in those cases the average LCC impacts are <u>not</u> equal to the difference between the LCC of a specific CSL and the LCC of the baseline product. DOE calculated the average LCC savings and the median PBP values by excluding the households that are not impacted by a standard at a given efficiency level.

LCC and PBP calculations were performed 10,000 times on the sample of households established for each residential product. Each LCC and PBP calculation was performed on a single household that was selected from the sample of the residential users. The selection of a household was based on its sample weight (*i.e.*, how representative a particular household is of other households in the distribution—either regionally or nationally) in the 2009 RECS Public Use Sample, as described in chapter 7 of the TSD. Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

Based on the Monte Carlo simulations that DOE performed, for each standard level, DOE calculated the share of households receiving a net LCC benefit, a net LCC cost, and no impact. DOE considered a household to receive no impact at a given standard level if DOE assigned it base case equipment whose efficiency is the same as, or is more than, the CSL.

8.4.1 Non-Weatherized, Non-Condensing Gas Furnace Fans

Table 8.4.1 shows the LCC and PBP results for non-weatherized, non-condensing gas furnace fans.

Table 8.4.1 Non-Weatherized, Non-Condensing Gas Furnace Fans: LCC and PBP Results

CSL	Technology Option	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
						% Households with			
		Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Average Savings (2012$)	Net Cost	No Impact	Net Benefit	Median
0	Baseline PSC	343	2146	2489	0	0%	100%	0%	---
1	Improved PSC	354	1943	2297	64	2%	68%	30%	1.3
2	Inverter-driven PSC	403	1649	2052	253	25%	25%	50%	4.0
3	Constant-torque BPM motor	414	1389	1803	442	18%	25%	57%	2.7
4	Constant-torque BPM motor + multi-stage	496	1273	1769	474	33%	14%	53%	5.4
5	Constant-airflow BPM motor + multi-stage	662	1333	1995	275	53%	12%	35%	11.5
6	Constant-airflow BPM motor + multi-stage + backward-curved impeller	697	1260	1957	313	58%	0%	42%	11.2

Figure 8.4.1 shows the range of LCC savings for the efficiency levels considered for non-weatherized, non-condensing gas furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have lifecycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

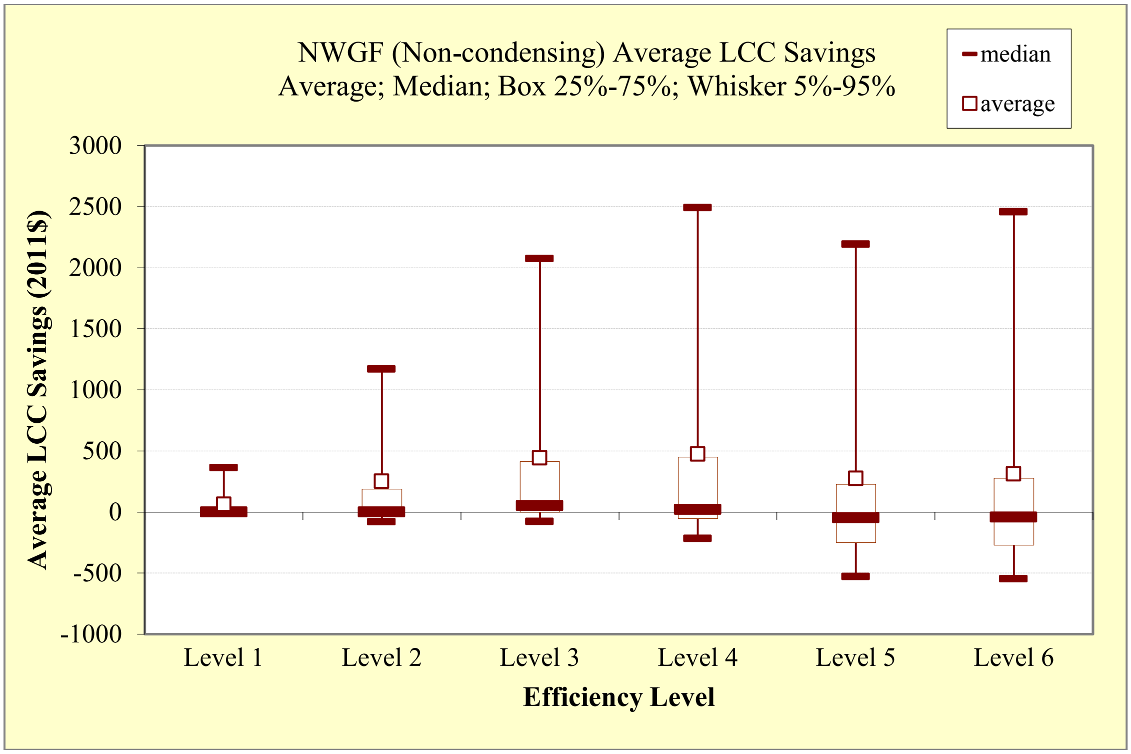

Figure 8.4.1 Distribution of LCC Savings for Non-Weatherized, Non-Condensing Gas Furnace Fans

Figure 8.4.2 show the range of PBPs for all efficiency levels considered for non-weatherized, non-condensing gas furnace fans.

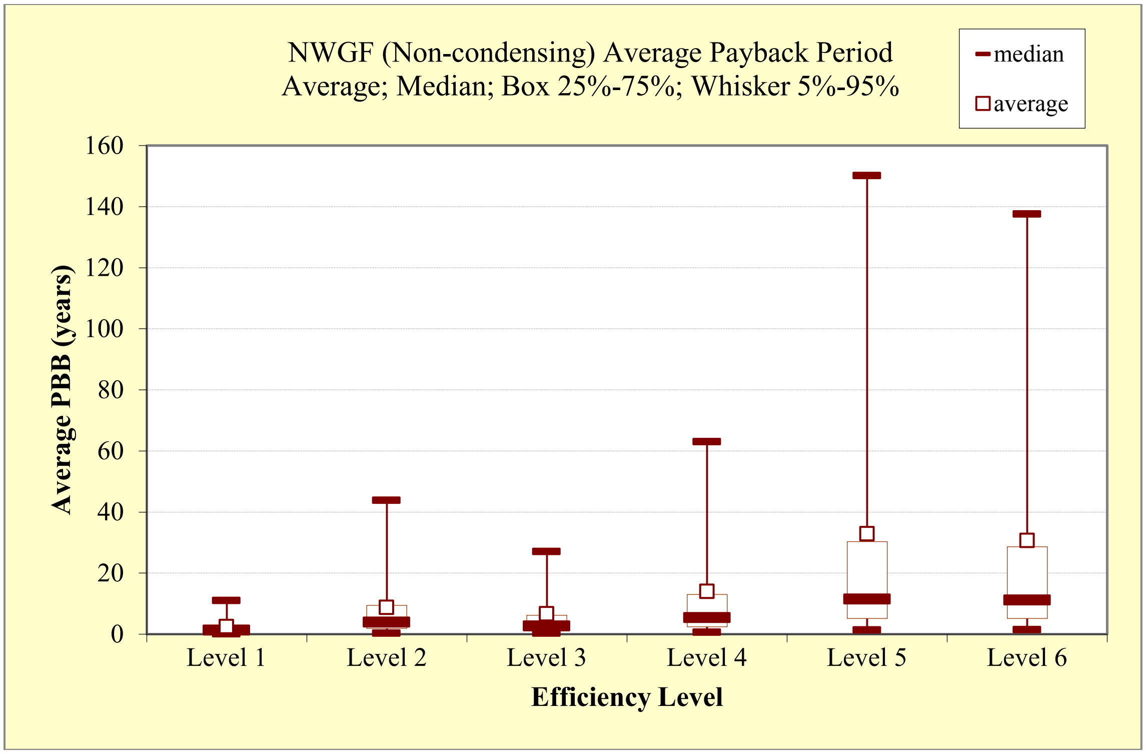

Figure 8.4.2 Distributions of PBP for Non-Weatherized, Non-Condensing Gas Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.2.

Table 8.4.2 Rebuttable Payback Period for Non-Weatherized, Non-Condensing Gas Furnace Fans

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.1
2	Improved PSC	2.5
3	Inverter-driven PSC	1.6
4	Constant-torque BPM motor	3.1
5	Constant-torque BPM motor + multi-stage	6.0
6	Constant-airflow BPM motor + multi-stage	6.2

8.4.2 Non-Weatherized, Condensing Gas Furnace Fans

Table 8.4.3 shows the LCC and PBP results for non-weatherized, condensing gas furnace fans.

Table 8.4.3 Non-Weatherized, Condensing Gas Furnace Fan: LCC and PBP Results

		Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
						% Households with			
CSL	**Technology Option**	**Average Installed Cost**	**Average Lifetime Operating Cost**	**Average LCC**	**Average Savings (2012$)**	**Net Cost**	**No Impact**	**Net Benefit**	**Median**
0	Baseline PSC	339	2259	2598	0	0%	100%	0%	---
1	Improved PSC	351	2066	2417	49	1%	75%	24%	1.4
2	Inverter-driven PSC	398	1775	2173	203	21%	41%	38%	4.1
3	Constant-torque BPM motor	408	1506	1914	361	10%	41%	49%	2.7
4	Constant-torque BPM motor + multi-stage	490	1414	1904	371	24%	34%	42%	5.4
5	Constant-airflow BPM motor + multi-stage	658	1488	2146	199	45%	29%	27%	11.7
6	Baseline PSC	692	1415	2107	238	57%	0%	43%	11.0

Figure 8.4.3 shows the range of LCC savings for the efficiency levels considered for non-weatherized, condensing gas furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

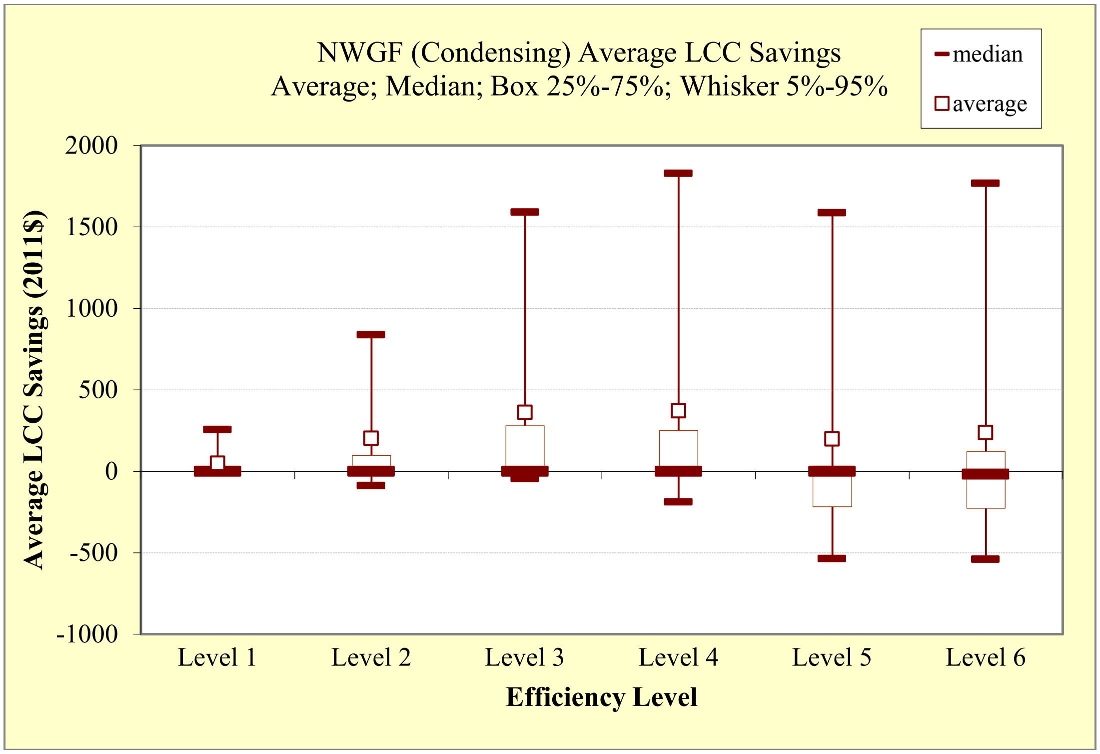

Figure 8.4.3 Distribution of LCC Savings for Non-Weatherized, Condensing Gas Furnace Fans

Figure 8.4.4 show the range of PBPs for all efficiency levels considered for non-weatherized, condensing gas furnace fans.

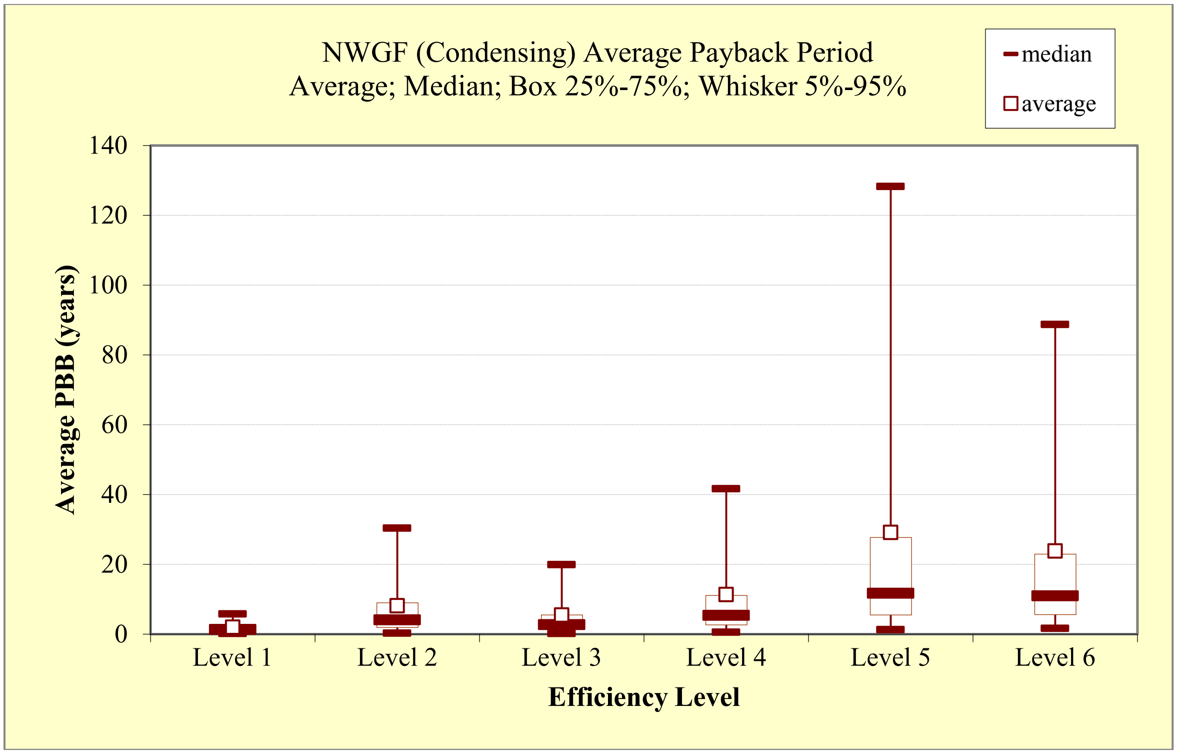

Figure 8.4.4 Distributions of PBP for Non-Weatherized, Condensing Gas Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.4.

Table 8.4.4 Rebuttable Payback Period for Non-Weatherized, Condensing Gas Furnace Fans

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.1
2	Improved PSC	2.3
3	Inverter-driven PSC	1.5
4	Constant-torque BPM motor	2.8
5	Constant-torque BPM motor + multi-stage	5.6
6	Constant-airflow BPM motor + multi-stage	5.7

8.4.3 Weatherized Gas Furnace Fans

Table 8.4.5 shows the LCC and PBP results for weatherized gas furnace fans.

Table 8.4.5 Weatherized Gas Furnace Fan: LCC and PBP Results

CSL	Technology Option	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
		Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Average Savings (2012$)	% Households with			Median
						Net Cost	No Impact	Net Benefit	
0	Baseline PSC	329	1944	2273	0	0%	100%	0%	---
1	Improved PSC	340	1759	2099	35	0%	81%	18%	1.3
2	Inverter-driven PSC	387	1549	1936	104	13%	56%	31%	4.9
3	Constant-torque BPM motor	397	1276	1673	228	7%	56%	37%	2.7
4	Constant-torque BPM motor + multi-stage	476	1170	1645	247	25%	33%	41%	6.4
5	Constant-airflow BPM motor + multi-stage	636	1290	1926	39	51%	27%	22%	15.5
6	Baseline PSC	670	1228	1898	67	63%	0%	37%	13.3

Figure 8.4.5 shows the range of LCC savings for the efficiency levels considered for weatherized gas furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The ‘whiskers’ at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

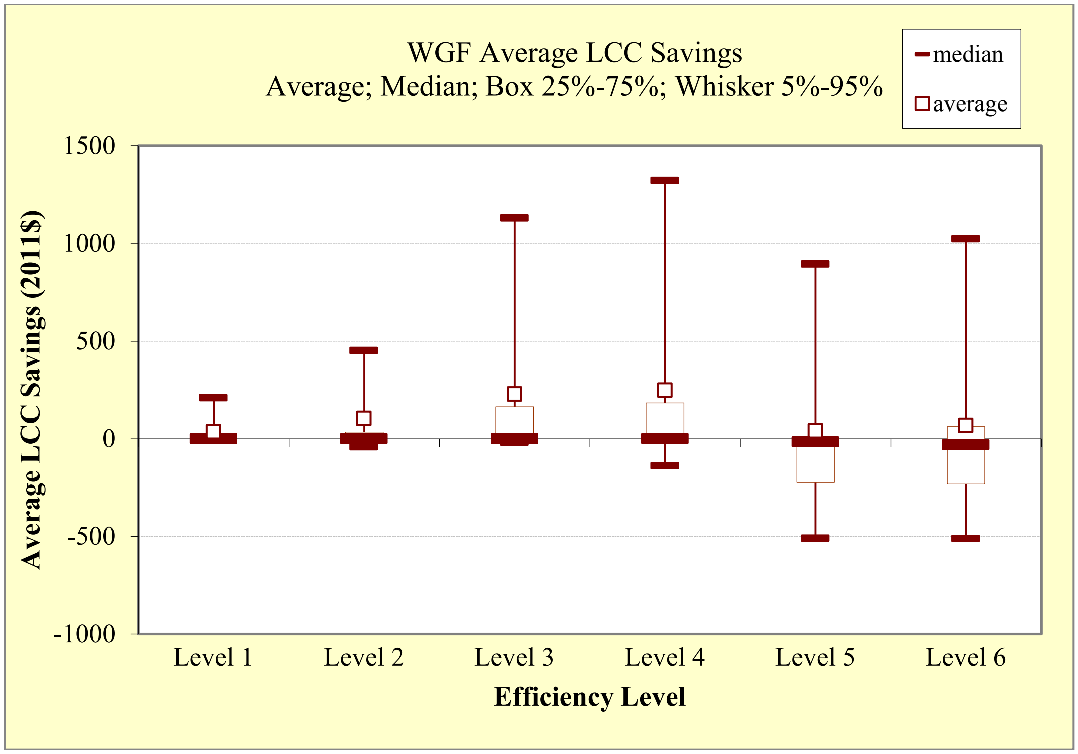

Figure 8.4.5 **Distribution of LCC Savings for Weatherized Gas Furnace Fans**

Figure 8.4.6 shows the range of PBPs for all efficiency levels considered for weatherized gas furnace fans.

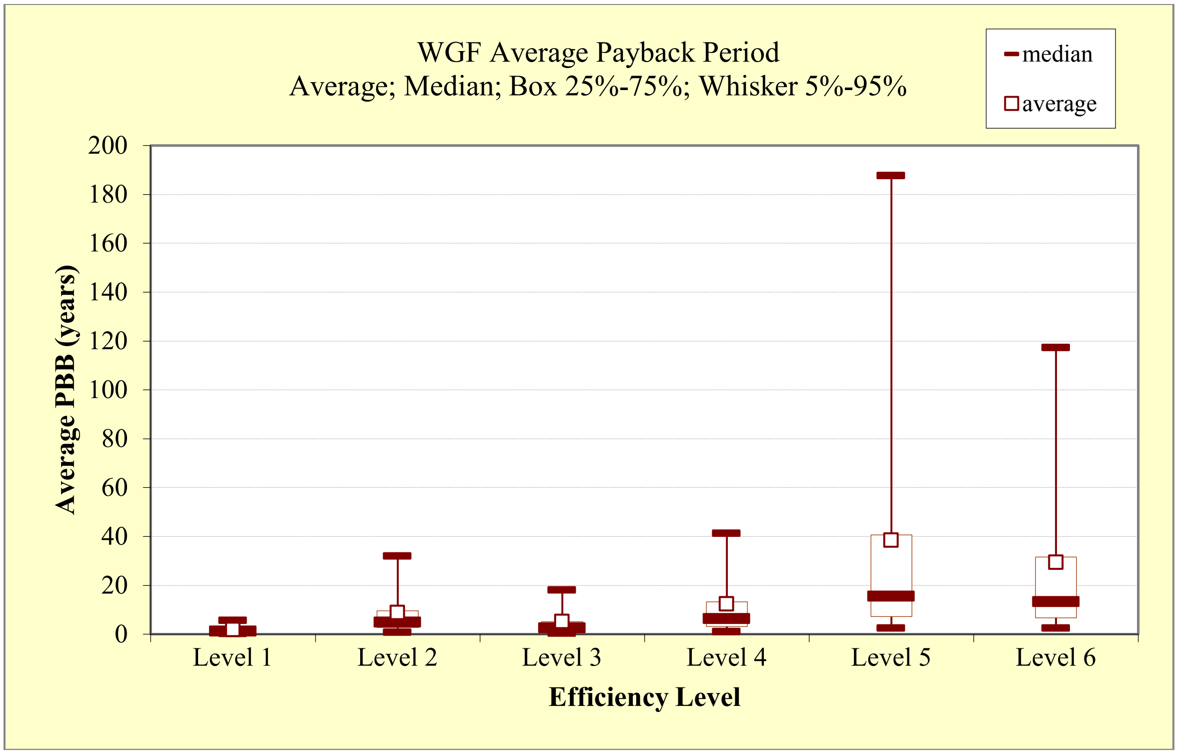

Figure 8.4.6 **Distributions of PBP for Weatherized Gas Furnace Fans**

The rebuttable PBP for each efficiency level is shown in Table 8.4.6.

Table 8.4.6 **Rebuttable Payback Period for Weatherized Gas Furnace Fans**

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.4
2	Improved PSC	3.1
3	Inverter-driven PSC	2.0
4	Constant-torque BPM motor	3.8
5	Constant-torque BPM motor + multi-stage	7.4
6	Constant-airflow BPM motor + multi-stage	7.6

8.4.4 Oil Furnace Fans

Table 8.4.7 shows the LCC and PBP results for oil furnace fans.

Table 8.4.7 Oil Furnace Fan: LCC and PBP Results

CSL	Technology Option	Life-Cycle Cost (2012$) Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Life-Cycle Cost Savings Average Savings (2012$)	% Households with Net Cost	No Impact	Net Benefit	Payback Period (years) Median
0	Baseline PSC	387	2540	2927	0	0%	100%	0%	---
1	Improved PSC	404	2389	2794	40	12%	71%	18%	5.5
2	Inverter-driven PSC	470	2042	2512	245	46%	28%	26%	12.3
3	Constant-torque BPM motor	482	1896	2378	344	43%	28%	29%	7.0
4	Constant-torque BPM motor + multi-stage	570	1833	2402	326	49%	28%	23%	12.1
5	Constant-airflow BPM motor + multi-stage	798	1887	2685	120	58%	28%	14%	27.5
6	Baseline PSC	833	1840	2673	132	79%	0%	21%	25.4

Figure 8.4.7 show the range of LCC savings for the efficiency levels considered for oil furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

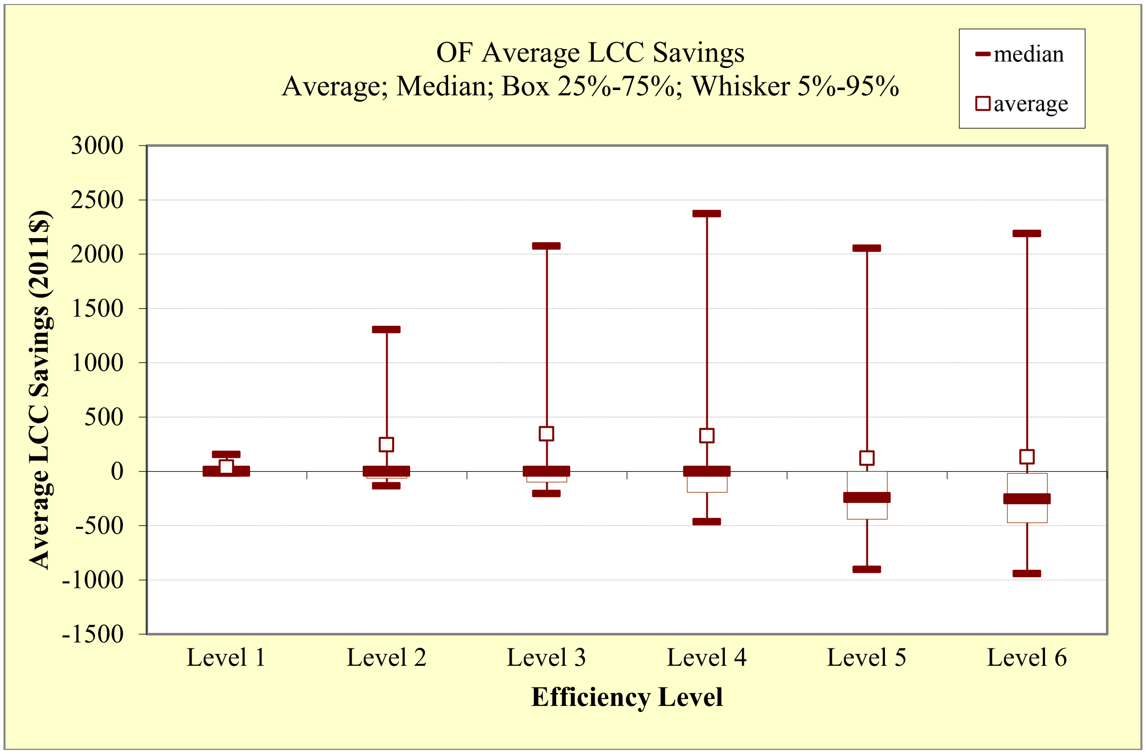

Figure 8.4.7 Distribution of LCC Savings for Oil Furnace Fans

Figure 8.4.8 show the range of PBPs for all efficiency levels considered for oil furnace fans.

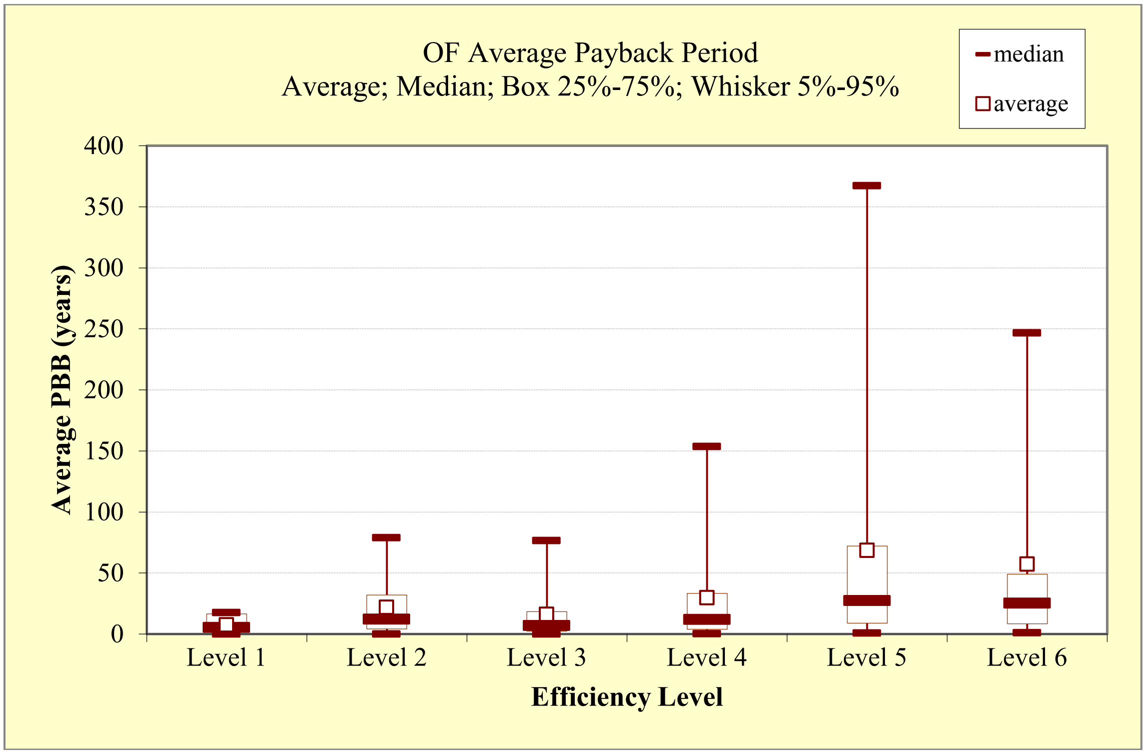

Figure 8.4.8 Distributions of PBP for Oil Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.8.

Table 8.4.8 Rebuttable Payback Period for Oil Furnace Fan

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.8
2	Improved PSC	3.7
3	Inverter-driven PSC	2.5
4	Constant-torque BPM motor	4.0
5	Constant-torque BPM motor + multi-stage	8.1
6	Constant-airflow BPM motor + multi-stage	8.2

8.4.5 Electric Furnace Fans

Table 8.4.9 shows the LCC and PBP results for electric furnace/modular blower fans.

Table 8.4.9 Electric Furnace/Modular Blower Fan: LCC and PBP Results

CSL	Technology Option	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
		Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Average Savings (2012$)	% Households with			Median
						Net Cost	No Impact	Net Benefit	
0	Baseline PSC	241	1198	1439	0	0%	100%	0%	---
1	Improved PSC	252	1100	1352	21	5%	73%	21%	2.4
2	Inverter-driven PSC	295	954	1249	84	28%	37%	34%	6.2
3	Constant-torque BPM motor	294	830	1124	160	20%	37%	42%	3.2
4	Constant-torque BPM motor + multi-stage	315	771	1086	185	27%	25%	48%	3.5
5	Constant-airflow BPM motor + multi-stage	450	855	1305	18	52%	25%	23%	12.8
6	Baseline PSC	482	824	1306	17	68%	0%	32%	13.4

Figure 8.4.9 show the range of LCC savings for the efficiency levels considered for electric furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have lifecycle cost savings above this value. The ‘whiskers’ at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

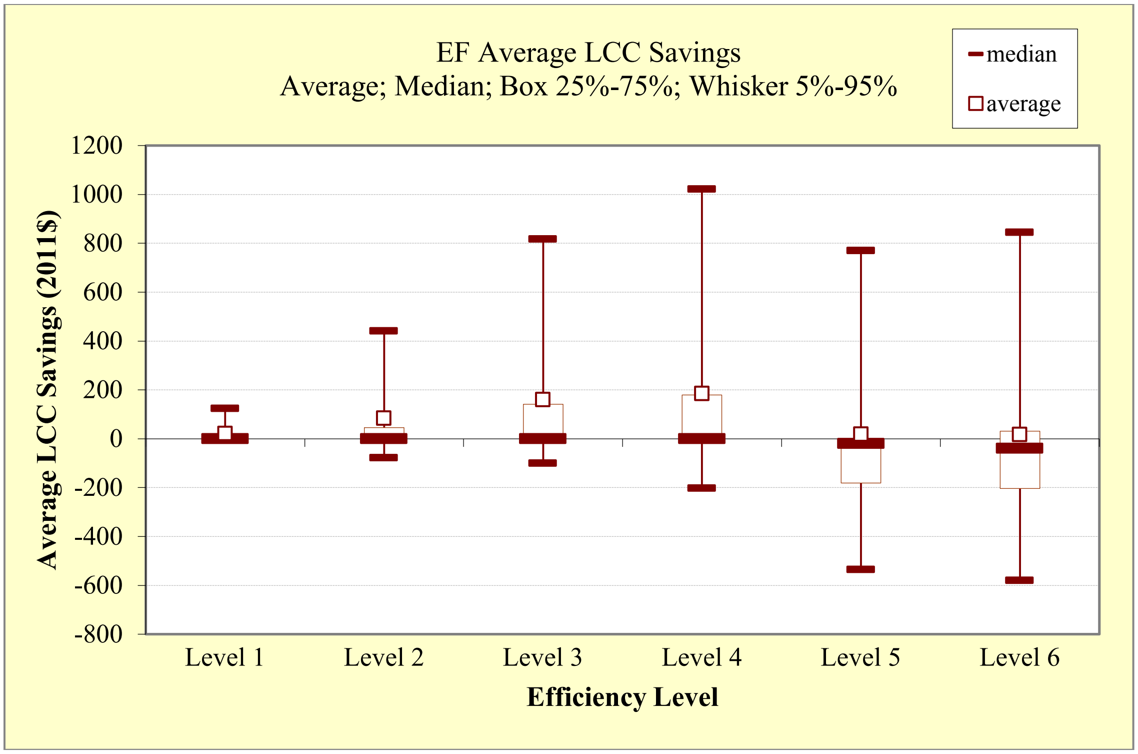

Figure 8.4.9 **Distribution of LCC Savings for Electric Furnace Fans**

Figure 8.4.10 shows the range of PBPs for all efficiency levels considered for electric furnace fans.

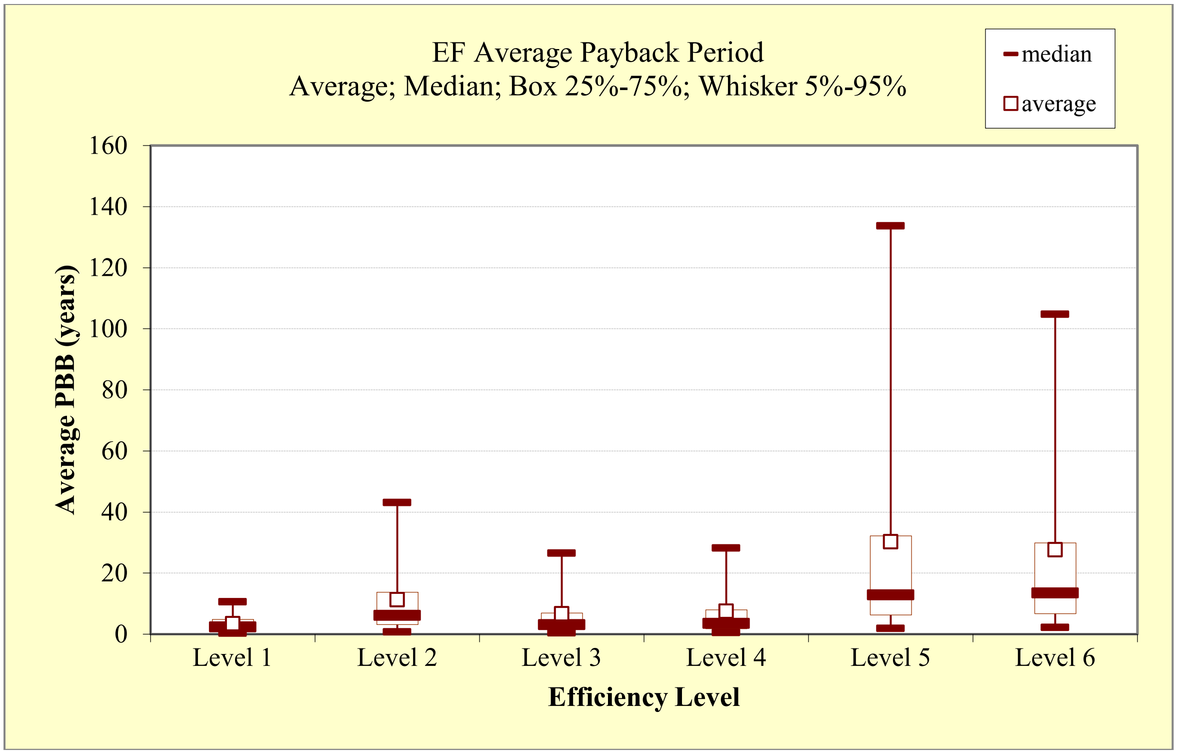

Figure 8.4.10 Distributions of PBP for Electric Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.10.

Table 8.4.10 Rebuttable Payback Period for Electric Furnace/Modular Blower Fan

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.1
2	Improved PSC	2.5
3	Inverter-driven PSC	1.6
4	Constant-torque BPM motor	1.8
5	Constant-torque BPM motor + multi-stage	4.7
6	Constant-airflow BPM motor + multi-stage	5.0

8.4.6 Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fans

Table 8.4.11 shows the LCC and PBP results for manufactured home non-weatherized, non-condensing gas furnace fans.

Table 8.4.11 Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fans: LCC and PBP Results

		Life-Cycle Cost (2012$)			**Life-Cycle Cost Savings**				**Payback Period (years)**
						% Households with			
CSL	**Technology Option**	**Average Installed Cost**	**Average Lifetime Operating Cost**	**Average LCC**	**Average Savings (2012$)**	**Net Cost**	**No Impact**	**Net Benefit**	**Median**
0	Baseline PSC	254	1144	1398	0	0%	100%	0%	---
1	Improved PSC	265	1070	1335	26	13%	56%	32%	3.3
2	Inverter-driven PSC	310	955	1265	97	62%	0%	38%	10.7
3	Constant-torque BPM motor	315	901	1216	146	58%	0%	42%	7.0
4	Constant-torque BPM motor + multi-stage	391	876	1267	95	70%	0%	30%	13.1
5	Constant-airflow BPM motor + multi-stage	537	927	1464	-102	85%	0%	15%	26.2
6	Baseline PSC	569	909	1478	-116	85%	0%	15%	26.7

Figure 8.4.11 shows the range of LCC savings for the efficiency levels considered for manufactured home non-weatherized, non-condensing gas furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The ‘whiskers’ at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

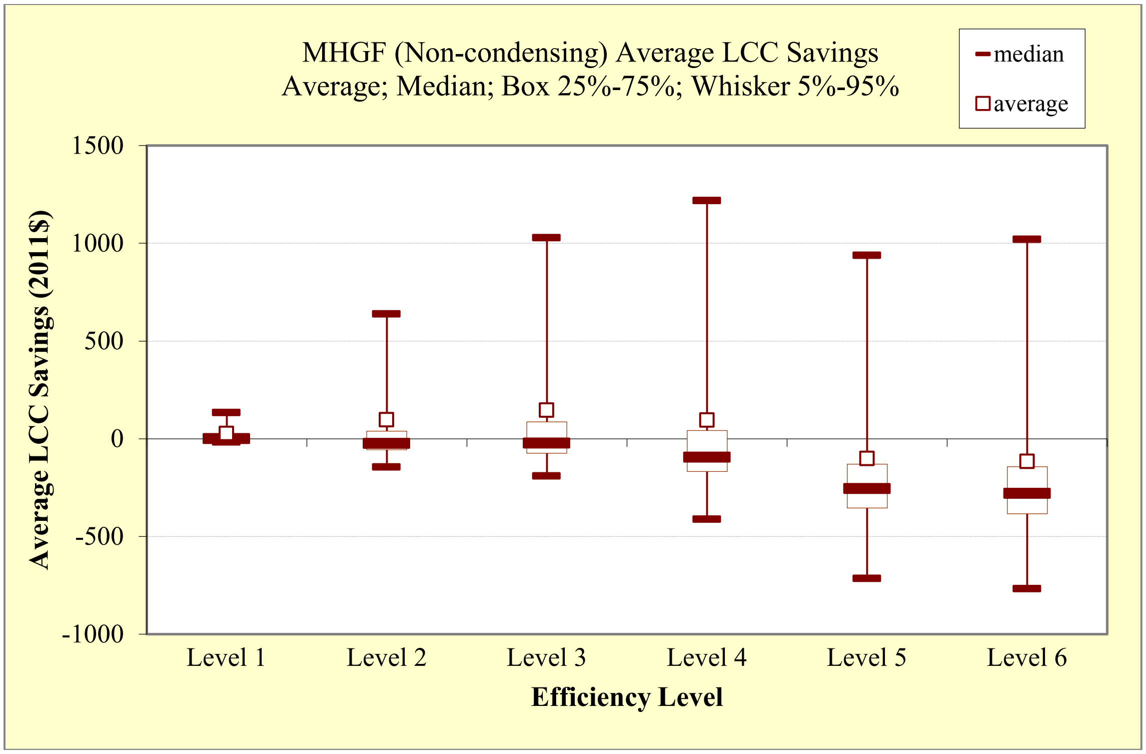

Figure 8.4.11 Distribution of LCC Savings for Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fans

Figure 8.4.12 shows the range of PBPs for all efficiency levels considered for manufactured home non-weatherized, non-condensing gas furnace fans.

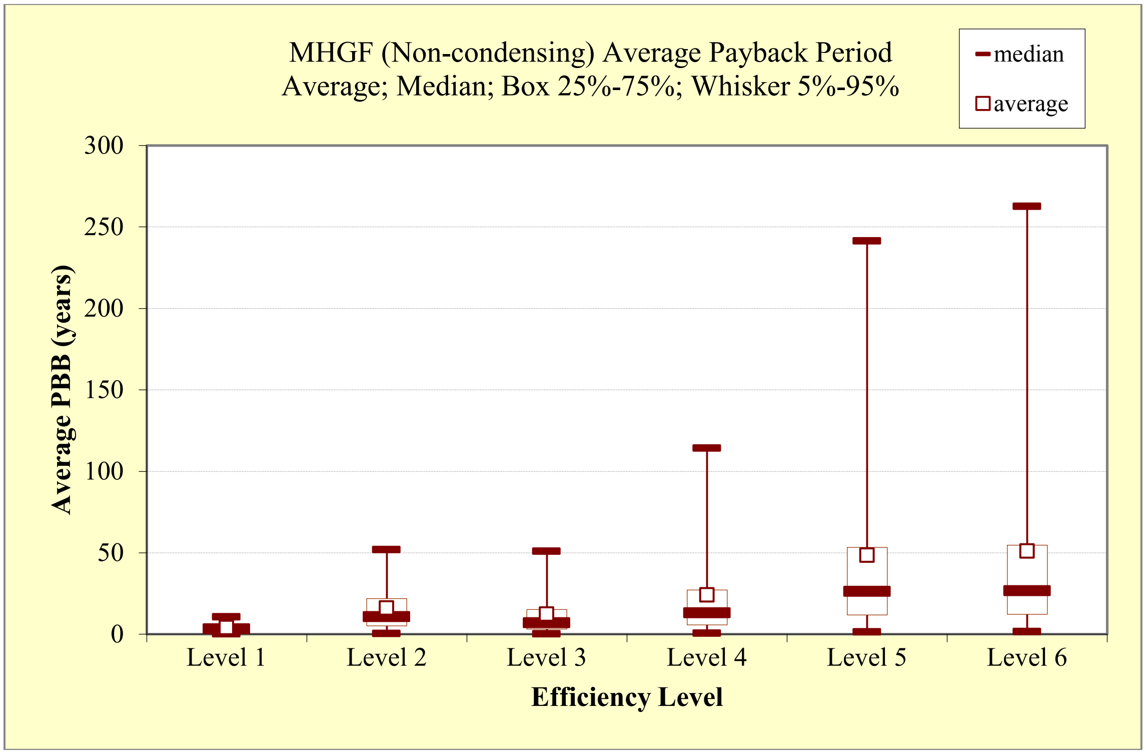

Figure 8.4.12 Distributions of PBP for Manufactured Home, Non-Weatherized, Non-Condensing Gas Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.12.

Table 8.4.12 Rebuttable Payback Period for Manufactured Home Non-Weatherized, Non-Condensing Gas Furnace Fans

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.3
2	Improved PSC	3.0
3	Inverter-driven PSC	1.9
4	Constant-torque BPM motor	3.6
5	Constant-torque BPM motor + multi-stage	7.0
6	Constant-airflow BPM motor + multi-stage	7.3

8.4.7 Manufactured Home Non-Weatherized, Condensing Gas Furnace Fans

Table 8.4.13 shows the LCC and PBP results for manufactured home non-weatherized, condensing gas furnace fans.

Table 8.4.13 Manufactured Home Non-Weatherized, Condensing Gas Furnace Fans: LCC and PBP Results

		Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
						% Households with			
CSL	Technology Option	Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Average Savings (2012$)	Net Cost	No Impact	Net Benefit	Median
0	Baseline PSC	271	1355	1626	0	0%	100%	0%	---
1	Improved PSC	282	1261	1543	27	7%	68%	26%	2.7
2	Inverter-driven PSC	326	1123	1449	96	43%	29%	28%	10.5
3	Constant-torque BPM motor	334	1039	1373	152	38%	29%	32%	6.5
4	Constant-torque BPM motor + multi-stage	410	1005	1416	111	68%	4%	27%	14.8
5	Constant-airflow BPM motor + multi-stage	564	1053	1618	-82	82%	4%	14%	34.3
6	Baseline PSC	597	1025	1622	-86	84%	0%	16%	32.2

Figure 8.4.13 shows the range of LCC savings for the efficiency levels considered for manufactured home non-weatherized, condensing gas furnace fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

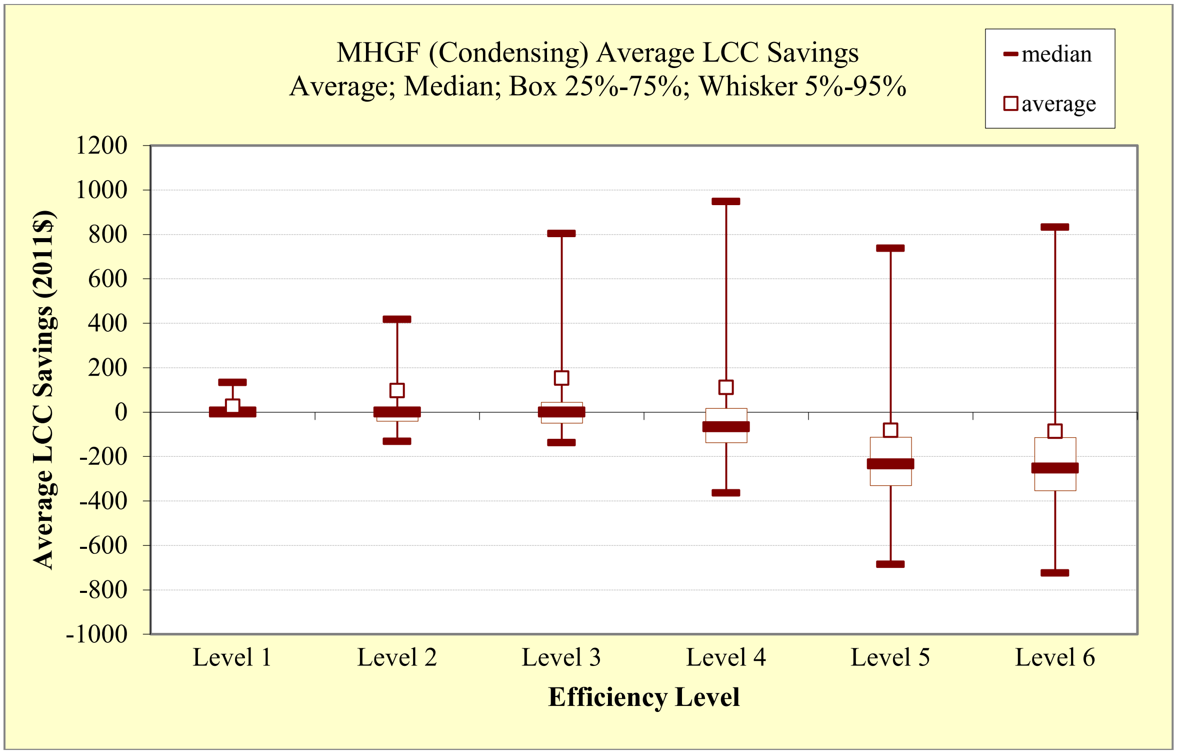

Figure 8.4.13 Distribution of LCC Savings for Manufactured Home Non-Weatherized, Condensing Gas Furnace Fans

Figure 8.4.14 shows the range of PBPs for all efficiency levels considered for manufactured home non-weatherized, condensing gas furnace fans.

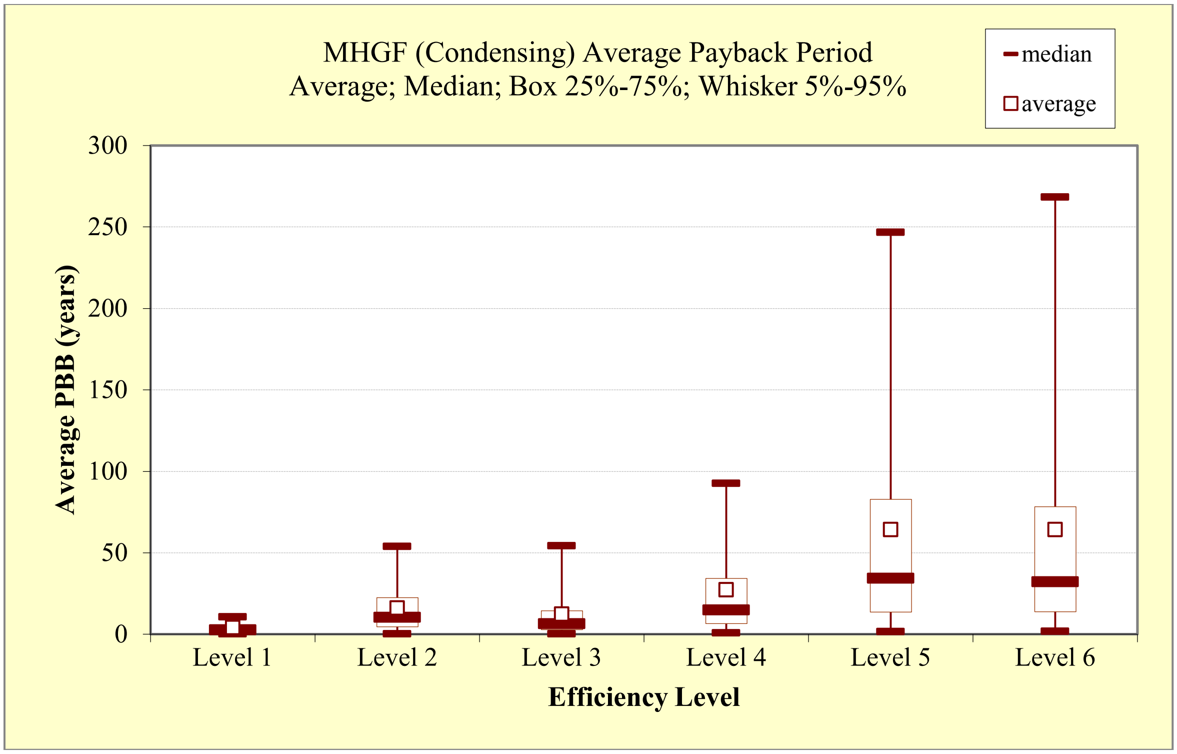

Figure 8.4.14 Distributions of PBP for Manufactured Home Non-Weatherized, Condensing Gas Furnace Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.14.

Table 8.4.14 Rebuttable Payback Period for Manufactured Home Non-Weatherized, Condensing Gas Furnace Fans

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.3
2	Improved PSC	2.8
3	Inverter-driven PSC	1.8
4	Constant-torque BPM motor	3.4
5	Constant-torque BPM motor + multi-stage	6.7
6	Constant-airflow BPM motor + multi-stage	6.8

8.4.8 Manufactured Home Electric Furnace/Modular Blower Fans

Table 8.4.15 shows the LCC and PBP results for manufactured home electric furnace/modular blower fans.

Table 8.4.15 Manufactured Home Electric Furnace/Module Blower Fans: LCC and PBP Results

CSL	Technology Option	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Payback Period (years)
		Average Installed Cost	Average Lifetime Operating Cost	Average LCC	Average Savings (2012$)	% Households with Net Cost	% Households with No Impact	% Households with Net Benefit	Median
0	Baseline PSC	192	663	855	0	0%	100%	0%	---
1	Improved PSC	202	608	810	14	8%	71%	21%	2.5
2	Inverter-driven PSC	243	561	804	20	37%	38%	25%	10.0
3	Constant-torque BPM motor	241	499	739	64	28%	38%	34%	4.3
4	Constant-torque BPM motor + multi-stage	259	464	723	78	34%	26%	40%	4.6
5	Constant-airflow BPM motor + multi-stage	382	539	921	-70	59%	26%	15%	16.8
6	Baseline PSC	412	525	937	-86	82%	0%	18%	17.1

Figure 8.4.15 shows the range of LCC savings for the efficiency levels considered for manufactured home electric furnace/modular blower fans. For each standard level, the top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The bar at the middle of the box indicates the median; 50 percent of the households have life-cycle cost savings above this value. The 'whiskers' at the bottom and the top of the box indicate the 5th and 95th percentiles. The small box shows the average LCC savings for each standard level.

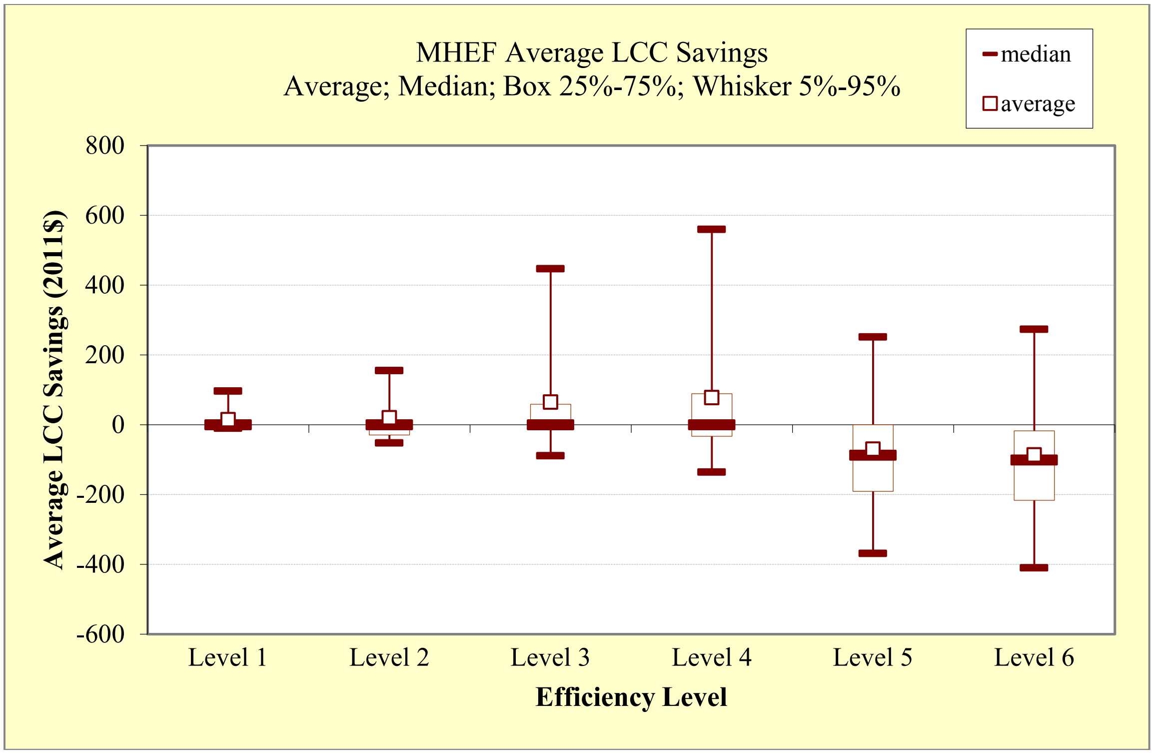

Figure 8.4.15 Distribution of LCC Savings for Manufactured Home Electric Furnace/Modular Blower Fans

Figure 8.4.16 shows the range of PBPs for all efficiency levels considered for manufactured home electric furnace/modular blower fans.

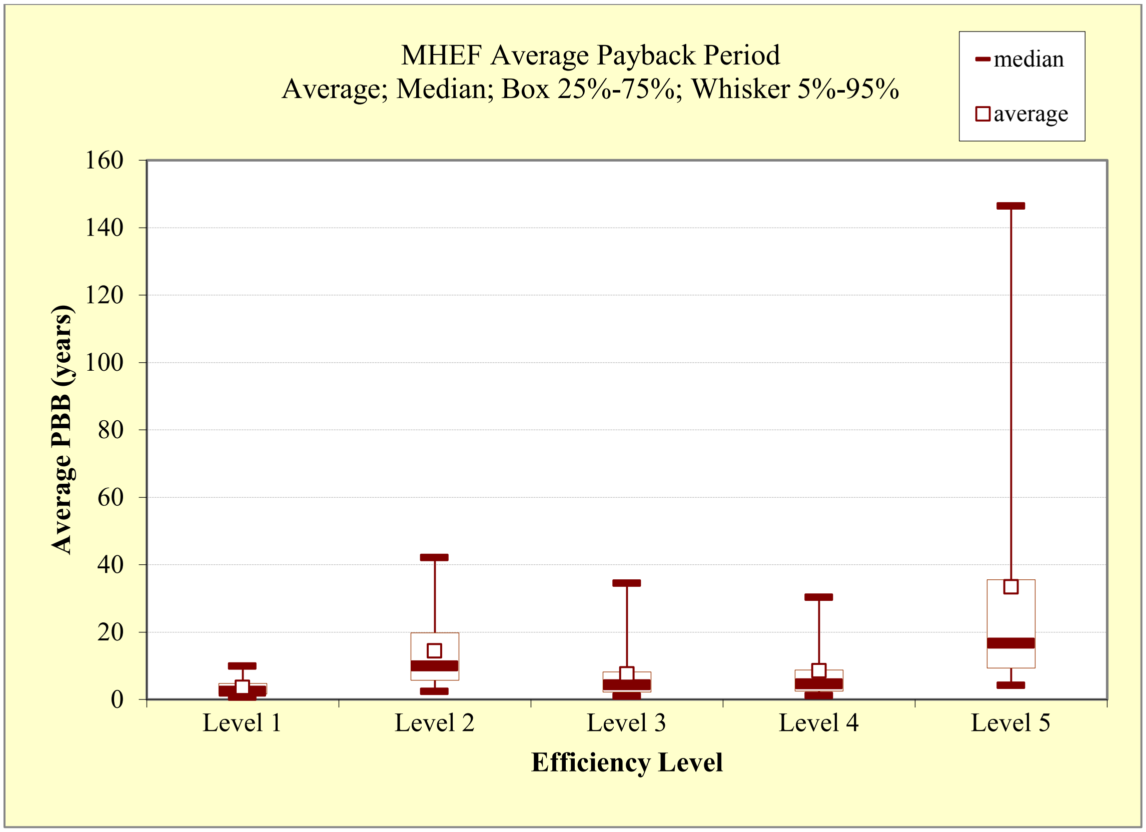

Figure 8.4.16 Distributions of PBP for Manufactured Home Electric Furnace/Modular Blower Fans

The rebuttable PBP for each efficiency level is shown in Table 8.4.16.

Table 8.4.16 Rebuttable Payback Period for Manufactured Home Electric Furnace/Modular Blower Fans

Efficiency Level	Technology Option	Rebuttable Payback Period *years*
1	Baseline PSC	1.5
2	Improved PSC	3.3
3	Inverter-driven PSC	2.1
4	Constant-torque BPM motor	2.4
5	Constant-torque BPM motor + multi-stage	6.2
6	Constant-airflow BPM motor + multi-stage	6.6

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APPENDIX 8-A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR FURNACE FANS

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APPENDIX 8-A. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR FURNACE FANS

8-A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel spreadsheets available on the Department of Energy's (DOE's) furnace fan rulemaking website: http://www1.eere.energy.gov/buildings/appliance_standards/residential/furnace_fans.html. From that page, follow the links to the notice of Preliminary Analysis rulemaking phase and then to Analytical Tools.

8-A.2 STARTUP

DOE's spreadsheet enables users to perform life-cycle cost (LCC) and payback period (PBP) analyses for each product class. One spreadsheet exists for all nine furnace fan product classes.

To examine the spreadsheets, DOE assumes that the user has access to a personal computer with a hardware configuration capable of running Windows XP or later. All LCC spreadsheets require Microsoft Excel 2003 or later installed under the Windows operating system. Because certain variables inside the spreadsheets are defined as distributions, a copy of Crystal Ball (a commercially available add-on program) is required to view them.

8-A.3 DESCRIPTION OF LIFE-CYCLE COST WORKSHEETS

For all of the furnace fan product classes, DOE created a single spreadsheet containing a collection of worksheets. Each worksheet represents a conceptual component within the LCC calculation. To facilitate navigability and identify how worksheets are related, each worksheet contains an area on the extreme left showing variables imported to and exported from the current worksheet. The LCC spreadsheet contains the following worksheets:

Summary	The *Summary* worksheet contains a user interface to manipulate energy price trends and start year inputs, and to run the Crystal Ball simulation. LCC and PBP simulation results for each efficiency level are also displayed here.
LCC&PB Calcs	The *LCC&PB Calcs* worksheet shows LCC calculation results for different efficiency levels for a single Residential Energy Consumption Survey (RECS) 2009 household.[1] During a Crystal Ball simulation, the spreadsheet records the LCC and PBP values for every sampled household.
Rebuttable Payback	The *Rebuttable Payback* worksheet contains the total and incremental manufacturer costs, retail prices, the installation costs, the repair and maintenance costs, energy use calculations, and the simple PBP calculations for each efficiency level. DOE's furnace fan test procedure is used to calculate parameters used in energy use calculations.

Equip Price	The *Equip Price* worksheet calculates retail price values used as inputs in the LCC calculations in the *Summary* worksheet. DOE applied baseline and incremental markups to calculate final retail prices. DOE calculated the markups differently for replacement units and new units.
Installation Cost	The *Installation Cost* worksheet provides the weighted average installation cost for each design option. These results are used to calculate the total installed prices of the design options.
Maintenance and Repair Cost	The *Maintenance and Repair Cost* worksheet provides the maintenance and repair costs for each design option. These results are used to determine operating costs for the design options.
Labor Costs	The *Labor Cost* worksheet provides the labor cost by region as used to determine the installation and repair/maintenance costs.
RECS Sample	The *RECS* worksheet contains the RECS 2009 household data for each product class. During a Crystal Ball simulation, DOE uses these household characteristics to determine the analysis parameters.
Energy Use	The *Energy Use* worksheet calculates annual energy use by fuel type, depending on product class. The annual energy use calculations for each design option are inputs to the *LCC&PB Calcs* worksheet to calculate the annual operating cost of the LCC.
Static pressure Studies	The *Static Pressure Studies* worksheet shows the data from all reference used to calculate the external static pressure conditions for each household in the furnace fan sample.
Base Case Fan Efficiency	The *Base Case* worksheet determines the efficiency level of the base case units in 2019.
Energy Price	The *Energy Price* worksheet shows the estimated monthly natural gas, electricity, and oil prices.
Energy Price Data	The *Energy Price Data* worksheet shows the annual series of state level energy price data for all fuel types.
Energy Price Trends	The *Energy Price Trends* worksheet shows the future price trends of the different heating fuels. DOE used energy price data and forecasts from the Energy Information Administration's (EIA's) Annual Energy Outlook 2012for the period until 2035 and extrapolated beyond 2035.[2]

Discount Rate	The *Discount Rate* worksheet contains the distributions of discount rates for replacement and new units.
Lifetime	The *Lifetime* worksheet contains the distribution of lifetimes for equipment of that product class.
Furnace & AC Specs	The *Furnace and AC* worksheet contains furnace and AC parameters data used in the analysis.
Models Directory	The *Models Directory* worksheet includes characteristics of the furnace fan products used in the analysis.
AFUE and SEER (Existing)	The *Existing AFUE and SEER* worksheet includes the furnace and air conditioning efficiency for all years during the period 1966-2005.
Energy Use Adjustment Factors	The *Energy Use Adjustment Factors* worksheet contains adjustment factors for normal heating degree days and cooling degree days, as well as building shell efficiency index.
Census Population Data	The *Census Population Data* worksheet contains the Census estimated housing units by State.
Weather Data	The *Weather Data* worksheet contains heating degree days, cooling degree days, heating and cooling outdoor design temperature, and annual mean temperature by weather station.
Shipments	The *Shipments* worksheet contains historical furnace shipments by State by product class.
Forecast Cells	The *Forecast Cells* worksheet contains the outcome of the Monte Carlo simulations for the sample of 10,000 households for many parameters used in the analysis and the documentation.
NIA Inputs	The *NIA Inputs* worksheet contains intermediate inputs used for DOE's National Impact Analysis. These inputs include fuel and electricity use, total installed price, operating cost, and base case distributions for each product class and efficiency level. The inputs are presented for the South and North regions, and for replacement and new construction housing markets. The *NIA Inputs* worksheet also includes energy price and shipment information, as well as household sample fractions by Census division.
TSD Tables	The *TSD Tables* worksheet contains the tables generated for use in the

documentation describing the LCC Analysis.

TSD Ch.8 (Figures)	The *TSD Ch.8 (Figures)* worksheet contains the Figures generated for use in the documentation describing the LCC Analysis results in Ch.8.
Definitions	The *Definitions* worksheet contains variable definitions used in the analysis.

Figure 8-A.3.1 depicts how these various inputs are used in order to generate the LCC and PBP outputs.

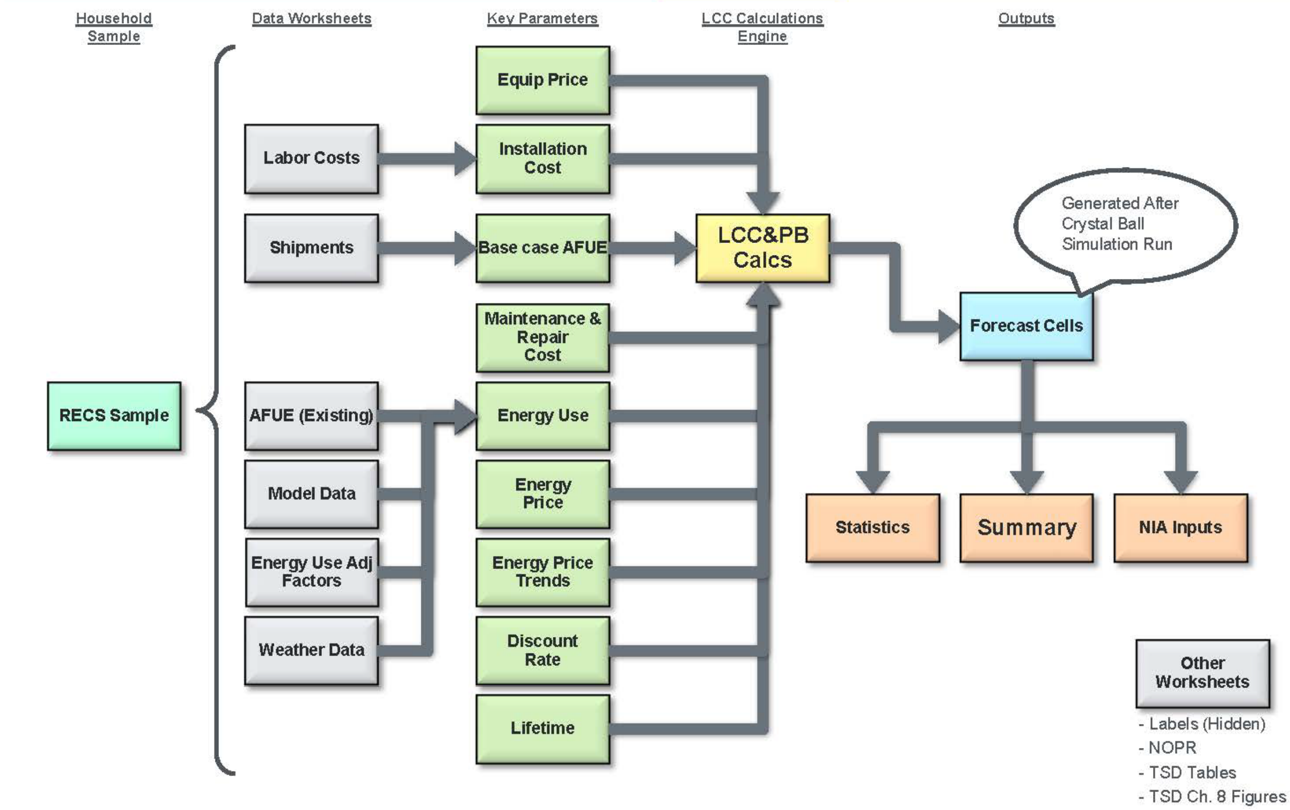

Figure 8-A.3.1 LCC and Payback Calculation Process

8-A.4 BASIC INSTRUCTIONS FOR OPERATING THE LIFE-CYCLE COST SPREADSHEETS

Basic instructions for operating the LCC spreadsheet are as follows:

1. Once the LCC spreadsheet has been downloaded, open the file using Excel. Click “Enable Macro” when prompted and then click on the tab for the *Summary* worksheet.

2. Use Excel's View/Zoom commands at the top menu bar to change the size of the display to fit your monitor.

3. The user can change the parameters listed under USER OPTIONS on the *Summary* worksheet. There are three drop-down boxes and one command button. The default parameters are:

    a. Energy Price Trend: Defaults to “AEO 2012 - Reference Case.” To change the input, use the drop-down menu and select the desired trend (Reference, Low, or High).

    b. Start Year: Defaults to “2019.” To change the value, use the drop-down menu and select the desired year.

    c. # of Trials: Defaults to “10,000.” To change the value, use the drop-down menu and select the desired number of trials (1,000, 2,000, 3,000, 5,000, or 10,000).

    d. Learning Curve: Defaults to “No Learning.” To change the value, use the drop-down menu.

4. To run the Crystal Ball simulation, click the “run” button (you must re-run after changing any parameters). The spreadsheet will then be minimized. You can monitor the progress of the simulation by watching the count of iterations at the left bottom corner. When the simulation is finished, the worksheet named *Summary* will reappear with the results.

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APPENDIX 8-B. USER INSTRUCTIONS FOR THE LIFE-CYCLE COST ANALYSIS SPREADSHEET FOR FURNACE FANS

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APPENDIX 8-B. UNCERTAINTY AND VARIABILITY IN LCC ANALYSIS

8-B.1 INTRODUCTION

Analysis of energy conservation standards involves calculations of impacts, for example, the impact of a standard on consumer life-cycle cost (LCC). In order to perform the calculation, the analyst must first: 1) specify the equation or model that will be used; 2) define the quantities in the equation; and 3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, unambiguity and precision are rarely the case. In almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (i.e., there is uncertainty) or the model and/or the numerical values for each quantity in the model depend upon other conditions (i.e., there is variability).

Thorough analysis involves accounting for uncertainty and variability. While the simplest analysis involves a single numerical value for each quantity in a calculation, arguments can arise about what the appropriate value is for each quantity. Explicit analysis of uncertainty and variability is intended to provide more complete information to the decision-making process.

8-B.2 UNCERTAINITY

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. water heater, direct heating equipment, or pool heater) is not directly recorded, but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8-B.3 VARIABILITY

Variability means that different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, water heater energy consumption depends upon the specific circumstances and behaviors of the occupants (e.g., number of persons, length and temperature of showers, etc.). Variability makes specifying an appropriate population value more difficult in as much as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (e.g., hours of use) to other variables that are better known or easier to forecast (e.g., persons per household).

8-B.4 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability:

- scenario analysis, and
- probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the life-cycle cost of an appliance could be calculated for energy rates of 2, 8, and 14¢ per kWh.

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used and crossover points can be identified. (An example of a crossover point is the energy rate above which the life-cycle cost is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (e.g., electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (e.g., the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (e.g., manufacturing cost to improve energy efficiency to some level may be estimated to be $10 ± $3).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations, that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8-B.5 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and payback period (PBP) analyses, DOE used Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in, to conduct probability analyses. The probability analyses used Monte Carlo simulation and probability distributions.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a model. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation selects variable values at random to simulate a model. When you roll a die, you know that either a 1, 2, 3, 4, 5, or 6 will come up, but you do not know which for any particular roll. It's the same with the variables that have a known range of values but an uncertain value for any particular time or event (e.g., equipment lifetime, discount rate, and installation cost).

For each uncertain variable (one that has a range of possible values), possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include:

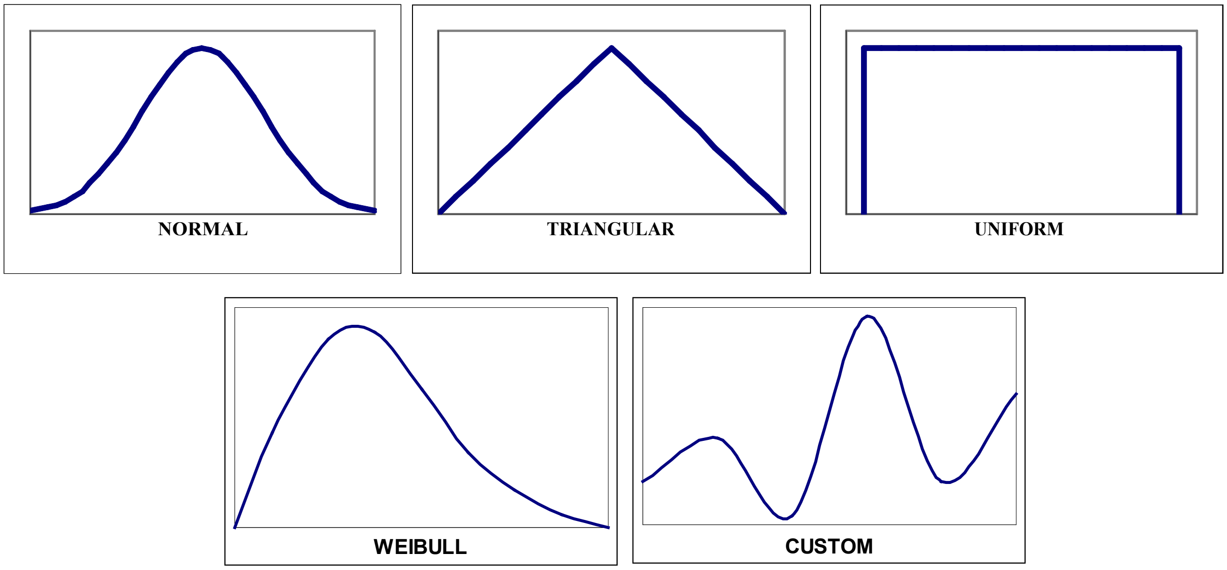

Figure 8-B.5.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for the cell. Crystal Ball simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. During a single trial, Crystal Ball randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the spreadsheet.

APPENDIX 8-C. ENERGY PRICE CALCULATIONS FOR FURNACE FANS

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APPENDIX 8-C. ENERGY PRICE CALCULATIONS FOR FURNACE FANS

8-C.1 INTRODUCTION

Figure 8-C.1.1 depicts the household energy price calculation process, which also encompasses average energy price, seasonal marginal price factor, and monthly price factor calculations.

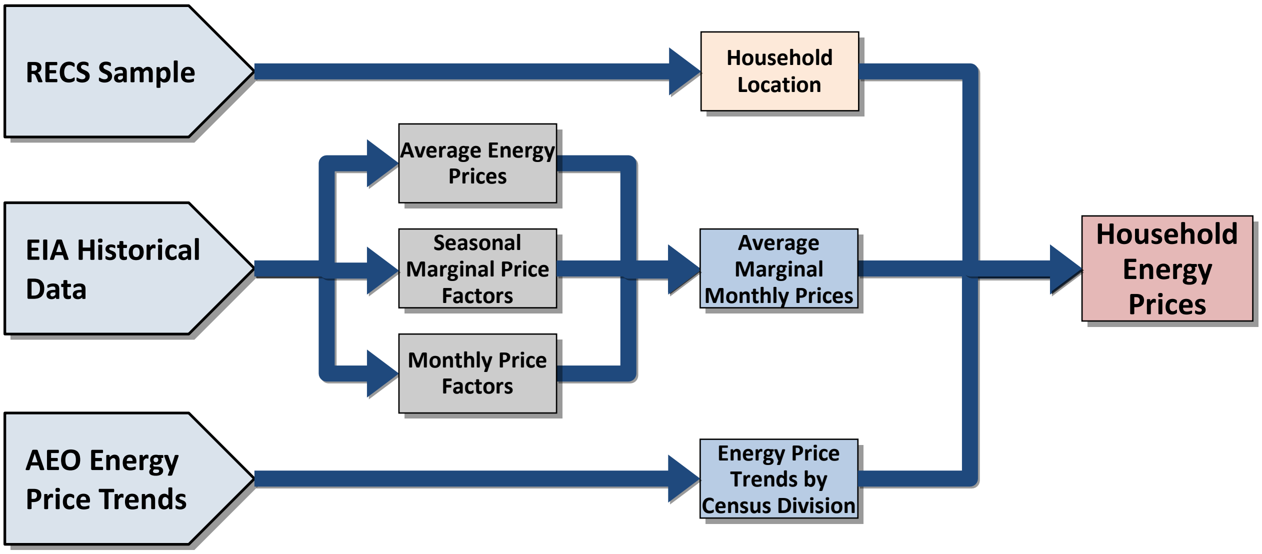

Figure 8-C.1.1 Household Energy Price Calculation Process

8-C.2 RECS SAMPLE MAPPING PROCESS

To match the state data from EIA to the RECS household sample divided into 30 geographical divisions, DOE used projected number of households by state in 2019. RECS 2009 provides 27 regions (also called reportable domains). The 27th region originally includes Oregon, Washington, Alaska, and Hawaii. Alaska and Hawaii are subdivided into separate regions (28 and 29, respectively), based on cooling and heating degree days. In addition, region 14 originally includes West Virginia, which has been disaggregated into region 30 based on cooling and heating degree days. Table 8-C.2.1 shows projected number of households by state in 2019. See appendix 7-A for further details.

Table 8-C.2.1 Number of RECS households by region and by product class

Region		NWGFnc	NWGFc	WGF	OF	EF	MHGFnc	MHGFc	MHEF
1	CT,ME,NH,RI,VT	9,131.04	356,110.58	5,752.22	637,006.56	5,586.39	-	-	-
2	Massachusetts	15,661.58	610,801.65	11,380.83	335,790.96	17,544.88	10,979.12	10,443.55	-
3	New York	521,391.97	1,508,994.10	34,551.06	451,308.77	34,823.42	4,108.08	2,429.31	-
4	New Jersey	498,938.07	1,311,761.96	51,489.41	87,585.36	12,919.65	39,486.56	22,426.45	-
5	Pennsylvania	56,460.91	2,201,975.65	55,606.57	414,544.82	25,792.75	90,492.00	86,077.75	-
6	Illinois	1,276,543.81	2,307,305.39	96,392.21	-	94,324.89	-	-	-
7	Indiana, Ohio	717,994.03	4,326,884.64	112,940.59	82,787.14	271,760.63	116,439.55	87,425.23	8,546.62
8	Michigan	326,570.86	2,199,014.88	53,598.53	80,111.71	27,933.26	142,481.80	109,853.58	-
9	Wisconsin	42,315.42	1,650,301.25	40,195.07	112,900.54	45,769.89	26,396.18	25,108.56	-
10	IA, MN, ND, SD	70,995.77	2,768,834.89	73,379.55	122,459.45	95,321.90	127,875.59	121,637.76	2,496.11
11	Kansas, Nebraska	443,718.26	936,251.93	40,139.22	-	93,665.60	108,298.01	55,598.43	11,109.75
12	Missouri	546,907.50	910,671.53	43,121.38	8,211.93	296,912.59	72,260.84	32,829.30	32,467.76
13	Virginia	112,779.97	849,780.50	193,547.37	62,775.88	80,594.66	25,899.13	20,466.61	69,917.09
14	DE, DC, MD, WV	116,286.06	626,316.83	152,474.49	236,978.82	85,330.23	-	-	111,525.00
15	Georgia	1,513,157.67	358,598.51	392,205.57	9,286.83	483,369.59	25,063.44	2,655.23	18,299.20
16	NC, SC	449,118.61	1,370,731.57	371,099.68	77,467.06	629,668.97	51,700.02	31,233.06	178,192.32
17	Florida	389,503.95	23,273.29	86,727.62	-	1,463,617.78	67,637.88	1,962.10	151,000.01
18	AL, KY, MS	749,779.55	725,081.18	302,873.13	-	486,367.81	127,097.57	41,425.15	55,095.46
19	Tennessee	380,338.88	437,882.62	177,732.31	-	397,640.15	-	-	90,659.92
20	AR, LA, OK	1,209,338.82	182,460.63	280,782.54	-	849,811.96	99,667.52	6,991.32	91,365.41
21	Texas	3,543,914.32	354,443.53	809,064.45	-	1,648,322.54	103,556.39	4,931.95	212,066.69
22	Colorado	937,921.43	593,677.74	21,313.88	-	72,986.49	127,647.23	30,686.65	-
23	ID, MT, UT, WY	756,447.67	922,093.57	34,131.48	-	78,300.51	80,831.36	30,609.62	-
24	Arizona	550,801.27	264,353.83	179,806.73	-	286,446.53	143,894.84	27,848.00	29,945.36
25	NV, NM	929,442.05	265,057.80	217,877.51	38,507.25	65,120.22	102,537.82	12,796.23	6,039.69
26	California	4,534,961.32	1,504,858.89	900,144.20	33,489.68	590,030.04	155,108.09	22,072.87	27,005.19
27	OR, WA	864,849.00	887,758.11	16,928.06	85,499.31	219,715.40	15,701.59	5,325.48	93,129.53
28	Alaska	47,484.66	34,571.36	-	-	-	17,812.38	4,753.70	-
29	Hawaii	47,484.66	34,571.36	-	-	-	17,812.38	4,753.70	-
30	West Virginia	3,582.68	139,724.50	3,235.92	62,010.58	11,327.47	-	-	23,848.86
31	United States	21,663,821.81	30,664,144.27	4,758,491.57	2,938,722.66	8,471,006.21	1,900,785.36	802,341.61	1,212,709.98

Table 8-C.2.2 Projected 2019 Household Population

	State	State Code	RECS 2009 Domain	Projected 2019 Household Population
1	Alabama	AL	18	2,279,398
2	Alaska	AK	28	354,287
3	Arizona	AZ	24	3,148,993
4	Arkansas	AR	20	1,395,746
5	California	CA	26	15,020,600
6	Colorado	CO	22	2,546,760
7	Connecticut	CT	1	1,529,165
8	Delaware	DE	14	442,337
9	District of Columbia	DC	14	364,958
10	Florida	FL	17	9,980,016
11	Georgia	GA	15	4,528,680
12	Hawaii	HI	29	577,627
13	Idaho	ID	23	729,199
14	Illinois	IL	6	5,422,636
15	Indiana	IN	7	2,912,846
16	Iowa	IA	10	1,397,184
17	Kansas	KS	11	1,314,470
18	Kentucky	KY	18	2,024,227
19	Louisiana	LA	20	2,136,220
20	Maine	ME	1	718,119
21	Maryland	MD	14	2,584,709
22	Massachusetts	MA	2	2,994,036
23	Michigan	MI	8	4,477,323
24	Minnesota	MN	10	2,491,716
25	Mississippi	MS	18	1,310,000
26	Missouri	MO	12	2,813,175
27	Montana	MT	23	514,519
28	Nebraska	NE	11	859,767
29	Nevada	NV	25	1,283,421
30	New Hampshire	NH	1	619,072
31	New Jersey	NJ	4	3,703,111
32	New Mexico	NM	25	978,693
33	New York	NY	3	8,479,435
34	North Carolina	NC	16	4,814,044
35	North Dakota	ND	10	369,043
36	Ohio	OH	7	5,153,239
37	Oklahoma	OK	20	1,819,937
38	Oregon	OR	27	1,813,901

	State	State Code	RECS 2009 Domain	Projected 2019 Household Population
39	Pennsylvania	PA	5	5,720,154
40	Rhode Island	RI	1	457,508
41	South Carolina	SC	16	2,352,711
42	South Dakota	SD	10	401,344
43	Tennessee	TN	19	3,036,563
44	Texas	TX	21	11,717,997
45	Utah	UT	23	1,147,456
46	Vermont	VT	1	323,723
47	Virginia	VA	13	3,733,679
48	Washington	WA	27	3,236,796
49	West Virginia	WV	30	898,385
50	Wisconsin	WI	9	2,714,552
51	Wyoming	WY	23	293,373
	United States	US	31	141,993,268

8-C.3 AVERAGE MARGINAL MONTHLY PRICES

8-C.3.1 Average Annual Prices Determination

8-C.3.1.1 Annual Electrical Prices

DOE derived 2011 annual electricity prices from EIA Form 826 data.[1] The EIA Form 826 data include energy prices by State. DOE calculated annual electricity prices for each geographical area by averaging monthly energy prices by State to get State electricity prices. For areas with more than one State, DOE weighted each State's average price by its number of households. Table 8-C.3.2 shows the average prices for each geographic area.

Table 8-C.3.1 2011 Monthly Electricity Prices by State (2012$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2011
Alabama	0.103	0.106	0.109	0.109	0.112	0.113	0.113	0.114	0.115	0.117	0.121	0.133	0.11
Alaska	0.164	0.165	0.167	0.174	0.176	0.180	0.189	0.184	0.183	0.182	0.179	0.178	0.18
Arizona	0.098	0.099	0.102	0.110	0.118	0.118	0.118	0.117	0.115	0.111	0.103	0.100	0.11
Arkansas	0.079	0.079	0.085	0.091	0.094	0.095	0.096	0.096	0.097	0.095	0.093	0.087	0.09
California	0.158	0.148	0.148	0.146	0.151	0.153	0.163	0.156	0.153	0.143	0.154	0.153	0.15
Colorado	0.104	0.105	0.106	0.111	0.111	0.119	0.121	0.121	0.120	0.110	0.110	0.108	0.11
Connecticut	0.180	0.176	0.179	0.181	0.186	0.184	0.181	0.178	0.180	0.186	0.185	0.182	0.18
Delaware	0.129	0.130	0.138	0.139	0.147	0.141	0.138	0.137	0.140	0.141	0.140	0.136	0.14
District of Columbia	0.136	0.136	0.152	0.137	0.140	0.141	0.130	0.131	0.132	0.133	0.119	0.123	0.13
Florida	0.115	0.114	0.116	0.116	0.117	0.118	0.118	0.118	0.118	0.117	0.117	0.116	0.12
Georgia	0.097	0.098	0.109	0.107	0.113	0.120	0.120	0.121	0.116	0.109	0.105	0.102	0.11
Hawaii	0.301	0.310	0.317	0.329	0.346	0.358	0.362	0.370	0.375	0.367	0.366	0.362	0.35
Idaho	0.079	0.078	0.078	0.079	0.081	0.085	0.085	0.086	0.068	0.079	0.079	0.075	0.08
Illinois	0.103	0.112	0.119	0.119	0.124	0.121	0.119	0.116	0.128	0.129	0.124	0.112	0.12
Indiana	0.092	0.094	0.099	0.105	0.105	0.101	0.100	0.100	0.108	0.111	0.103	0.098	0.10
Iowa	0.093	0.096	0.100	0.104	0.106	0.111	0.116	0.112	0.114	0.111	0.103	0.097	0.11
Kansas	0.094	0.097	0.103	0.107	0.110	0.111	0.113	0.113	0.110	0.105	0.104	0.100	0.11
Kentucky	0.085	0.087	0.091	0.093	0.093	0.091	0.091	0.091	0.095	0.096	0.093	0.091	0.09
Louisiana	0.080	0.083	0.089	0.090	0.092	0.096	0.095	0.095	0.096	0.095	0.087	0.083	0.09
Maine	0.157	0.158	0.153	0.154	0.154	0.153	0.151	0.153	0.154	0.154	0.154	0.153	0.15
Maryland	0.132	0.135	0.137	0.139	0.141	0.138	0.132	0.135	0.135	0.133	0.128	0.129	0.13
Massachusetts	0.147	0.145	0.147	0.142	0.152	0.153	0.143	0.152	0.157	0.141	0.146	0.154	0.15
Michigan	0.121	0.125	0.124	0.126	0.132	0.138	0.138	0.140	0.133	0.136	0.128	0.132	0.13
Minnesota	0.103	0.103	0.105	0.109	0.112	0.114	0.116	0.116	0.118	0.113	0.106	0.103	0.11
Mississippi	0.096	0.097	0.106	0.107	0.107	0.103	0.100	0.100	0.100	0.103	0.105	0.101	0.10
Missouri	0.079	0.082	0.089	0.094	0.105	0.109	0.112	0.114	0.103	0.101	0.093	0.087	0.10
Montana	0.091	0.093	0.094	0.095	0.098	0.102	0.104	0.104	0.105	0.103	0.098	0.096	0.10
Nebraska	0.078	0.081	0.084	0.089	0.091	0.104	0.108	0.106	0.110	0.096	0.090	0.084	0.09
Nevada	0.116	0.119	0.120	0.121	0.121	0.116	0.115	0.115	0.115	0.114	0.118	0.111	0.12
New Hampshire	0.163	0.163	0.164	0.165	0.169	0.168	0.163	0.165	0.165	0.167	0.167	0.167	0.17
New Jersey	0.161	0.167	0.164	0.162	0.163	0.160	0.163	0.166	0.161	0.159	0.161	0.159	0.16
New Mexico	0.096	0.101	0.103	0.105	0.104	0.115	0.118	0.124	0.114	0.129	0.103	0.106	0.11
New York	0.173	0.175	0.176	0.175	0.184	0.191	0.193	0.193	0.189	0.189	0.180	0.173	0.18
North Carolina	0.094	0.099	0.101	0.103	0.105	0.102	0.104	0.105	0.110	0.112	0.104	0.101	0.10
North Dakota	0.070	0.073	0.075	0.083	0.090	0.103	0.099	0.101	0.101	0.093	0.086	0.084	0.09
Ohio	0.100	0.105	0.110	0.112	0.116	0.120	0.123	0.122	0.121	0.120	0.117	0.110	0.11
Oklahoma	0.080	0.083	0.096	0.101	0.097	0.097	0.097	0.099	0.111	0.105	0.095	0.084	0.10
Oregon	0.092	0.095	0.093	0.095	0.095	0.097	0.099	0.098	0.099	0.098	0.098	0.096	0.10
Pennsylvania	0.125	0.127	0.131	0.133	0.136	0.137	0.137	0.137	0.140	0.138	0.136	0.133	0.13
Rhode Island	0.162	0.164	0.158	0.162	0.135	0.141	0.130	0.143	0.145	0.124	0.132	0.143	0.14
South Carolina	0.102	0.108	0.112	0.113	0.115	0.108	0.111	0.112	0.119	0.116	0.115	0.113	0.11
South Dakota	0.083	0.084	0.086	0.090	0.096	0.103	0.102	0.099	0.103	0.101	0.096	0.092	0.09
Tennessee	0.093	0.093	0.098	0.098	0.100	0.098	0.101	0.100	0.101	0.102	0.100	0.100	0.10

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2011
Texas	0.109	0.108	0.113	0.113	0.114	0.114	0.113	0.113	0.113	0.114	0.114	0.111	0.11
Utah	0.082	0.083	0.084	0.084	0.089	0.093	0.094	0.096	0.094	0.094	0.090	0.090	0.09
Vermont	0.157	0.160	0.160	0.164	0.165	0.163	0.162	0.163	0.163	0.172	0.166	0.162	0.16
Virginia	0.096	0.097	0.102	0.105	0.109	0.111	0.113	0.114	0.113	0.112	0.109	0.105	0.11
Washington	0.081	0.081	0.081	0.082	0.083	0.085	0.085	0.084	0.086	0.085	0.085	0.084	0.08
West Virginia	0.088	0.088	0.091	0.094	0.098	0.094	0.095	0.097	0.099	0.100	0.097	0.095	0.09
Wisconsin	0.124	0.126	0.127	0.129	0.132	0.137	0.133	0.132	0.137	0.133	0.131	0.128	0.13
Wyoming	0.083	0.085	0.087	0.089	0.092	0.095	0.097	0.095	0.096	0.101	0.096	0.092	0.09
United States	0.103	0.106	0.109	0.109	0.112	0.113	0.113	0.114	0.115	0.117	0.121	0.133	0.11

All prices in 2011$ were converted to 2012$ to be consistent with the rest of the prices used in the analysis. This conversion was performed using Consumer Price Index.[a]

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[a] ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

Table 8-C.3.2 Average Residential Electricity Prices by Region in 2011

	Geographic Area	2012$/kWh
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$0.171
2	Massachusetts	$0.151
3	New York	$0.186
4	New Jersey	$0.166
5	Pennsylvania	$0.137
6	Illinois	$0.121
7	Indiana, Ohio	$0.112
8	Michigan	$0.134
9	Wisconsin	$0.134
10	Iowa, Minnesota, North Dakota, South Dakota	$0.108
11	Kansas, Nebraska	$0.103
12	Missouri	$0.099
13	Virginia	$0.109
14	Delaware, District of Columbia, Maryland	$0.138
15	Georgia	$0.112
16	North Carolina, South Carolina	$0.108
17	Florida	$0.119
18	Alabama, Kentucky, Mississippi	$0.105
19	Tennessee	$0.101
20	Arkansas, Louisiana, Oklahoma	$0.094
21	Texas	$0.115
22	Colorado	$0.114
23	Idaho, Montana, Utah, Wyoming	$0.091
24	Arizona	$0.111
25	Nevada, New Mexico	$0.116
26	California	$0.155
27	Oregon, Washington	$0.090
28	Alaska	$0.180
29	Hawaii	$0.354
30	West Virginia	$0.097
31	U.S. Average	$0.120

8-C.3.1.2 Annual Natural Gas Prices

DOE obtained the data for natural gas prices from EIA's Natural Gas Navigator,[2] which includes monthly natural gas prices by State for residential, commercial, and industrial customers. For areas with more than one State, DOE weighted each State's average price by its number of households. Table 8-C.3.4 displays the 2011 annual natural gas prices.

Table 8-C.3.3 2011 Monthly Natural Gas Prices by State (2011$/cu ft)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2011
Alabama	13.26	13.47	14.85	15.93	18.54	20.27	21.19	21.42	20.40	19.17	16.19	14.82	17.46
Alaska	8.64	8.66	8.77	9.05	9.67	9.60	9.70	9.41	9.13	8.70	8.23	8.43	9.00
Arizona	13.12	13.24	14.03	15.98	17.62	19.38	21.75	22.73	22.23	19.44	15.46	13.00	17.33
Arkansas	9.25	9.30	10.74	13.05	15.19	17.85	19.90	21.55	19.57	18.04	12.58	10.59	14.80
California	9.59	9.89	9.64	9.95	10.47	11.10	11.06	11.25	10.67	10.33	9.20	9.14	10.19
Colorado	7.47	7.56	8.14	7.83	8.92	12.15	13.71	13.89	12.46	9.28	7.59	7.43	9.70
Connecticut	12.54	12.83	12.89	13.25	14.74	17.19	18.59	20.38	19.58	17.26	14.37	13.12	15.56
Delaware	13.91	14.02	14.81	14.69	19.02	21.74	22.74	22.63	22.97	20.90	15.10	14.68	18.10
District of Columbia	12.56	12.68	12.55	12.85	15.14	17.41	16.63	15.85	13.73	13.17	13.33	12.87	14.06
Florida	14.80	15.97	17.12	17.88	21.25	22.41	23.18	23.86	23.16	21.86	18.99	16.93	19.78
Georgia	11.97	13.68	14.60	19.27	21.64	24.37	25.81	26.19	26.62	18.61	14.98	13.79	19.29
Hawaii	46.60	50.65	59.72	56.16	57.72	60.72	57.88	55.70	56.34	60.21	51.58	51.62	55.41
Idaho	8.82	8.73	9.02	8.95	9.13	8.91	9.49	9.91	9.26	8.80	8.42	8.49	8.99
Illinois	7.43	7.60	8.01	8.61	9.93	12.77	16.44	16.49	14.99	11.45	8.98	7.91	10.88
Indiana	8.12	9.02	9.38	11.66	12.75	15.51	15.72	16.14	13.49	9.32	8.36	8.06	11.46
Iowa	8.41	8.54	8.82	9.32	10.62	13.84	16.00	17.27	15.93	12.47	9.77	8.53	11.63
Kansas	8.50	8.52	9.16	10.53	13.05	16.11	18.37	19.70	18.22	14.70	10.11	8.60	12.96
Kentucky	8.55	9.38	9.45	11.94	13.81	17.27	19.04	20.63	19.15	12.99	10.18	9.51	13.49
Louisiana	9.39	9.68	10.63	13.36	14.95	15.96	16.69	17.27	16.24	14.32	11.65	9.98	13.34
Maine	13.92	13.95	13.62	13.93	14.34	13.92	15.60	16.81	15.33	15.23	13.99	15.06	14.64
Maryland	10.37	11.20	11.18	12.49	15.86	19.40	20.00	19.11	18.51	12.71	12.36	11.78	14.58
Massachusetts	14.34	14.15	14.63	13.96	13.20	14.20	16.15	16.26	15.29	11.73	12.71	12.36	14.08
Michigan	10.08	10.04	9.94	10.20	11.08	13.20	14.75	15.67	13.91	11.47	10.17	9.52	11.67
Minnesota	8.79	8.79	8.40	8.56	9.47	11.08	11.97	12.75	10.58	9.35	8.25	7.98	9.66
Mississippi	8.10	9.07	9.59	9.67	11.43	12.49	13.53	13.64	13.22	11.75	9.72	8.22	10.87
Missouri	9.68	9.93	10.97	13.20	15.00	21.94	26.32	26.51	23.79	18.84	13.28	10.00	16.62
Montana	8.14	8.30	8.48	8.79	9.25	10.40	12.22	12.83	12.18	9.68	8.51	8.13	9.74
Nebraska	7.81	7.81	8.05	8.67	9.68	12.84	14.94	15.73	15.02	12.75	9.44	7.90	10.89
Nevada	9.86	10.05	10.41	11.07	11.83	12.27	13.59	14.03	13.81	12.90	10.28	9.17	11.61
New Hampshire	13.45	13.75	13.91	14.95	16.21	16.07	19.79	19.26	18.30	17.23	15.06	13.84	15.99
New Jersey	11.78	11.85	11.02	11.94	12.88	13.63	14.02	14.71	14.29	12.85	11.91	9.84	12.56
New Mexico	8.07	8.08	8.59	9.40	10.35	11.76	13.81	14.54	13.89	12.08	9.47	8.03	10.67
New York	12.05	12.27	12.73	13.60	15.88	19.74	19.77	19.78	19.75	16.56	13.93	12.65	15.73
North Carolina	10.45	12.01	11.86	14.62	19.02	21.94	22.85	22.26	21.11	14.95	11.73	11.74	16.21

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. 2011
North Dakota	7.07	7.25	7.45	7.84	9.82	12.70	14.90	14.92	12.54	9.27	7.76	7.42	9.91
Ohio	9.21	9.61	9.51	11.10	13.41	17.57	20.80	22.95	20.68	13.98	10.20	8.76	13.98
Oklahoma	7.00	7.66	9.29	11.95	15.30	20.28	24.63	27.07	25.04	21.73	12.58	8.41	15.91
Oregon	11.91	11.00	11.12	11.77	12.00	13.37	14.94	15.29	14.97	12.33	11.40	11.06	12.60
Pennsylvania	11.22	11.38	11.96	11.88	14.02	17.76	19.39	20.13	18.84	14.55	12.66	11.77	14.63
Rhode Island	13.98	14.63	15.04	17.24	18.87	19.93	20.99	20.41	18.48	16.55	14.99	13.42	17.04
South Carolina	10.45	12.60	12.29	15.05	17.38	20.21	25.06	24.23	23.35	15.86	12.12	11.86	16.71
South Dakota	7.81	8.07	8.24	8.11	8.92	10.87	13.18	14.08	13.10	10.46	8.71	7.93	9.96
Tennessee	8.56	8.99	10.12	10.79	13.19	16.07	18.73	18.33	17.41	13.42	10.65	9.81	13.01
Texas	8.01	8.52	9.74	12.90	14.67	15.99	17.58	18.21	16.65	14.28	10.01	8.50	12.92
Utah	8.56	8.73	8.80	8.29	7.67	8.08	9.42	9.96	9.92	9.26	7.89	7.79	8.70
Vermont	14.66	14.31	14.51	15.05	16.72	20.16	23.03	24.99	23.93	21.08	17.56	16.57	18.55
Virginia	10.98	11.84	11.40	13.40	17.45	19.22	20.66	18.88	18.97	14.66	12.88	12.63	15.25
Washington	11.72	11.79	11.92	12.20	13.00	14.06	15.48	16.03	15.92	13.26	11.81	11.27	13.21
West Virginia	10.03	10.21	10.41	11.08	13.04	15.64	17.22	18.05	16.13	11.37	10.79	10.40	12.86
Wisconsin	9.50	9.30	9.39	9.93	10.06	13.27	13.61	14.62	11.85	9.45	9.79	8.98	10.81
Wyoming	7.68	7.92	8.06	8.44	9.02	10.09	13.85	15.64	14.73	11.23	8.54	8.00	10.27
United States	9.90	10.14	10.43	11.27	12.50	14.70	16.14	16.67	15.63	12.85	10.78	9.84	12.57

All prices in 2011$ were converted to 2012$ to be consistent with the rest of the prices used in the analysis. This conversion was performed using Consumer Price Index.[b] DOE also used a conversion factor (1.023) to convert from Cubit feet of natural gas to And to MMBtu.[c]

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[b] ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

[c] http://www.eia.gov/tools/faqs/faq.cfm?id=45&t=7

Table 8-C.3.4 Average Residential Natural Gas Prices by Region in 2011

	Geographic Area	**2012$/MMBtu**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$15.87
2	Massachusetts	$14.05
3	New York	$15.69
4	New Jersey	$12.53
5	Pennsylvania	$14.60
6	Illinois	$10.86
7	Indiana, Ohio	$13.04
8	Michigan	$11.64
9	Wisconsin	$10.79
10	Iowa, Minnesota, North Dakota, South Dakota	$10.27
11	Kansas, Nebraska	$12.12
12	Missouri	$16.58
13	Virginia	$15.21
14	Delaware, District of Columbia, Maryland	$14.95
15	Georgia	$19.25
16	North Carolina, South Carolina	$16.34
17	Florida	$19.74
18	Alabama, Kentucky, Mississippi	$14.46
19	Tennessee	$12.98
20	Arkansas, Louisiana, Oklahoma	$14.56
21	Texas	$12.89
22	Colorado	$9.68
23	Idaho, Montana, Utah, Wyoming	$9.13
24	Arizona	$17.29
25	Nevada, New Mexico	$11.18
26	California	$10.17
27	Oregon, Washington	$12.96
28	Alaska	$8.98
29	Hawaii	$55.28
30	West Virginia	$12.84
31	U.S. Average	$12.54

8-C.3.1.3 Annual LPG Prices

DOE collected 2011 average LPG prices from EIA's 2011 State Energy Consumption, Price, and Expenditures Estimates (SEDS). [3] SEDS includes annual LPG prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one State, DOE weighted each State's average price by its number of households. See Table 8-C.3.6.

Table 8-C.3.5 2011 Average LPG Prices by State (2011$/MMBtu)

Geographical Area	Avg. 2011
Alabama	28.31
Alaska	29.36
Arizona	38.46
Arkansas	35.22
California	29.94
Colorado	34.00
Connecticut	26.46
Delaware	35.42
District of Columbia	32.22
Florida	34.15
Georgia	40.75
Hawaii	28.16
Idaho	64.01
Illinois	27.26
Indiana	23.86
Iowa	23.35
Kansas	23.81
Kentucky	23.87
Louisiana	28.32
Maine	29.37
Maryland	34.47
Massachusetts	36.76
Michigan	37.59
Minnesota	23.81
Mississippi	24.00
Missouri	30.27
Montana	23.41
Nebraska	25.72
Nevada	23.69
New Hampshire	35.45
New Jersey	31.46
New Mexico	35.91
New York	28.72
North Carolina	34.21
North Dakota	29.12
Ohio	23.58
Oklahoma	26.91
Oregon	23.47
Pennsylvania	28.85
Rhode Island	31.27
South Carolina	42.36
South Dakota	30.74
Tennessee	23.36
Texas	29.56
Utah	30.50
Vermont	27.25
Virginia	31.98
Washington	27.22
West Virginia	29.24
Wisconsin	28.90
Wyoming	22.65
United States	28.31

All prices in 2011$ were converted to 2012$ to be consistent with the rest of the prices used in the analysis. This conversion was performed using Consumer Price Index.[d]

Table 8-C.3.6 Average Residential LPG Prices by Region in 2011

	Geographic Area	**2012$/MMBtu**
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$35.85
2	Massachusetts	$38.37
3	New York	$34.92
4	New Jersey	$36.65
5	Pennsylvania	$31.92
6	Illinois	$24.35
7	Indiana, Ohio	$26.15
8	Michigan	$24.30
9	Wisconsin	$23.12
10	Iowa, Minnesota, North Dakota, South Dakota	$24.35
11	Kansas, Nebraska	$24.29
12	Missouri	$23.89
13	Virginia	$27.78
14	Delaware, District of Columbia, Maryland	$36.63
15	Georgia	$28.74
16	North Carolina, South Carolina	$30.27
17	Florida	$41.59
18	Alabama, Kentucky, Mississippi	$29.80
19	Tennessee	$30.17
20	Arkansas, Louisiana, Oklahoma	$28.08
21	Texas	$31.13
22	Colorado	$27.01
23	Idaho, Montana, Utah, Wyoming	$27.46
24	Arizona	$35.95
25	Nevada, New Mexico	$33.21
26	California	$34.70
27	Oregon, Washington	$29.70
28	Alaska	$39.26
29	Hawaii	$65.33
30	West Virginia	$29.50
31	U.S. Average	$28.90

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[d] ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

8-C.3.1.4 Annual Fuel Oil Prices

DOE collected 2011 average fuel oil prices from EIA's SEDS.[3] SEDS includes annual fuel oil prices for residential, commercial, industrial, and transportation consumers by state. For areas with more than one State, DOE weighted each State's average price by its number of households. See Table 8-C.3.8.

Table 8-C.3.7 2011 Monthly Fuel Oil Prices by State (2011$/MMBtu)

Geographical Area	Avg. 2011
Alabama	25.69
Alaska	24.64
Arizona	26.33
Arkansas	28.06
California	25.11
Colorado	28.37
Connecticut	24.88
Delaware	25.47
District of Columbia	24.45
Florida	25.92
Georgia	27.10
Hawaii	26.59
Idaho	27.38
Illinois	25.63
Indiana	27.16
Iowa	27.36
Kansas	27.10
Kentucky	27.18
Louisiana	27.10
Maine	24.64
Maryland	25.19
Massachusetts	25.92
Michigan	25.19
Minnesota	27.10
Mississippi	27.32
Missouri	25.35
Montana	26.65
Nebraska	24.18
Nevada	26.97
New Hampshire	28.13
New Jersey	23.43
New Mexico	26.17
New York	24.91
North Carolina	25.59
North Dakota	26.91
Ohio	26.85
Oklahoma	26.97
Oregon	26.72
Pennsylvania	26.33
Rhode Island	25.89
South Carolina	25.67
South Dakota	27.10
Tennessee	26.59
Texas	27.36
Utah	25.17
Vermont	25.61
Virginia	25.86
Washington	26.85
West Virginia	28.04
Wisconsin	27.10
Wyoming	26.85
United States	25.69

All prices in 2011$ were converted to 2012$ to be consistent with the rest of the prices used in the analysis. This conversion was performed using Consumer Price Index.[e]

Table 8-C.3.8 Average Residential Fuel Oil Prices by Region in 2011

	Geographic Area	2012$/MMBtu
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	$25.65
2	Massachusetts	$25.71
3	New York	$26.12
4	New Jersey	$26.71
5	Pennsylvania	$26.43
6	Illinois	$27.72
7	Indiana, Ohio	$27.67
8	Michigan	$27.66
9	Wisconsin	$27.41
10	Iowa, Minnesota, North Dakota, South Dakota	$27.72
11	Kansas, Nebraska	$27.66
12	Missouri	$27.20
13	Virginia	$27.41
14	Delaware, District of Columbia, Maryland, West Virginia	$26.26
15	Georgia	$27.14
16	North Carolina, South Carolina	$27.53
17	Florida	$27.66
18	Alabama, Kentucky, Mississippi	$26.22
19	Tennessee	$27.93
20	Arkansas, Louisiana, Oklahoma	$26.00
21	Texas	$25.69
22	Colorado	$25.39
23	Idaho, Montana, Utah, Wyoming	$25.81
24	Arizona	$28.64
25	Nevada, New Mexico	$27.29
26	California	$28.96
27	Oregon, Washington	$27.99
28	Alaska	$26.87
29	Hawaii	$27.95
30	West Virginia	$27.66
31	U.S. Average	$26.22

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[e] ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt

For furnace fans, the Department of Energy (DOE) developed monthly energy price factors and used monthly energy consumption data for the life-cycle cost and payback period calculations. DOE developed monthly energy price factors to capture robust seasonal trends in monthly energy prices.

8-C.3.2 Monthly Energy Price Factors Determination

In order to convert annual energy prices into monthly energy prices, DOE determined monthly energy price factors.

8-C.3.2.1 Monthly Residential Electricity Price Factor Calculations

DOE collected historical electricity prices from 1990 to 2011 from EIA's Form 826.[1] These data are published annually and include annual electricity sales, revenues from electricity sales, and average price for the residential, commercial, industrial, and transportation sectors by State. DOE aggregated the data into 30 geographical areas described in Chapter 8 (section 8.2.2.2 Energy Prices).

For each geographic region, DOE determined average electricity prices from 1990 to 2011 by weighting the average residential electricity prices for each State by the number households projected in 2019 in each state.

As an example, to illustrate the methodology for producing monthly price factors, the following tables and charts show the calculation of monthly average electricity price factors, based on California historic electricity price data. Table 8-C.3.9 shows the average residential electricity prices for California.

Table 8-C.3.1 1990-2011 Average Residential Electricity Prices for California (nominal cents / kWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1990	9.68	9.90	9.97	9.68	9.97	9.95	10.43	10.45	10.00	9.69	9.82	10.08	9.97
1991	10.42	10.54	10.70	10.71	10.82	10.83	11.10	11.21	10.88	10.83	10.63	10.78	10.79
1992	10.93	10.76	10.91	10.91	11.07	11.10	11.47	11.59	11.21	10.80	10.81	11.17	11.06
1993	11.10	10.91	11.11	11.15	11.39	11.50	11.66	11.76	11.32	11.18	11.21	11.29	11.30
1994	11.12	11.13	11.27	11.46	11.34	11.59	11.84	11.83	11.53	11.14	11.20	11.52	11.41
1995	11.31	11.28	11.56	11.39	11.64	11.73	11.99	12.05	11.77	11.42	11.37	11.65	11.60
1996	11.43	11.16	11.25	11.27	11.53	10.42	11.56	11.88	11.36	11.36	11.00	11.52	11.31
1997	11.23	11.01	11.26	11.30	11.55	11.61	11.84	11.92	11.62	11.59	11.28	11.64	11.49
1998	10.96	10.23	9.92	10.35	10.70	10.56	10.75	10.92	10.86	10.49	10.51	10.56	10.57
1999	10.47	10.47	10.47	10.57	10.67	10.87	10.87	10.97	10.67	10.87	10.57	10.67	10.68
2000	10.50	10.50	10.68	10.16	10.84	11.12	11.12	11.36	10.82	10.99	10.94	11.37	10.87
2001	10.89	11.14	11.29	11.14	11.97	12.87	13.05	12.80	12.87	12.49	12.12	12.26	12.07
2002	13.03	12.58	12.58	12.05	12.82	12.87	13.28	12.92	11.61	11.98	12.55	13.31	12.63
2003	12.81	12.41	11.42	12.51	12.74	13.12	13.50	12.90	10.08	10.47	12.54	12.45	12.24
2004	12.59	12.39	12.14	11.43	11.97	12.40	12.19	12.50	12.18	11.43	12.50	12.40	12.18
2005	12.19	12.33	11.28	12.12	12.57	13.40	13.16	13.43	12.14	11.30	12.80	12.91	12.47
2006	13.14	13.45	13.72	13.99	14.04	15.17	16.65	14.89	14.57	12.20	14.47	14.47	14.23
2007	14.98	14.18	13.82	13.74	14.15	14.72	15.13	15.11	15.10	12.53	14.37	14.46	14.36
2008	13.78	13.39	13.18	12.94	13.55	14.46	14.38	14.51	14.01	13.09	14.17	13.76	13.77
2009	14.66	14.10	14.10	13.93	14.94	14.72	15.60	15.85	15.45	13.80	14.30	14.70	14.68
2010	15.18	14.21	14.78	13.91	14.91	15.00	15.02	15.19	14.84	14.11	14.67	14.96	14.73
2011	15.78	14.82	14.76	14.6	15.14	15.32	16.25	15.6	15.27	14.3	15.4	15.29	15.21

DOE then calculated monthly energy price factors by dividing the monthly prices by the annual average for each year. Table 8-C.3.10 and Figure 8-C.3.1 show the calculated results for California.

Table 8-C.3.2 Monthly Electricity Price Factors for 1990-2011 for California

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.97	0.99	1.00	0.97	1.00	1.00	1.05	1.05	1.00	0.97	0.99	1.01
1991	0.97	0.98	0.99	0.99	1.00	1.00	1.03	1.04	1.01	1.00	0.99	1.00
1992	0.99	0.97	0.99	0.99	1.00	1.00	1.04	1.05	1.01	0.98	0.98	1.01
1993	0.98	0.97	0.98	0.99	1.01	1.02	1.03	1.04	1.00	0.99	0.99	1.00
1994	0.97	0.98	0.99	1.00	0.99	1.02	1.04	1.04	1.01	0.98	0.98	1.01
1995	0.97	0.97	1.00	0.98	1.00	1.01	1.03	1.04	1.01	0.98	0.98	1.01
1996	1.01	0.99	0.99	1.00	1.02	0.92	1.02	1.05	1.00	1.00	0.97	1.02
1997	0.98	0.96	0.98	0.98	1.01	1.01	1.03	1.04	1.01	1.01	0.98	1.01
1998	1.04	0.97	0.94	0.98	1.01	1.00	1.02	1.03	1.03	0.99	0.99	1.00
1999	0.98	0.98	0.98	0.99	1.00	1.02	1.02	1.03	1.00	1.02	0.99	1.00
2000	0.97	0.97	0.98	0.94	1.00	1.02	1.02	1.05	1.00	1.01	1.01	1.05
2001	0.90	0.92	0.94	0.92	0.99	1.07	1.08	1.06	1.07	1.03	1.00	1.02
2002	1.03	1.00	1.00	0.95	1.01	1.02	1.05	1.02	0.92	0.95	0.99	1.05
2003	1.05	1.01	0.93	1.02	1.04	1.07	1.10	1.05	0.82	0.85	1.02	1.02
2004	1.03	1.02	1.00	0.94	0.98	1.02	1.00	1.03	1.00	0.94	1.03	1.02
2005	0.98	0.99	0.90	0.97	1.01	1.07	1.06	1.08	0.97	0.91	1.03	1.04
2006	0.92	0.95	0.96	0.98	0.99	1.07	1.17	1.05	1.02	0.86	1.02	1.02
2007	1.04	0.99	0.96	0.96	0.99	1.03	1.05	1.05	1.05	0.87	1.00	1.01
2008	1.00	0.97	0.96	0.94	0.98	1.05	1.04	1.05	1.02	0.95	1.03	1.00
2009	1.00	0.96	0.96	0.95	1.02	1.00	1.06	1.08	1.05	0.94	0.97	1.00
2010	1.03	0.96	1.00	0.94	1.01	1.02	1.02	1.03	1.01	0.96	1.00	1.02
2011	1.04	0.97	0.97	0.96	1.00	1.01	1.07	1.03	1.00	0.94	1.01	1.01
Avg	0.99	0.98	0.97	0.97	1.00	1.02	1.05	1.05	1.00	0.96	1.00	1.01

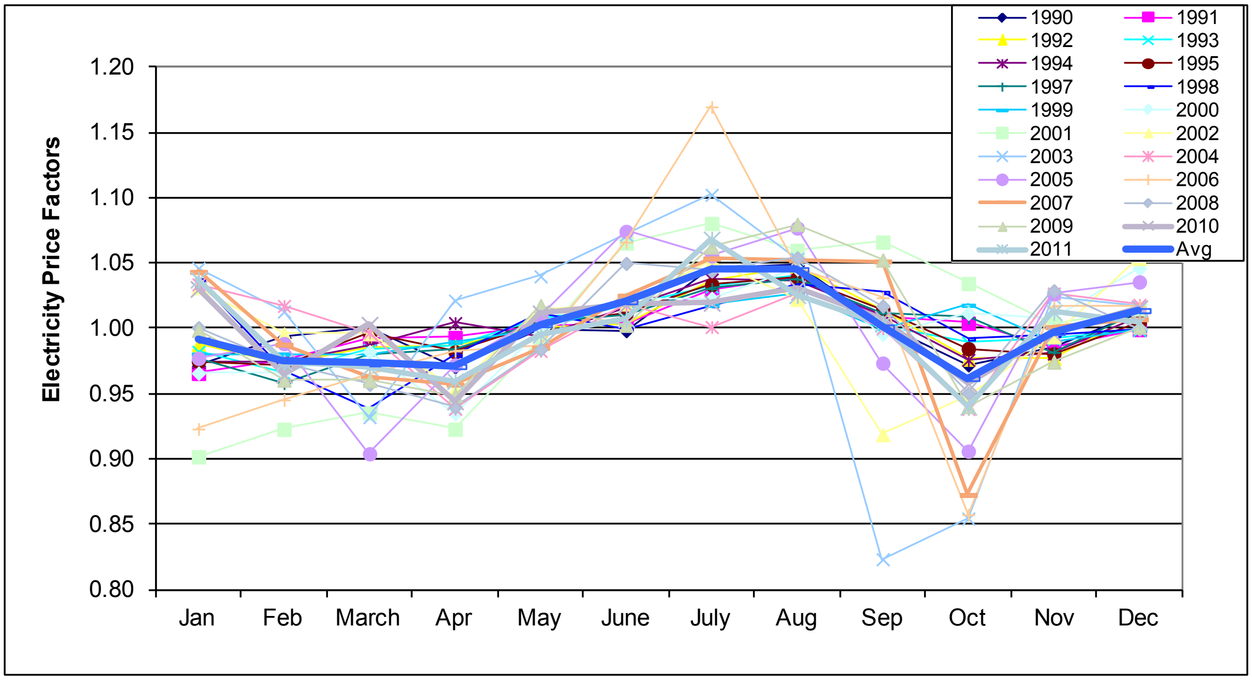

Figure 8-C.3.1 Monthly Electricity Price Factors for 1990–2011 for California

DOE then averaged the monthly energy price factors for 1990 to 2011 to develop an average energy price factor for each month. DOE performed the same calculations for each geographic region to develop the average monthly energy price factors shown in Table 8-C.3.11, which include the results for California.

Table 8-C.3.3 Monthly Electricity Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.98	0.98	0.99	0.99	1.01	1.01	1.00	1.01	1.01	1.01	1.01	1.00
Massachusetts	0.98	0.98	0.98	0.98	1.00	1.02	1.00	1.01	1.02	1.02	0.99	1.01
New York	0.95	0.96	0.96	0.97	1.00	1.04	1.05	1.05	1.05	1.01	0.99	0.98
New Jersey	0.94	0.95	0.95	0.96	0.98	1.06	1.09	1.09	1.07	0.97	0.97	0.97
Pennsylvania	0.92	0.93	0.95	0.97	1.02	1.06	1.07	1.06	1.05	1.02	0.98	0.96
Illinois	0.88	0.91	0.95	1.00	1.04	1.07	1.08	1.06	1.07	1.07	0.97	0.90
Indiana, Ohio	0.89	0.92	0.95	1.01	1.05	1.06	1.03	1.04	1.05	1.05	1.00	0.94
Michigan	0.97	0.98	0.97	0.98	0.99	1.03	1.04	1.05	1.02	0.99	0.98	0.99
Wisconsin	0.96	0.99	0.98	1.00	1.02	1.03	1.00	1.01	1.01	1.02	1.00	0.98
Iowa, Minnesota, North Dakota, South Dakota	0.91	0.93	0.95	0.98	1.03	1.07	1.08	1.07	1.05	1.01	0.97	0.94
Kansas, Nebraska	0.88	0.91	0.94	0.98	1.02	1.10	1.10	1.11	1.09	1.00	0.96	0.91
Missouri	0.84	0.86	0.91	0.96	1.09	1.18	1.16	1.16	1.05	0.98	0.94	0.88
Virginia	0.91	0.92	0.95	0.99	1.03	1.07	1.06	1.07	1.05	1.02	0.98	0.93
Delaware, District of Columbia, Maryland	0.89	0.90	0.91	0.93	1.03	1.12	1.12	1.12	1.09	1.01	0.95	0.93
Georgia	0.90	0.93	0.96	0.97	1.02	1.09	1.10	1.11	1.06	1.00	0.96	0.91
North Carolina, South Carolina	0.94	0.96	0.98	1.01	1.02	1.00	1.02	1.02	1.03	1.05	1.01	0.97
Florida	0.98	1.00	1.00	1.01	1.00	0.99	1.00	1.00	1.00	1.01	1.02	1.00
Alabama, Kentucky, Mississippi	0.92	0.95	0.97	1.02	1.03	1.03	1.02	1.03	1.02	1.03	1.01	0.97
Tennessee	0.96	0.97	0.98	1.01	1.02	1.01	0.99	0.99	1.00	1.04	1.03	1.00
Arkansas, Louisiana, Oklahoma	0.90	0.94	0.97	1.00	1.02	1.05	1.05	1.05	1.06	1.04	0.98	0.94
Texas	0.91	0.93	0.96	0.99	1.02	1.05	1.05	1.05	1.05	1.04	0.98	0.95
Colorado	0.96	0.97	0.97	0.99	1.02	1.03	1.02	1.02	1.02	1.02	1.00	0.98
Idaho, Montana, Utah, Wyoming	0.96	0.97	0.97	0.98	1.00	1.03	1.04	1.03	1.02	1.03	0.99	0.98
Arizona	0.88	0.91	0.93	0.98	1.08	1.08	1.07	1.06	1.06	1.06	0.94	0.95
Nevada, New Mexico	0.97	0.99	1.00	1.02	1.01	1.00	0.99	1.00	1.00	1.03	1.02	0.99
California	0.99	0.98	0.97	0.97	1.00	1.02	1.05	1.04	1.00	0.96	1.00	1.01
Oregon, Washington	0.98	0.99	0.99	0.98	0.98	0.99	1.00	1.00	1.01	1.02	1.02	1.02
Alaska	0.95	0.96	0.98	0.99	1.02	1.02	1.03	1.03	1.01	1.01	1.01	0.98
Hawaii	0.94	0.95	0.98	1.00	1.04	1.02	1.00	1.01	1.02	1.05	1.02	0.97
West Virginia	0.93	0.94	0.96	0.99	1.02	1.04	1.05	1.05	1.04	1.03	0.99	0.96
United States	0.93	0.94	0.96	0.99	1.02	1.04	1.05	1.05	1.04	1.03	0.99	0.96

8-C.3.2.2 Monthly Residential Natural Gas Price Factor Calculations

DOE collected historical natural gas prices from 1989 to 2011 from the Energy Information Administration's (EIA's) Natural Gas Navigator.[2] The Natural Gas Navigator includes annual and monthly natural gas prices for residential, commercial, and industrial consumers by State. DOE aggregated the data into 29 geographical areas described in Chapter 8 (section 8.2.2.2 Energy Prices).

For each geographic area, DOE determined average natural gas prices from 1989 to 2011 by weighting the average residential natural gas prices for each State by the number households projected in 2019 in each state.

Again, as an example for how DOE determined monthly natural gas price factors, the methodology used to determine monthly average price factors can be seen below. Table 8-C.3.12 shows the historic average residential gas prices for California.

Table 8-C.3.4 1989-2010 Average Residential Natural Gas Prices for California ($/tcf)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1989	5.84	5.63	5.21	4.62	5.69	6.09	6.07	5.90	6.10	6.11	5.12	5.38	5.65
1990	5.72	5.77	5.64	5.07	5.96	6.22	6.07	5.90	6.04	6.15	5.36	5.99	5.82
1991	6.60	6.03	6.04	5.91	6.33	6.68	6.52	6.42	6.48	6.46	5.92	6.21	6.30
1992	6.15	6.03	5.76	5.52	5.99	6.28	6.27	6.21	6.29	6.35	5.60	5.80	6.02
1993	6.20	6.02	5.87	5.71	6.10	6.58	6.61	6.61	6.67	6.69	6.29	6.33	6.31
1994	6.36	6.25	6.13	6.55	5.62	6.64	6.55	6.68	6.66	6.71	6.33	6.63	6.43
1995	6.52	6.39	6.28	6.22	6.58	7.11	6.88	6.76	6.90	6.66	5.78	5.92	6.50
1996	6.48	6.33	6.21	6.01	6.39	6.99	8.28	6.85	5.94	6.67	6.41	6.20	6.56
1997	6.27	6.27	6.42	6.18	6.38	7.70	7.05	7.56	7.42	7.80	7.48	7.20	6.98
1998	7.27	6.48	6.77	6.79	7.00	7.31	7.06	7.20	7.00	6.87	6.79	6.88	6.95
1999	6.82	6.54	6.22	5.98	6.22	6.82	7.04	7.21	6.88	7.51	7.13	6.52	6.74
2000	6.32	7.01	7.07	7.20	7.78	8.38	8.93	8.75	8.84	9.89	9.54	10.48	8.35
2001	12.23	13.91	13.92	12.05	11.74	11.40	8.75	8.26	7.33	6.05	5.88	6.08	9.80
2002	7.13	6.69	6.01	6.86	7.31	7.18	7.22	7.17	7.28	7.52	7.89	7.75	7.17
2003	8.85	8.78	9.49	9.25	8.99	9.47	9.79	9.57	9.59	9.29	8.64	9.00	9.23
2004	9.88	9.86	8.71	8.28	9.29	10.04	10.06	10.07	9.92	9.73	10.86	10.74	9.79
2005	10.98	10.74	9.98	10.38	11.13	10.86	11.42	11.44	12.78	14.79	15.50	14.02	12.00
2006	14.18	13.24	11.75	10.91	11.88	10.86	10.66	11.10	11.61	9.97	10.83	11.17	11.51
2007	10.96	11.65	11.14	11.48	12.53	13.00	12.90	11.85	11.20	11.64	11.48	11.18	11.75
2008	11.87	12.27	12.31	13.98	15.41	16.17	17.69	15.79	13.58	12.47	10.07	9.95	13.46
2009	10.55	9.73	8.38	8.62	8.75	9.01	9.44	9.82	9.12	9.52	9.53	9.65	9.34
2010	10.38	10.67	9.02	9.68	10.26	10.22	10.46	10.73	10.29	10.2	8.61	9.47	10.00
2011	9.59	9.89	9.64	9.95	10.47	11.1	11.06	11.25	10.67	10.33	9.20	9.14	10.19

DOE then calculated monthly energy price factors for each year by dividing the residential natural gas prices for each month by the natural gas annual average price for each year. Table 8-C.3.13 and Figure 8-C.3.2 show the calculated results for California.

Table 8-C.3.5 1989-2011 Monthly Natural Gas Price Factors for California

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989	1.03	1.00	0.92	0.82	1.01	1.08	1.07	1.04	1.08	1.08	0.91	0.95
1990	0.98	0.99	0.97	0.87	1.02	1.07	1.04	1.01	1.04	1.06	0.92	1.03
1991	1.05	0.96	0.96	0.94	1.00	1.06	1.03	1.02	1.03	1.03	0.94	0.99
1992	1.02	1.00	0.96	0.92	0.99	1.04	1.04	1.03	1.04	1.05	0.93	0.96
1993	0.98	0.95	0.93	0.91	0.97	1.04	1.05	1.05	1.06	1.06	1.00	1.00
1994	0.99	0.97	0.95	1.02	0.87	1.03	1.02	1.04	1.04	1.04	0.99	1.03
1995	1.00	0.98	0.97	0.96	1.01	1.09	1.06	1.04	1.06	1.02	0.89	0.91
1996	0.99	0.96	0.95	0.92	0.97	1.07	1.26	1.04	0.91	1.02	0.98	0.94
1997	0.90	0.90	0.92	0.89	0.91	1.10	1.01	1.08	1.06	1.12	1.07	1.03
1998	1.05	0.93	0.97	0.98	1.01	1.05	1.02	1.04	1.01	0.99	0.98	0.99
1999	1.01	0.97	0.92	0.89	0.92	1.01	1.04	1.07	1.02	1.11	1.06	0.97
2000	0.76	0.84	0.85	0.86	0.93	1.00	1.07	1.05	1.06	1.18	1.14	1.26
2001	1.25	1.42	1.42	1.23	1.20	1.16	0.89	0.84	0.75	0.62	0.60	0.62
2002	0.99	0.93	0.84	0.96	1.02	1.00	1.01	1.00	1.02	1.05	1.10	1.08
2003	0.96	0.95	1.03	1.00	0.97	1.03	1.06	1.04	1.04	1.01	0.94	0.98
2004	1.01	1.01	0.89	0.85	0.95	1.03	1.03	1.03	1.01	0.99	1.11	1.10
2005	0.91	0.89	0.83	0.86	0.93	0.90	0.95	0.95	1.06	1.23	1.29	1.17
2006	1.23	1.15	1.02	0.95	1.03	0.94	0.93	0.96	1.01	0.87	0.94	0.97
2007	0.93	0.99	0.95	0.98	1.07	1.11	1.10	1.01	0.95	0.99	0.98	0.95
2008	0.88	0.91	0.91	1.04	1.14	1.20	1.31	1.17	1.01	0.93	0.75	0.74
2009	1.13	1.04	0.90	0.92	0.94	0.96	1.01	1.05	0.98	1.02	1.02	1.03
2010	1.04	1.07	0.90	0.97	1.03	1.02	1.05	1.07	1.03	1.02	0.86	0.95
2011	0.94	0.97	0.95	0.98	1.03	1.09	1.09	1.10	1.05	1.01	0.90	0.90
Avg	1.00	0.99	0.95	0.94	1.00	1.05	1.05	1.03	1.01	1.02	0.97	0.98

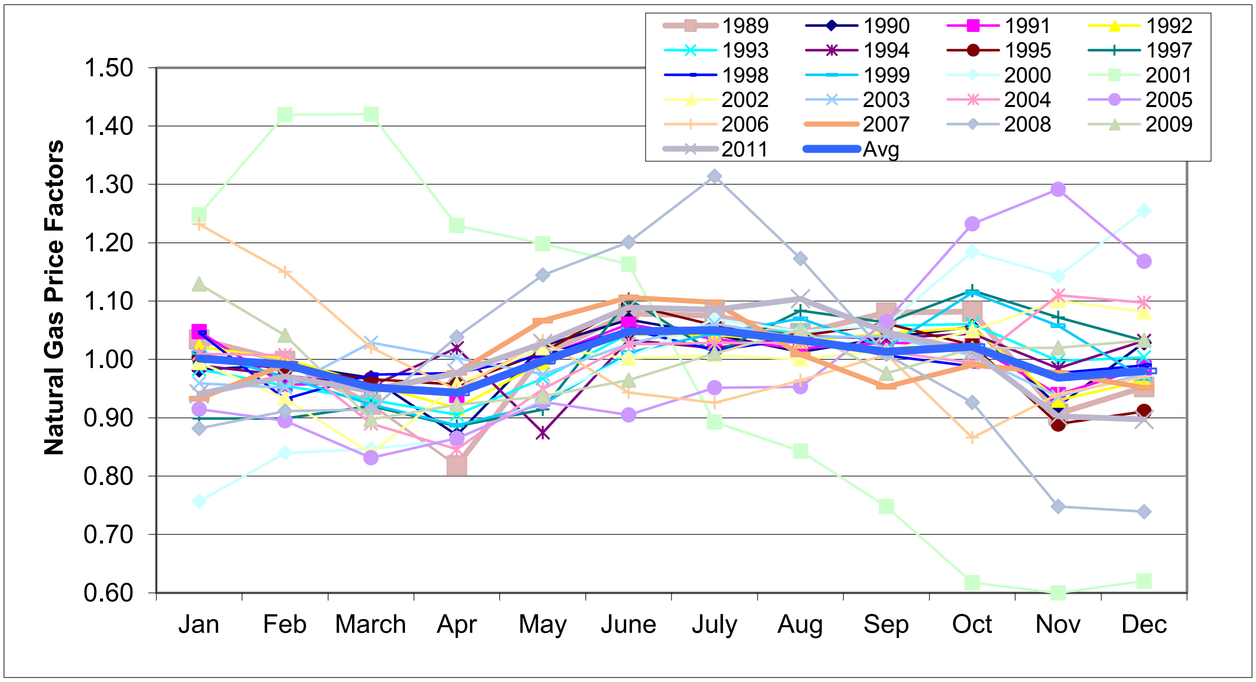

Figure 8-C.3.2 Monthly Natural Gas Price Factors for 1989-2011 for California

DOE then averaged the monthly energy price factors for 1989 to 2011 to develop an average energy price factor for each month. DOE performed the same calculations for each geographic area to develop the average monthly energy price factors shown in Table 8-C.3.14, which also includes the monthly energy price factor results calculated for California.

Table 8-C.3.6 Monthly Natural Gas Monthly Energy Price Factors

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.90	0.91	0.91	0.93	0.97	1.05	1.14	1.15	1.12	1.01	0.97	0.94
Massachusetts	0.98	0.99	0.98	1.01	0.92	0.96	1.05	1.10	1.07	0.92	1.02	1.01
New York	0.86	0.85	0.85	0.88	0.98	1.11	1.18	1.17	1.14	1.00	0.91	0.85
New Jersey	0.90	0.90	0.90	0.93	0.99	1.09	1.14	1.14	1.12	1.02	0.95	0.93
Pennsylvania	0.83	0.84	0.85	0.89	0.99	1.12	1.25	1.28	1.21	1.00	0.90	0.85
Illinois	0.83	0.84	0.83	0.88	1.04	1.19	1.27	1.29	1.19	0.96	0.87	0.82
Indiana, Ohio	0.84	0.85	0.86	0.92	1.01	1.15	1.24	1.25	1.18	0.96	0.87	0.85
Michigan	0.84	0.84	0.85	0.89	0.98	1.12	1.24	1.28	1.19	1.00	0.90	0.87
Wisconsin	0.96	0.94	0.94	0.96	0.96	1.09	1.12	1.14	1.06	0.90	0.98	0.96
Iowa, Minnesota, North Dakota, South Dakota	0.87	0.85	0.85	0.87	0.98	1.14	1.23	1.27	1.19	0.97	0.91	0.87
Kansas, Nebraska	0.82	0.82	0.82	0.88	0.98	1.14	1.22	1.27	1.24	1.08	0.89	0.84
Missouri	0.75	0.76	0.76	0.82	0.95	1.15	1.31	1.38	1.30	1.11	0.89	0.80
Virginia	0.83	0.81	0.79	0.86	1.01	1.17	1.27	1.26	1.26	1.04	0.87	0.84
Delaware, District of Columbia, Maryland	0.83	0.83	0.84	0.91	1.02	1.14	1.22	1.22	1.21	1.02	0.90	0.86
Georgia	0.75	0.79	0.82	0.90	1.09	1.22	1.28	1.27	1.20	1.07	0.84	0.79
North Carolina, South Carolina	0.81	0.81	0.82	0.87	0.99	1.17	1.24	1.29	1.24	1.04	0.88	0.86
Florida	0.81	0.83	0.88	0.94	1.02	1.09	1.12	1.14	1.13	1.12	1.02	0.90
Alabama, Kentucky, Mississippi	0.82	0.82	0.84	0.91	1.04	1.15	1.18	1.20	1.18	1.08	0.93	0.86
Tennessee	0.83	0.84	0.84	0.90	0.98	1.12	1.19	1.23	1.18	1.08	0.93	0.88
Arkansas, Louisiana, Oklahoma	0.78	0.78	0.80	0.87	1.03	1.14	1.21	1.24	1.21	1.14	0.96	0.84
Texas	0.78	0.79	0.81	0.92	1.06	1.16	1.20	1.23	1.22	1.10	0.91	0.81
Colorado	0.82	0.83	0.85	0.88	0.96	1.19	1.22	1.30	1.21	0.99	0.89	0.84
Idaho, Montana, Utah, Wyoming	0.92	0.92	0.94	0.92	0.96	1.04	1.12	1.17	1.10	0.98	0.96	0.94
Arizona	0.78	0.80	0.82	0.90	1.01	1.11	1.20	1.25	1.21	1.14	0.96	0.82
Nevada, New Mexico	0.81	0.82	0.85	0.92	1.04	1.20	1.18	1.23	1.19	1.06	0.90	0.82
California	1.00	0.99	0.95	0.94	1.00	1.05	1.05	1.03	1.01	1.02	0.97	0.98
Oregon, Washington	0.89	0.90	0.91	0.93	0.97	1.02	1.13	1.18	1.14	1.03	0.95	0.92
Alaska	0.94	0.94	0.95	0.97	1.01	1.04	1.12	1.11	1.03	0.98	0.94	0.96
Hawaii	0.95	0.96	0.96	0.97	0.99	1.00	1.01	1.04	1.03	1.04	1.03	1.01
West Virginia	0.84	0.84	0.85	0.88	0.96	1.15	1.28	1.27	1.18	0.97	0.90	0.89
United States	0.86	0.87	0.88	0.92	1.00	1.12	1.18	1.21	1.16	1.01	0.92	0.88

8-C.3.2.3 Monthly Residential Liquid Petroleum Gas Price Factor Calculations

DOE collected historical liquid petroleum gas (LPG) prices from 1995 to 2009 from EIA's Short-Term Energy Outlook.[4] The Short-Term Energy Outlook includes monthly LPG prices by Census Region (Northeast, South, Midwest, and West).[f]

The same process as used for electricity and natural gas price factors was used for calculating the monthly LPG price factors. These monthly price factors were calculated below, using data from the Northeast region. Table 8-C.3.15 shows the Northeast residential LPG prices from 1995 to 2009.

Table 8-C.3.7 Average LPG Prices for the Northeast (nominal cents / gallon)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1995	119	118	120	121	124	126	126	125	122	121	118	117	121
1996	123	125	128	125	130	131	129	127	127	133	135	145	130
1997	143	137	131	131	130	130	130	127	126	127	123	122	130
1998	121	120	120	123	124	124	122	121	119	118	115	114	120
1999	112	113	114	118	122	124	126	129	127	129	128	128	122
2000	132	148	148	145	148	151	155	154	157	159	156	160	151
2001	176	170	162	160	162	160	156	152	150	150	144	139	157
2002	139	138	139	143	142	144	143	141	141	142	142	142	141
2003	150	166	182	164	161	161	159	156	155	155	155	158	160
2004	169	173	171	168	170	173	173	176	181	187	193	187	177
2005	186	186	190	197	199	200	202	205	217	224	220	217	204
2006	221	220	220	225	231	237	242	244	240	232	229	228	231
2007	227	229	235	239	247	252	253	252	254	260	274	275	250
2008	282	280	284	292	306	320	333	329	324	305	280	267	300
2009	268	267	267	263	258	255	255	251	249	250	252	255	257

DOE then calculated monthly energy price factors for each year by dividing the prices for each month by the average price for each year. Table 8-C.3.16 and Figure 8-C.3.3 show the calculated results for the Northeast.

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[f] Refer to https://www.census.gov/geo/www/us_regdiv.pdf.

Table 8-C.3.8 Monthly LPG Price Factors for 1995–2009 for the Northeast

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0.98	0.97	0.99	1.00	1.02	1.03	1.04	1.03	1.00	1.00	0.97	0.96
1996	0.94	0.97	0.99	0.96	1.00	1.01	0.99	0.98	0.98	1.02	1.04	1.12
1997	1.10	1.06	1.01	1.01	1.01	1.00	1.00	0.98	0.97	0.98	0.95	0.94
1998	1.01	1.00	1.00	1.02	1.03	1.03	1.02	1.01	0.99	0.98	0.96	0.95
1999	0.92	0.92	0.93	0.96	1.00	1.02	1.03	1.05	1.04	1.06	1.05	1.04
2000	0.87	0.98	0.98	0.96	0.98	1.00	1.03	1.02	1.04	1.05	1.03	1.06
2001	1.12	1.08	1.03	1.02	1.04	1.02	0.99	0.97	0.96	0.96	0.92	0.89
2002	0.98	0.97	0.98	1.01	1.01	1.02	1.01	1.00	1.00	1.01	1.00	1.00
2003	0.94	1.04	1.13	1.03	1.01	1.00	1.00	0.97	0.97	0.97	0.97	0.99
2004	0.95	0.98	0.96	0.95	0.96	0.98	0.98	1.00	1.02	1.06	1.09	1.06
2005	0.91	0.91	0.93	0.97	0.98	0.98	0.99	1.01	1.07	1.10	1.08	1.07
2006	0.96	0.95	0.95	0.98	1.00	1.03	1.05	1.06	1.04	1.01	0.99	0.99
2007	0.91	0.92	0.94	0.96	0.99	1.01	1.01	1.01	1.02	1.04	1.10	1.10
2008	0.94	0.93	0.95	0.97	1.02	1.06	1.11	1.10	1.08	1.02	0.93	0.89
2009	1.04	1.04	1.04	1.02	1.00	0.99	0.99	0.97	0.97	0.97	0.98	0.99
Avg	0.97	0.98	0.99	0.99	1.00	1.01	1.02	1.01	1.01	1.01	1.00	1.00

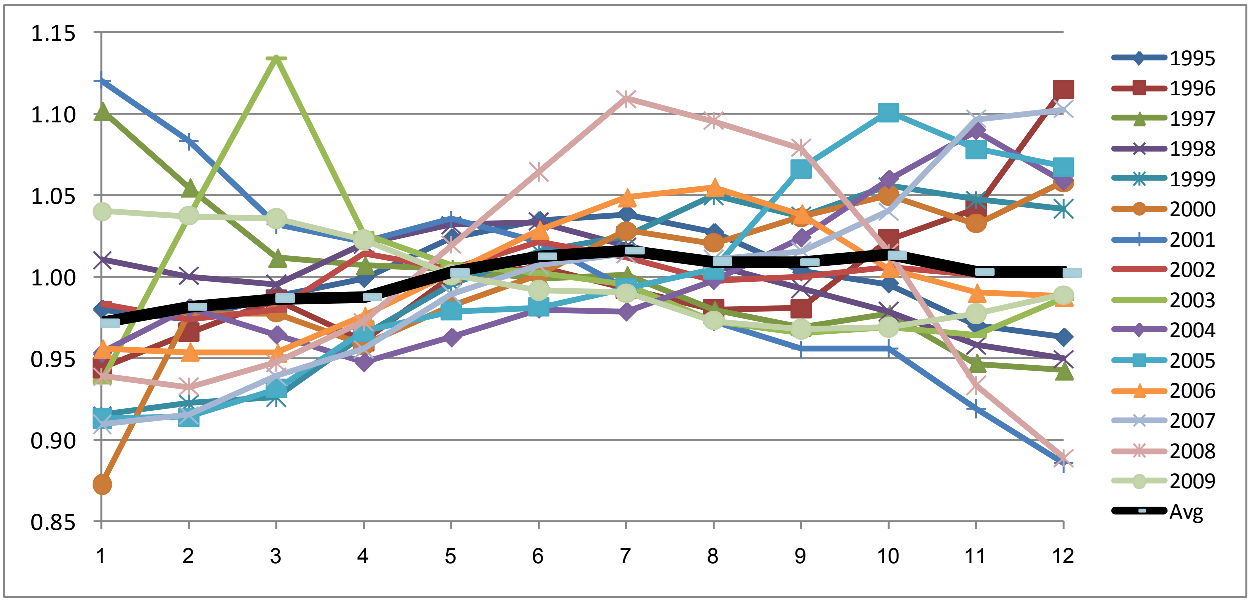

Figure 8-C.3.3 Monthly LPG Factors for 1995–2009 for the Northeast

DOE then averaged the monthly energy price factors for 1995 to 2009 to develop an average energy price factor for each month. DOE performed the same calculations for each Census Region to develop the average monthly energy price factors shown in Table 8-C.3.17, which includes the calculated Northeast region monthly LPG energy price factors.

Table 8-C.3.9 Monthly LPG Energy Price Factors

Census Regions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northeast	0.97	0.98	0.99	0.99	1.00	1.01	1.02	1.01	1.01	1.01	1.00	1.00
South	1.04	1.04	1.03	1.01	1.00	0.97	0.94	0.93	0.96	0.98	1.03	1.07
Midwest	1.04	1.04	1.03	1.01	0.99	0.97	0.95	0.93	0.96	1.00	1.03	1.06
West	1.05	1.05	1.03	1.01	0.99	0.96	0.92	0.91	0.95	1.01	1.04	1.08
U.S.	1.02	1.03	1.02	1.02	1.02	1.00	0.95	0.93	0.96	0.99	1.02	1.05

8-C.3.2.4 Monthly Residential Oil Price Factor Calculations

DOE collected historical oil prices from 1995 to 2009 from EIA's Short-Term Energy Outlook.[4] The Short-Term Energy Outlook includes monthly oil prices by Census Region (Northeast, South, Midwest, and West).

The same methodology for calculating monthly energy price factors for residential fuel oil. These monthly price factors were calculated below, using data from the Northeast region. Table 8-C.3.18 shows the Northeast residential oil prices from 1995 to 2009.

Table 8-C.3.10 Average Residential Oil Prices for the Northeast (nominal cents / gallon)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1995	91.9	92.6	91.7	90.2	91.7	90.2	87.2	86	87.2	88.9	91.2	96.8	90.5
1996	101.1	102.6	106.1	108.3	103.8	96.6	92.5	92.4	99.4	109	111.6	114.1	103
1997	114.4	111.6	107.5	105.4	102.6	98.4	93.6	91.2	93.3	97.8	99.5	99.6	101
1998	98.3	97.6	95.3	93.2	90.7	86.5	82.3	79.6	81.1	83.2	84.6	83.6	88
1999	85.4	84.7	85.4	87.2	86.4	85.1	85	86	93.6	99.5	105	109.8	91.1
2000	135	154	130.5	123.7	124	124	122.2	125.6	139.3	144.2	147.8	149.3	135
2001	146	141.4	136.9	134.7	131.9	127	121	121.2	123.7	121.4	118.4	115.9	128
2002	117.7	116.2	118.2	119.9	118.4	116	112.5	111.9	117.1	121.2	124.8	130.9	119
2003	140.9	159.8	163.4	143.6	137.3	132	125.5	125.9	128.4	132	136.7	142.4	139
2004	150.8	153	150.1	149.2	151	151	152.1	159.1	168.7	189.6	192.3	189.5	163
2005	191	194.4	203.8	206.4	202	211	216.8	229.6	252.3	251.8	242.9	243.7	220
2006	246.2	243.5	247.3	255	259.7	260	259.2	262.7	252.2	244.6	247.4	251.3	252
2007	245	254.2	258.2	261	261.6	263	269.6	263.4	273.7	288	318	325.3	273
2008	330.2	333.7	363.6	378.9	409.7	442	454.5	407.7	384.9	334.2	296.3	262.6	367
2009	259.4	246.9	237	236.6	231.8	246	240.7	253	248	259.7	272.1	276.4	251

DOE then calculated monthly energy price factors by dividing the monthly prices by the average price for each year. Table 8-C.3.19 and Figure 8-C.3.4 show the calculated results for the Northeast.

Table 8-C.3.11 Monthly Oil Prices Factors for 1995 – 2009 for Census Division 1

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	1.02	1.02	1.01	1.00	1.01	1.00	0.96	0.95	0.96	0.98	1.01	1.07
1996	0.98	0.99	1.03	1.05	1.01	0.94	0.90	0.90	0.96	1.06	1.08	1.11
1997	1.13	1.10	1.06	1.04	1.01	0.97	0.92	0.90	0.92	0.97	0.98	0.98
1998	1.12	1.11	1.08	1.06	1.03	0.98	0.94	0.90	0.92	0.95	0.96	0.95
1999	0.94	0.93	0.94	0.96	0.95	0.93	0.93	0.94	1.03	1.09	1.15	1.21
2000	1.00	1.14	0.97	0.92	0.92	0.92	0.91	0.93	1.03	1.07	1.10	1.11
2001	1.14	1.10	1.07	1.05	1.03	0.99	0.94	0.94	0.96	0.95	0.92	0.90
2002	0.99	0.98	1.00	1.01	1.00	0.98	0.95	0.94	0.99	1.02	1.05	1.10
2003	1.01	1.15	1.18	1.03	0.99	0.95	0.90	0.91	0.92	0.95	0.98	1.02
2004	0.93	0.94	0.92	0.92	0.93	0.92	0.93	0.98	1.04	1.16	1.18	1.16
2005	0.87	0.88	0.92	0.94	0.92	0.95	0.98	1.04	1.14	1.14	1.10	1.11
2006	0.98	0.96	0.98	1.01	1.03	1.03	1.03	1.04	1.00	0.97	0.98	1.00
2007	0.90	0.93	0.94	0.95	0.96	0.96	0.99	0.96	1.00	1.05	1.16	1.19
2008	0.90	0.91	0.99	1.03	1.12	1.21	1.24	1.11	1.05	0.91	0.81	0.72
2009	1.04	0.99	0.95	0.94	0.92	0.98	0.96	1.01	0.99	1.04	1.09	1.10
Avg	0.99	1.01	1.00	0.99	0.99	0.98	0.97	0.96	0.99	1.02	1.04	1.05

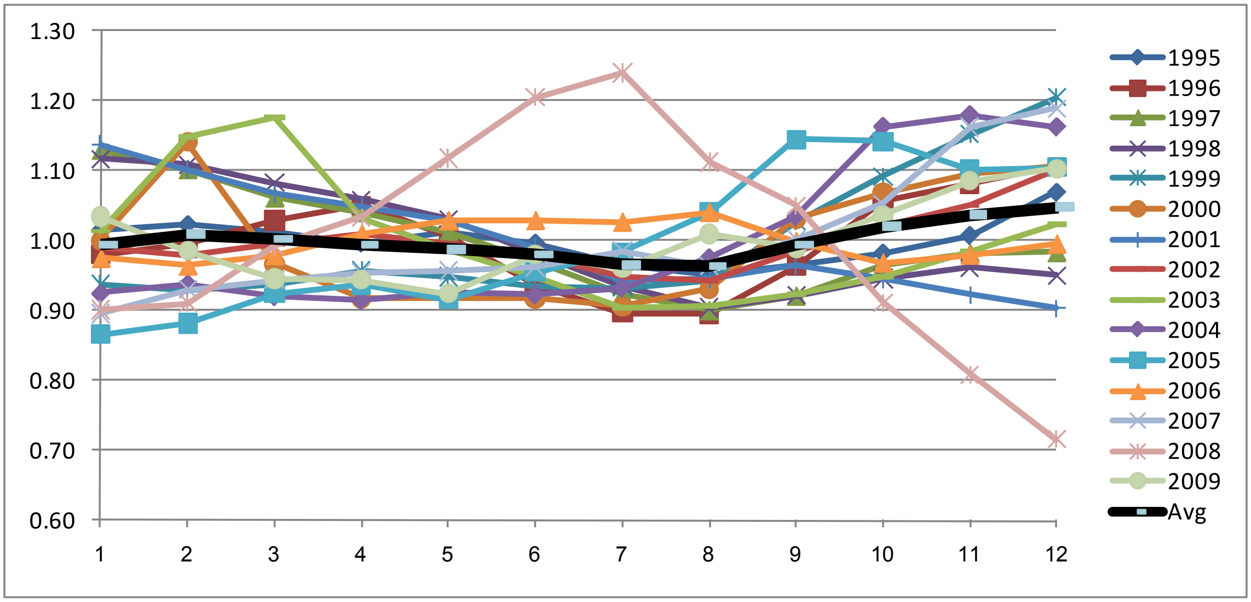

Figure 8-C.3.4 Monthly Oil Prices Factors for 1995–2009 for Census Division 1

DOE then averaged the monthly energy price factors for 1995 to 2009 to develop an average energy price factor for each month. DOE performed the same calculations for each Census Region to develop the average monthly energy price factors shown in Table 8-C.3.20, which includes the calculated Northeast region monthly oil energy price factors.

Table 8-C.3.12 Monthly Oil Energy Price Factors

Census Regions	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Northeast	0.99	1.01	1.00	0.99	0.99	0.98	0.97	0.96	0.99	1.02	1.04	1.05
South	0.96	0.97	0.98	0.99	0.98	0.98	0.98	1.00	1.03	1.05	1.05	1.04
Midwest	1.00	1.02	1.01	1.00	0.97	0.95	0.96	0.96	1.00	1.03	1.05	1.06
West	0.93	0.95	0.99	1.01	1.01	1.00	0.99	0.99	1.02	1.04	1.04	1.02
U.S.	0.99	1.01	1.00	0.99	0.99	0.98	0.96	0.97	1.00	1.02	1.04	1.05

8-C.3.3 Seasonal Marginal Price Factors Determination

Marginal energy prices are the prices consumers pay for the last unit of energy used. DOE used the marginal energy prices for each house for the cost of saved energy associated with the use of higher-efficiency equipment. Since marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with possible change to efficiency standards.

EIA provides historical monthly consumption and expenditures by state. This data was used to determine 10 year average marginal prices for the RECS 2009 geographical areas, which are then used to convert average monthly energy prices into marginal monthly energy prices. Since a furnace fan operates during both the heating and the cooling season, DOE determined summer and winter marginal price factors. EIA provided RECS 2009 billing data that had been gathered from a subset of RECS housing records. For each household with billing data, the following are provided for each billing cycle: the start and end date, the electricity consumption in kWh, the electricity cost in dollars, the natural gas bill in dollars, and the gas consumption in hundreds of cubic feet. This data was used to validate marginal energy price factors by RECS 2009 geographical area.

For oil-fired furnaces and boilers, DOE used the average oil prices for each house for both base case equipment and higher-efficiency equipment, as the data necessary for estimating marginal prices were not available. DOE used the same method for LPG-fired equipment.

8-C.3.3.1 Marginal Price Factor Calculation for Electricity and Natural Gas

EIA provides historical monthly consumption and expenditures by state. This data was used to determine 10 year average marginal prices for the RECS 2009 geographical areas DOE interpreted the slope of the regression line (consumption vs. expenditures) for each state as the marginal energy price for that state.

Table 8-C.3.21 and Table 8-C.3.22 show the resulting marginal electricity and natural gas marginal price factors.

Table 8-C.3.21 Marginal Electricity Price Factors using EIA 2002-2011 data

	Geographical Area	Summer	Winter
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.94	0.86
2	Massachusetts	0.96	0.98
3	New York	1.14	0.78
4	New Jersey	1.22	0.94
5	Pennsylvania	1.10	0.81
6	Illinois	1.00	0.70
7	Indiana, Ohio	1.01	0.74
8	Michigan	1.14	0.98
9	Wisconsin	1.01	0.91
10	Iowa, Minnesota, North Dakota, South Dakota	1.09	0.83
11	Kansas, Nebraska	1.17	0.72
12	Missouri	1.21	0.76
13	Virginia	1.09	0.84
14	Delaware, District of Columbia, Maryland	1.18	0.81
15	Georgia	1.16	0.82
16	North Carolina, South Carolina	0.98	0.83
17	Florida	1.00	0.81
18	Alabama, Kentucky, Mississippi	1.00	0.79
19	Tennessee	0.93	0.80
20	Arkansas, Louisiana, Oklahoma	1.05	0.70
21	Texas	1.06	0.84
22	Colorado	1.05	0.84
23	Idaho, Montana, Utah, Wyoming	1.04	0.92
24	Arizona	1.04	0.84
25	Nevada, New Mexico	1.03	0.89
26	California	1.16	1.08
27	Oregon, Washington	0.89	0.93
28	Alaska	0.79	0.89
29	Hawaii	1.51	1.14
30	West Virginia	0.92	0.84
31	**United States**	**1.08**	**0.80**

Table 8-C.3.22 Marginal Natural Gas Price Factors using EIA 2002-2011 data

Geographical Area	Summer	Winter
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.84	0.91
Massachusetts	0.89	0.98
New York	0.76	0.85
New Jersey	0.84	0.97
Pennsylvania	0.73	0.90
Illinois	0.69	0.92
Indiana, Ohio	0.75	0.95
Michigan	0.79	0.89
Wisconsin	0.81	0.91
Iowa, Minnesota, North Dakota, South Dakota	0.72	0.89
Kansas, Nebraska	0.69	0.93
Missouri	0.60	0.83
Virginia	0.69	0.93
Delaware, District of Columbia, Maryland	0.71	0.91
Georgia	0.51	0.89
North Carolina, South Carolina	0.67	0.88
Florida	0.65	0.79
Alabama, Kentucky, Mississippi	0.74	0.89
Tennessee	0.74	0.91
Arkansas, Louisiana, Oklahoma	0.65	0.85
Texas	0.56	0.84
Colorado	0.68	0.96
Idaho, Montana, Utah, Wyoming	0.83	0.94
Arizona	0.64	0.86
Nevada, New Mexico	0.72	0.88
California	0.86	1.03
Oregon, Washington	0.85	0.97
Alaska	0.85	0.95
Hawaii	0.50	0.51
West Virginia	0.80	0.92
United States	**0.80**	**0.92**

8-C.3.3.1 Marginal Price Factor Calculation for Electricity and Natural Gas

DOE used RECS 2009 billing data provided by EIA to validate the marginal energy prices. Deriving marginal energy prices by calculating energy bills based on even a detailed knowledge of a consumer's utility tariff is hampered by the lack of information on items that affect marginal energy prices but are not normally evident on utility tariffs. Taxes, special fees, and one-time surcharges or rebates included in the energy bill are examples of this type of item. Use of RECS billing data avoids having to estimate the effect of non-tariff items on consumer marginal energy prices.

DOE estimated average and marginal electricity and natural gas prices from the RECS monthly billing data. Marginal energy prices were calculated with a linear regression of monthly customer bills to monthly customer energy consumption for each household with billing data available. Household identifying features such as state, utility service area or zip code were not reported in the data preventing a localized aggregation. DOE therefore aggregated the energy prices into the available household identifying features (namely census division and four large states).

DOE interpreted the slope of the regression line for each household as the marginal energy price for that household. DOE kept the marginal energy prices only for sample housing records with regression values greater or equal to 85%. The 85% limit was chosen in order to get a close correlation between the cost and consumption data. Any higher limit excluded most of the housing records from the analysis; any lower limit lost the linearity of the relationship between the seasonal costs and consumption. The slopes of these regression lines are the estimate of the seasonal marginal prices for that household.

To determine the marginal price factor DOE divided the seasonal marginal and average electricity price for each household. DOE then aggregated the individual electricity and natural gas marginal price factors using the RECS household weights.

Table 8-C.3.23 Marginal Electricity Price Factors using RECS 2009 data

	Geographical Area	Winter	Summer
1	Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.94	0.86
2	Massachusetts	0.96	0.98
3	New York	1.14	0.78
4	New Jersey	1.22	0.94
5	Pennsylvania	1.10	0.81
6	Illinois	1.00	0.70
7	Indiana, Ohio	1.01	0.74
8	Michigan	1.14	0.98
9	Wisconsin	1.01	0.91
10	Iowa, Minnesota, North Dakota, South Dakota	1.09	0.83
11	Kansas, Nebraska	1.17	0.72
12	Missouri	1.21	0.76
13	Virginia	1.09	0.84
14	Delaware, District of Columbia, Maryland	1.18	0.81
15	Georgia	1.16	0.82
16	North Carolina, South Carolina	0.98	0.83
17	Florida	1.00	0.81
18	Alabama, Kentucky, Mississippi	1.00	0.79
19	Tennessee	0.93	0.80
20	Arkansas, Louisiana, Oklahoma	1.05	0.70
21	Texas	1.06	0.84
22	Colorado	1.05	0.84
23	Idaho, Montana, Utah, Wyoming	1.04	0.92
24	Arizona	1.04	0.84
25	Nevada, New Mexico	1.03	0.89
26	California	1.16	1.08
27	Oregon, Washington	0.89	0.93
28	Alaska	0.79	0.89
29	Hawaii	1.51	1.14
30	West Virginia	0.92	0.84
31	**United States**	**1.08**	**0.80**

Table 8-C.3.24 Marginal Natural Gas Price Factors using RECS 2009 data

Geographical Area	Winter	Summer
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.84	0.91
Massachusetts	0.89	0.98
New York	0.76	0.85
New Jersey	0.84	0.97
Pennsylvania	0.73	0.90
Illinois	0.69	0.92
Indiana, Ohio	0.75	0.95
Michigan	0.79	0.89
Wisconsin	0.81	0.91
Iowa, Minnesota, North Dakota, South Dakota	0.72	0.89
Kansas, Nebraska	0.69	0.93
Missouri	0.60	0.83
Virginia	0.69	0.93
Delaware, District of Columbia, Maryland	0.71	0.91
Georgia	0.51	0.89
North Carolina, South Carolina	0.67	0.88
Florida	0.65	0.79
Alabama, Kentucky, Mississippi	0.74	0.89
Tennessee	0.74	0.91
Arkansas, Louisiana, Oklahoma	0.65	0.85
Texas	0.56	0.84
Colorado	0.68	0.96
Idaho, Montana, Utah, Wyoming	0.83	0.94
Arizona	0.64	0.86
Nevada, New Mexico	0.72	0.88
California	0.86	1.03
Oregon, Washington	0.85	0.97
Alaska	0.85	0.95
Hawaii	0.50	0.51
West Virginia	0.80	0.92
United States	**0.75**	**0.92**

8-C.3.4 Results

DOE then applied the marginal price factors to the monthly energy prices in appendix 7-B to develop marginal monthly energy prices for 2011 for electricity and natural gas (Table 8-C.3.23 and Table 8-C.3.24).

Table 8-C.3.23 Marginal Monthly Electricity Prices for 2011 Using Marginal Price Factors (2012$/kWh)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	0.143	0.144	0.145	0.159	0.161	0.161	0.160	0.161	0.161	0.162	0.147	0.146
Massachusetts	0.145	0.146	0.145	0.143	0.145	0.149	0.146	0.147	0.149	0.148	0.147	0.150
New York	0.138	0.139	0.140	0.206	0.211	0.219	0.222	0.222	0.222	0.215	0.145	0.142
New Jersey	0.146	0.147	0.148	0.193	0.198	0.215	0.219	0.219	0.215	0.196	0.151	0.150
Pennsylvania	0.103	0.104	0.105	0.147	0.154	0.160	0.161	0.159	0.157	0.154	0.110	0.107
Illinois	0.075	0.078	0.081	0.121	0.126	0.130	0.130	0.128	0.129	0.129	0.082	0.077
Indiana, Ohio	0.074	0.076	0.079	0.114	0.119	0.120	0.117	0.117	0.119	0.118	0.083	0.077
Michigan	0.128	0.128	0.127	0.150	0.151	0.157	0.159	0.160	0.157	0.151	0.129	0.130
Wisconsin	0.117	0.120	0.119	0.135	0.137	0.138	0.135	0.136	0.136	0.137	0.122	0.120
Iowa, Minnesota, North Dakota, South Dakota	0.081	0.083	0.085	0.115	0.121	0.126	0.127	0.126	0.123	0.119	0.087	0.084
Kansas, Nebraska	0.065	0.068	0.070	0.117	0.123	0.132	0.132	0.133	0.131	0.120	0.071	0.068
Missouri	0.063	0.065	0.068	0.115	0.131	0.142	0.140	0.139	0.127	0.118	0.071	0.066
Virginia	0.084	0.085	0.088	0.119	0.124	0.128	0.127	0.128	0.125	0.122	0.090	0.086
Delaware, District of Columbia, Maryland	0.100	0.101	0.102	0.152	0.167	0.183	0.183	0.182	0.178	0.164	0.106	0.104
Georgia	0.083	0.085	0.088	0.126	0.132	0.141	0.143	0.144	0.137	0.129	0.088	0.083
North Carolina, South Carolina	0.085	0.086	0.088	0.106	0.108	0.106	0.108	0.108	0.109	0.111	0.091	0.087
Florida	0.094	0.096	0.096	0.120	0.119	0.117	0.118	0.119	0.119	0.119	0.097	0.096
Alabama, Kentucky, Mississippi	0.077	0.079	0.081	0.107	0.109	0.109	0.108	0.109	0.108	0.109	0.084	0.081
Tennessee	0.078	0.078	0.080	0.094	0.095	0.094	0.093	0.093	0.093	0.097	0.083	0.081
Arkansas, Louisiana, Oklahoma	0.059	0.061	0.063	0.099	0.101	0.104	0.104	0.104	0.105	0.103	0.064	0.061
Texas	0.088	0.089	0.093	0.121	0.125	0.129	0.129	0.129	0.128	0.128	0.095	0.092
Colorado	0.092	0.093	0.093	0.120	0.124	0.125	0.123	0.123	0.123	0.123	0.096	0.094
Idaho, Montana, Utah, Wyoming	0.080	0.081	0.081	0.092	0.095	0.097	0.098	0.097	0.097	0.097	0.082	0.082
Arizona	0.082	0.085	0.088	0.114	0.126	0.126	0.124	0.124	0.123	0.123	0.089	0.089
Nevada, New Mexico	0.100	0.102	0.103	0.121	0.120	0.119	0.118	0.119	0.120	0.123	0.105	0.102
California	0.166	0.163	0.163	0.175	0.181	0.184	0.189	0.189	0.181	0.174	0.167	0.169
Oregon, Washington	0.082	0.083	0.083	0.078	0.078	0.079	0.080	0.080	0.081	0.081	0.085	0.085
Alaska	0.152	0.153	0.157	0.142	0.145	0.145	0.147	0.146	0.144	0.145	0.161	0.157
Hawaii	0.381	0.386	0.396	0.538	0.555	0.545	0.536	0.539	0.546	0.562	0.412	0.394
West Virginia	0.075	0.077	0.078	0.088	0.091	0.092	0.093	0.093	0.092	0.091	0.081	0.078
United States	0.089	0.091	0.093	0.129	0.132	0.135	0.136	0.136	0.135	0.133	0.096	0.093

Table 8-C.3.24 Marginal Monthly Natural Gas Prices for 2010 Using Marginal Price Factors (2012/MMbtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	13.02	13.14	13.22	12.40	12.96	13.95	15.12	15.39	14.98	13.44	14.01	13.59
Massachusetts	13.55	13.65	13.56	12.63	11.49	11.99	13.16	13.85	13.41	11.59	14.12	13.99
New York	11.45	11.27	11.39	10.50	11.60	13.20	14.05	13.85	13.50	11.91	12.12	11.36
New Jersey	10.93	10.90	10.90	9.80	10.48	11.54	12.02	12.01	11.79	10.77	11.47	11.24
Pennsylvania	10.85	11.00	11.17	9.45	10.56	12.00	13.33	13.64	12.94	10.70	11.81	11.21
Illinois	8.21	8.33	8.24	6.59	7.77	8.95	9.53	9.65	8.95	7.22	8.60	8.17
Indiana, Ohio	10.40	10.48	10.66	9.06	9.96	11.35	12.19	12.32	11.55	9.44	10.75	10.52
Michigan	8.65	8.66	8.75	8.14	8.94	10.28	11.36	11.76	10.91	9.13	9.32	8.95
Wisconsin	9.43	9.23	9.31	8.35	8.32	9.46	9.74	9.92	9.19	7.82	9.69	9.47
Iowa, Minnesota, North Dakota, South Dakota	7.93	7.71	7.75	6.50	7.29	8.50	9.15	9.42	8.85	7.22	8.27	7.96
Kansas, Nebraska	9.15	9.18	9.17	7.37	8.27	9.62	10.27	10.69	10.41	9.09	10.01	9.43
Missouri	10.33	10.35	10.40	8.18	9.46	11.47	13.01	13.73	12.90	11.08	12.22	10.99
Virginia	11.73	11.43	11.12	9.04	10.61	12.29	13.31	13.15	13.15	10.87	12.27	11.84
Delaware, District of Columbia, Maryland	11.30	11.27	11.40	9.60	10.82	12.10	12.87	12.91	12.82	10.79	12.23	11.61
Georgia	12.76	13.54	14.06	8.79	10.70	11.89	12.48	12.39	11.73	10.43	14.34	13.47
North Carolina, South Carolina	11.66	11.62	11.80	9.55	10.91	12.85	13.66	14.20	13.64	11.46	12.76	12.35
Florida	12.65	12.94	13.72	12.05	13.18	13.98	14.38	14.70	14.52	14.36	15.86	14.04
Alabama, Kentucky, Mississippi	10.58	10.54	10.81	9.81	11.15	12.35	12.70	12.95	12.69	11.60	12.03	11.15
Tennessee	9.74	9.92	9.91	8.65	9.49	10.81	11.52	11.85	11.40	10.38	10.91	10.29
Arkansas, Louisiana, Oklahoma	9.66	9.63	9.83	8.27	9.84	10.83	11.48	11.83	11.54	10.86	11.88	10.32
Texas	8.43	8.52	8.75	6.72	7.68	8.47	8.74	8.93	8.85	8.04	9.83	8.73
Colorado	7.65	7.73	7.94	5.82	6.37	7.89	8.07	8.56	8.02	6.56	8.29	7.88
Idaho, Montana, Utah, Wyoming	7.91	7.94	8.10	7.03	7.32	7.88	8.55	8.91	8.37	7.46	8.25	8.05
Arizona	11.55	11.87	12.24	9.95	11.14	12.26	13.30	13.88	13.41	12.61	14.27	12.28
Nevada, New Mexico	7.92	8.09	8.31	7.31	8.32	9.58	9.43	9.81	9.50	8.46	8.80	8.00
California	10.52	10.40	10.00	8.28	8.75	9.20	9.21	9.06	8.89	8.97	10.17	10.29
Oregon, Washington	11.19	11.30	11.38	10.34	10.76	11.33	12.53	13.07	12.63	11.44	11.91	11.56
Alaska	8.02	8.06	8.14	7.42	7.75	8.01	8.60	8.49	7.89	7.50	8.05	8.23
Hawaii	26.80	27.11	27.11	26.83	27.37	27.60	28.13	28.74	28.65	28.72	28.96	28.48
West Virginia	9.87	9.92	10.01	9.02	9.89	11.80	13.15	13.07	12.13	9.95	10.56	10.45
United States	9.93	10.00	10.07	9.20	10.05	11.24	11.90	12.13	11.63	10.12	10.57	10.15

DOE then applied the regional monthly energy price factors to the annual LPG data presented in chapter 8 to develop monthly energy prices for 2011 (Table 8-C.3.25). Each geographical area was matched with the appropriate Census Region.

Table 8-C.3.25 Monthly LPG Prices for 2011 Using Average Price Factors (2012/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	34.85	35.20	35.39	35.42	35.96	36.32	36.43	36.21	36.18	36.34	35.98	35.95
Massachusetts	37.29	37.67	37.88	37.90	38.48	38.86	38.99	38.75	38.72	38.89	38.50	38.47
New York	33.94	34.29	34.47	34.49	35.02	35.37	35.48	35.26	35.24	35.40	35.04	35.02
New Jersey	35.63	35.99	36.18	36.21	36.76	37.13	37.25	37.02	36.99	37.16	36.78	36.76
Pennsylvania	31.02	31.34	31.51	31.53	32.01	32.33	32.44	32.23	32.21	32.35	32.03	32.01
Illinois	25.37	25.36	25.05	24.66	24.36	23.50	22.80	22.73	23.26	23.95	25.04	26.15
Indiana, Ohio	27.24	27.23	26.90	26.49	26.16	25.24	24.49	24.42	24.98	25.72	26.89	28.08
Michigan	25.31	25.31	25.00	24.61	24.31	23.45	22.75	22.69	23.21	23.90	24.99	26.10
Wisconsin	24.08	24.07	23.78	23.41	23.12	22.31	21.65	21.58	22.08	22.74	23.77	24.82
Iowa, Minnesota, North Dakota, South Dakota	25.36	25.35	25.05	24.66	24.35	23.50	22.80	22.73	23.26	23.95	25.04	26.14
Kansas, Nebraska	25.30	25.29	24.99	24.60	24.30	23.44	22.74	22.68	23.20	23.89	24.98	26.08
Missouri	24.89	24.88	24.58	24.20	23.90	23.06	22.37	22.31	22.82	23.50	24.57	25.66
Virginia	28.88	28.97	28.53	27.98	27.54	27.02	26.40	25.91	26.55	27.65	28.51	29.44
Delaware, District of Columbia, Maryland	38.08	38.20	37.62	36.89	36.31	35.63	34.81	34.15	35.01	36.46	37.59	38.81
Georgia	29.88	29.97	29.52	28.95	28.49	27.96	27.32	26.80	27.47	28.61	29.50	30.45
North Carolina, South Carolina	31.46	31.56	31.08	30.48	30.00	29.44	28.76	28.22	28.92	30.13	31.06	32.07
Florida	43.24	43.37	42.72	41.89	41.23	40.45	39.53	38.78	39.75	41.40	42.69	44.07
Alabama, Kentucky, Mississippi	30.98	31.08	30.61	30.02	29.54	28.99	28.32	27.79	28.48	29.66	30.58	31.58
Tennessee	31.36	31.46	30.99	30.39	29.91	29.35	28.67	28.13	28.83	30.03	30.96	31.97
Arkansas, Louisiana, Oklahoma	29.19	29.28	28.84	28.28	27.84	27.31	26.69	26.18	26.84	27.95	28.82	29.75
Texas	32.36	32.46	31.97	31.35	30.86	30.28	29.59	29.03	29.75	30.99	31.95	32.98
Colorado	28.38	28.43	27.94	27.31	26.65	25.89	24.95	24.64	25.61	27.15	28.02	29.11
Idaho, Montana, Utah, Wyoming	28.86	28.91	28.41	27.77	27.10	26.32	25.37	25.05	26.04	27.60	28.49	29.60
Arizona	37.77	37.84	37.20	36.35	35.47	34.46	33.22	32.80	34.09	36.13	37.30	38.75
Nevada, New Mexico	34.90	34.96	34.36	33.58	32.77	31.83	30.69	30.30	31.50	33.38	34.46	35.80
California	36.47	36.53	35.91	35.09	34.25	33.26	32.07	31.66	32.91	34.88	36.00	37.41
Oregon, Washington	31.21	31.27	30.73	30.03	29.31	28.47	27.44	27.10	28.17	29.86	30.81	32.02
Alaska	41.25	41.33	40.62	39.69	38.74	37.63	36.27	35.82	37.23	39.46	40.73	42.31
Hawaii	68.65	68.78	67.60	66.06	64.47	62.63	60.37	59.61	61.97	65.67	67.78	70.42
West Virginia	30.66	30.76	30.30	29.71	29.24	28.69	28.03	27.50	28.19	29.36	30.27	31.25
United States	29.56	29.74	29.55	29.34	29.37	28.77	27.48	26.85	27.67	28.56	29.48	30.38

DOE then applied the regional monthly energy price factors to the annual oil data presented in chapter 8 to develop monthly energy prices for 2011 (Table 8-C.3.26). Each Census Division and Large State was matched with the appropriate Census Region.

Table 8-C.3.26 Monthly Oil Prices for 2011 Using Average Price Factors (2012/MMBtu)

Geographical Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	25.52	25.89	25.71	25.49	25.33	25.16	24.76	24.73	25.52	26.17	26.60	26.89
Massachusetts	25.58	25.95	25.77	25.55	25.40	25.22	24.82	24.79	25.58	26.23	26.67	26.95
New York	25.99	26.37	26.18	25.96	25.80	25.62	25.22	25.19	25.99	26.65	27.09	27.38
New Jersey	26.57	26.96	26.78	26.55	26.38	26.20	25.79	25.76	26.58	27.25	27.71	28.00
Pennsylvania	26.29	26.68	26.49	26.26	26.10	25.92	25.51	25.48	26.29	26.96	27.41	27.70
Illinois	26.48	26.78	27.15	27.32	27.28	27.21	27.04	27.63	28.62	29.23	29.19	28.73
Indiana, Ohio	26.43	26.73	27.10	27.27	27.23	27.16	26.99	27.58	28.56	29.18	29.14	28.68
Michigan	26.42	26.72	27.09	27.26	27.22	27.15	26.98	27.57	28.55	29.17	29.13	28.67
Wisconsin	26.18	26.47	26.84	27.01	26.97	26.90	26.73	27.32	28.29	28.90	28.86	28.40
Iowa, Minnesota, North Dakota, South Dakota	26.47	26.77	27.14	27.31	27.27	27.21	27.03	27.63	28.61	29.23	29.19	28.73
Kansas, Nebraska	26.42	26.72	27.09	27.26	27.22	27.15	26.97	27.57	28.55	29.17	29.12	28.67
Missouri	25.98	26.28	26.64	26.81	26.77	26.70	26.53	27.12	28.08	28.69	28.64	28.19
Virginia	27.53	27.83	27.71	27.34	26.50	26.16	26.18	26.44	27.41	28.15	28.66	28.96
Delaware, District of Columbia, Maryland	26.38	26.67	26.55	26.19	25.39	25.06	25.09	25.34	26.27	26.97	27.46	27.75
Georgia	27.26	27.56	27.44	27.07	26.24	25.90	25.93	26.18	27.15	27.87	28.38	28.68
North Carolina, South Carolina	27.65	27.96	27.83	27.46	26.62	26.28	26.30	26.56	27.54	28.27	28.79	29.09
Florida	27.78	28.09	27.97	27.59	26.75	26.40	26.43	26.69	27.67	28.41	28.93	29.23
Alabama, Kentucky, Mississippi	26.34	26.63	26.51	26.16	25.36	25.03	25.05	25.30	26.23	26.93	27.43	27.71
Tennessee	28.05	28.36	28.23	27.86	27.00	26.65	26.68	26.94	27.93	28.68	29.21	29.51
Arkansas, Louisiana, Oklahoma	26.11	26.40	26.28	25.93	25.14	24.81	24.84	25.08	26.00	26.70	27.19	27.47
Texas	25.81	26.09	25.97	25.63	24.84	24.52	24.54	24.79	25.70	26.39	26.87	27.15
Colorado	23.72	24.13	25.20	25.64	25.60	25.51	25.11	25.16	26.01	26.43	26.42	25.81
Idaho, Montana, Utah, Wyoming	24.11	24.53	25.61	26.07	26.02	25.93	25.53	25.57	26.44	26.87	26.85	26.23
Arizona	26.75	27.21	28.42	28.92	28.87	28.77	28.32	28.37	29.34	29.81	29.79	29.11
Nevada, New Mexico	25.49	25.93	27.08	27.56	27.51	27.41	26.99	27.04	27.95	28.40	28.39	27.74
California	27.05	27.51	28.73	29.24	29.19	29.08	28.64	28.69	29.66	30.14	30.12	29.43
Oregon, Washington	26.15	26.60	27.78	28.27	28.22	28.12	27.68	27.73	28.67	29.14	29.12	28.45
Alaska	25.10	25.54	26.67	27.14	27.09	26.99	26.58	26.63	27.53	27.97	27.96	27.31
Hawaii	26.11	26.55	27.73	28.22	28.17	28.07	27.64	27.69	28.63	29.09	29.07	28.40
West Virginia	27.78	28.09	27.97	27.59	26.75	26.40	26.43	26.69	27.67	28.41	28.93	29.23
United States	26.01	26.38	26.27	26.09	25.87	25.65	25.29	25.34	26.19	26.85	27.26	27.47

8-C.4 HOUSEHOLD ENERGY PRICE ADJUSTMENT FACTOR

RECS 2009 reports the total annual consumption and expenditure of each energy use type. From this data DOE determined average energy prices per geographical area. To take into account that household energy prices vary inside a geographical area, DOE developed an adjustment factor based on the reported average energy price in RECS 2009 divided by the average energy price of the geographical region. This factor was then multiplied times the monthly marginal energy prices (for natural gas and electricity) or the monthly price developed above to come up with the household energy price.

8-C.5 ENERGY PRICE TRENDS

DOE used *AEO 2012* Reference Case scenarios for the nine census divisions. DOE applied the projected energy price for each of the nine census divisions to each household in the sample based on the household's location.

To arrive at prices in future years, DOE multiplied the prices described in the preceding section by the forecast of annual average price changes in EIA's *AEO 2012.*[5] Figure 8-C.4.1 shows the national residential electricity price trend. To estimate the trend after 2035, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2020–2035 for electricity, natural gas, and LPG.

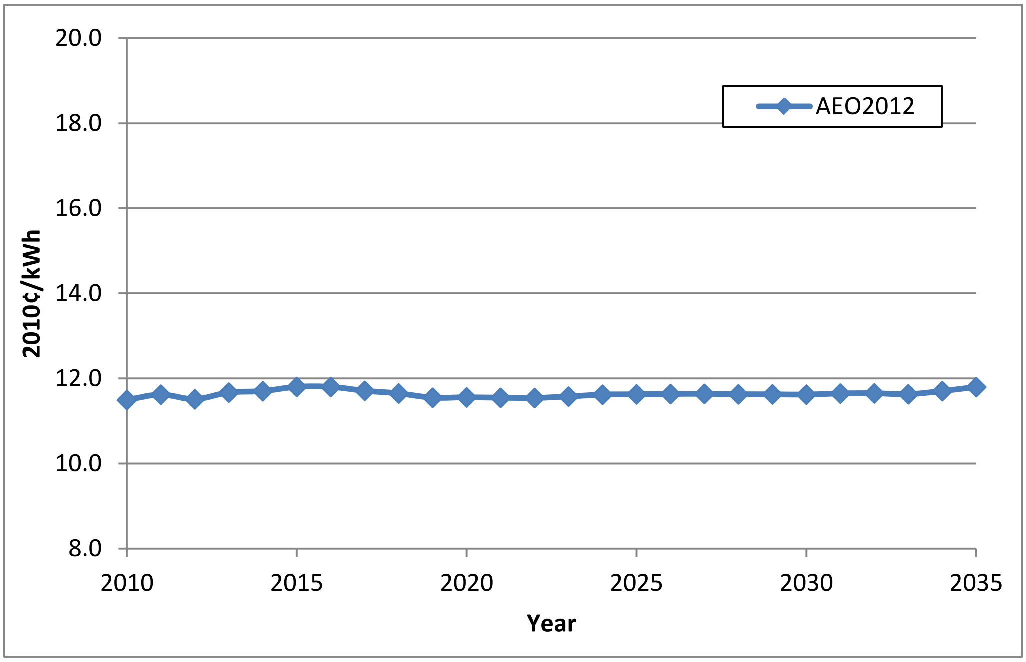

Figure 8-C.5.1 Projected National Electricity Price

Figure 8-C.4.2 shows the residential national electricity price trends, disaggregated by the nine census divisions.

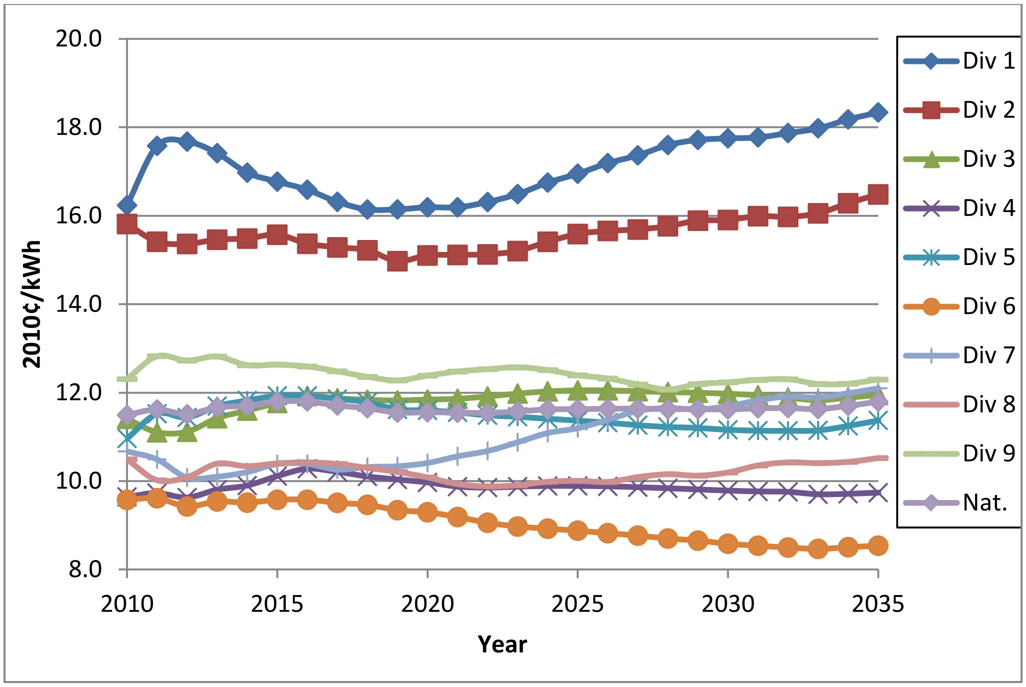

Figure 8-C.5.2 Projected Division Electricity Prices

Figure 8-C.4.3 shows the residential national natural gas price trends.

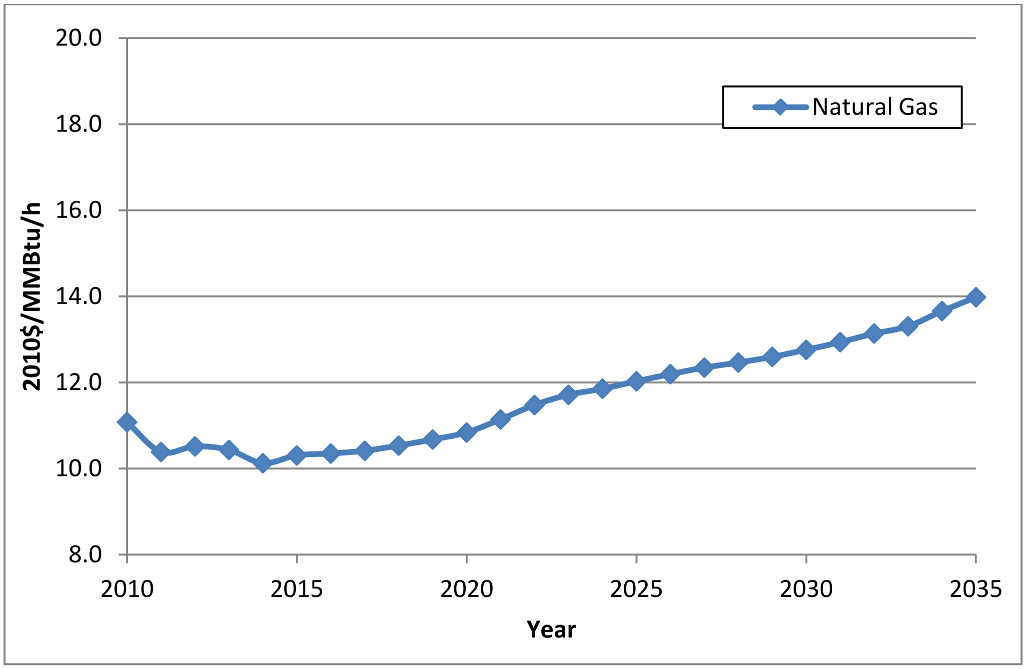

Figure 8-C.5.3 Projected National Natural Gas Price

Figure 8-C.4.4 shows the residential national natural gas price trends, disaggregated by the nine census divisions.

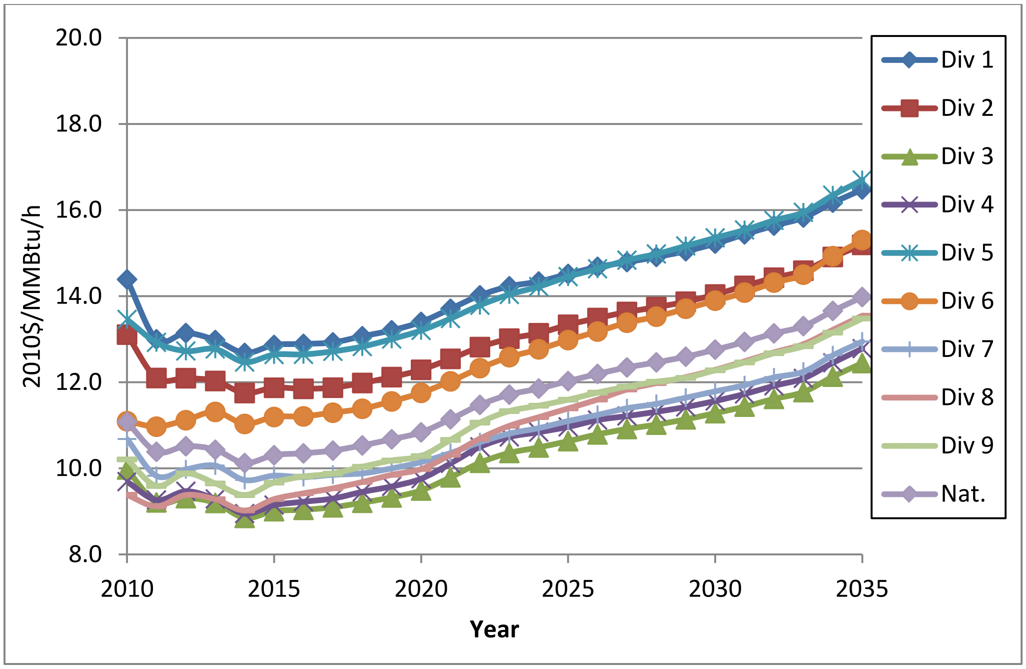

Figure 8-C.5.4 Projected Division Natural Gas Prices

Figure 8-C.4.5 shows the residential national LPG price trends.

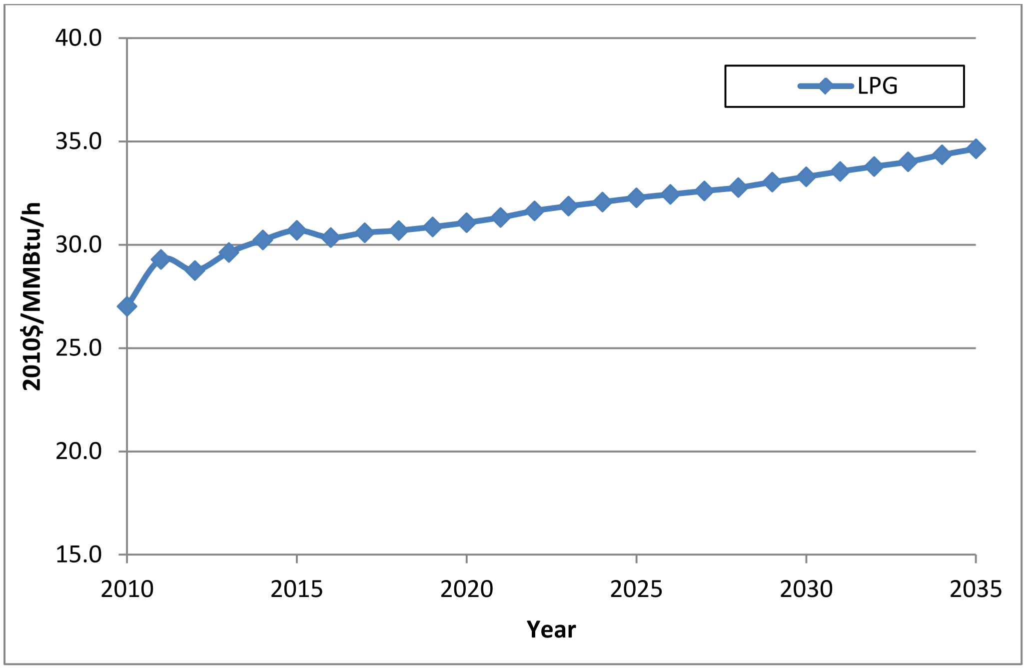

Figure 8-C.5.5 Projected National LPG Prices

Figure 8-C.4.6 shows the residential national LPG price trends, disaggregated by the nine census divisions.

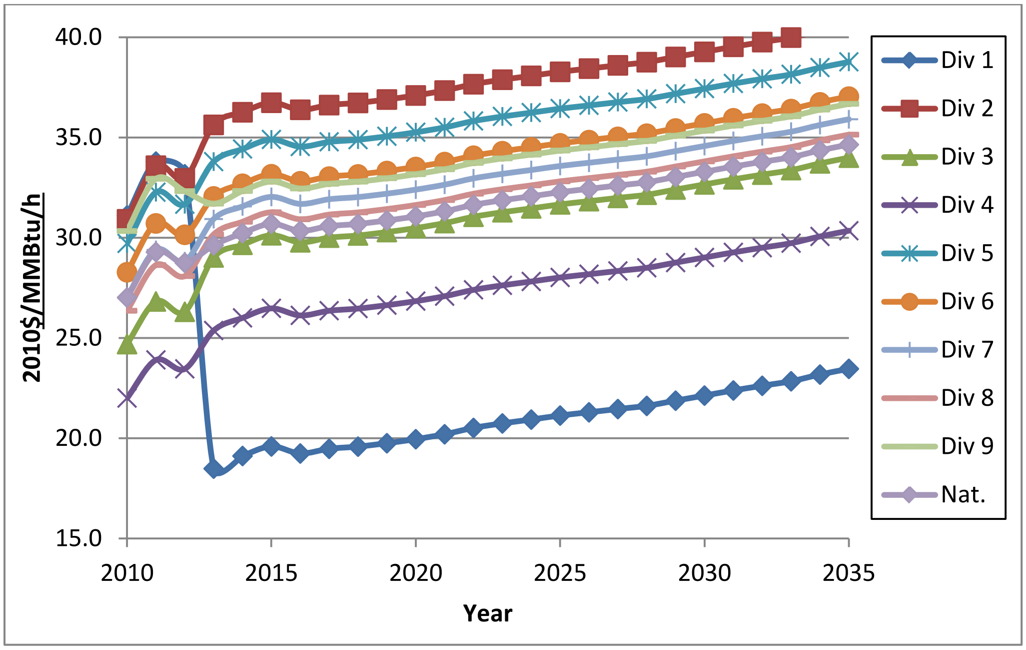

Figure 8-C.5.6 Projected Division LPG Prices

Figure 8-C.4.7 shows the residential national fuel oil price trends.

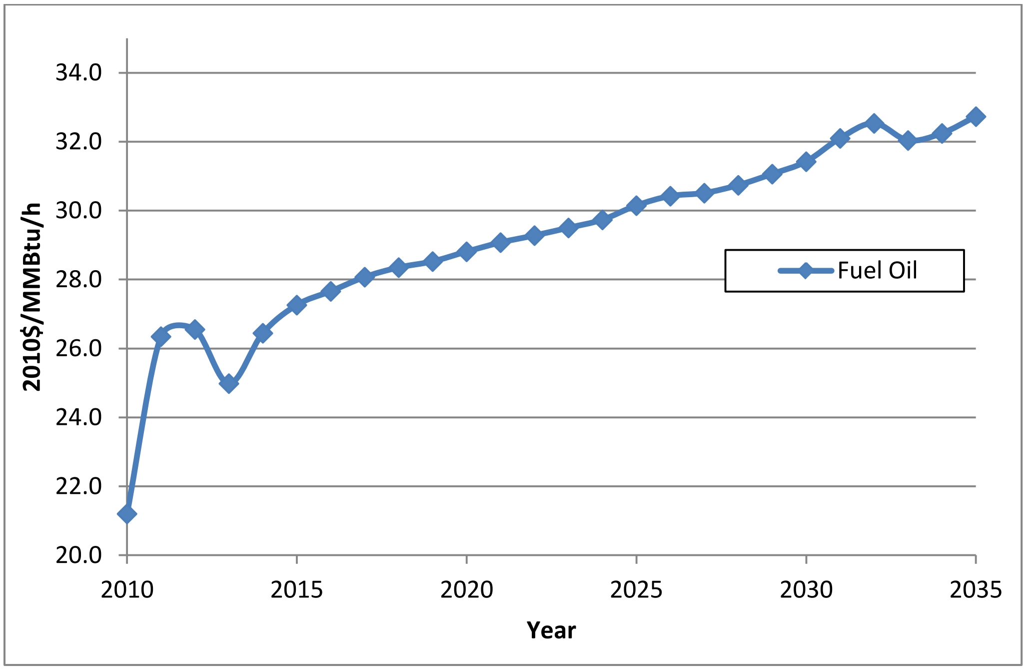

Figure 8-C.5.7 Projected National Fuel Oil Prices

Figure 8-C.4.8 shows the residential national fuel oil price trends, disaggregated by the nine census divisions.

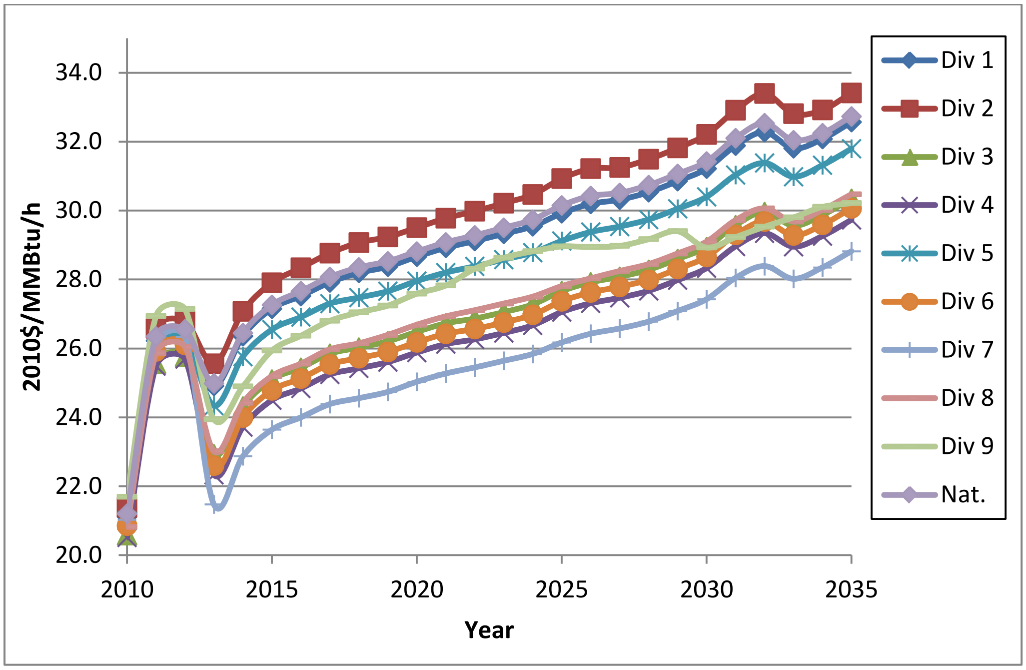

Figure 8-C.5.8 Projected Division Fuel Oil Prices

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2. U.S. Department of Energy - Energy Information Administration, *Natural Gas Navigator*. 2013. http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm

3. Energy Information Administration, *2011 State Energy Consumption, Price, and Expenditure Estimates (SEDS)*, 2013. Washington, DC. <http://www.eia.doe.gov/emeu/states/_seds.html>

4. U.S. Department of Energy - Energy Information Administration, *Short-Term Energy Outlook*. 2009. http://eia.doe.gov/steo

5. Energy Information Administration, *Annual Energy Outlook 2012 with Projections to 2035*, 2012. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf>

APPENDIX 8-D. INSTALLATION, MAINTENANCE, REPAIR COST DETERMINATION FOR FURNACE FANS

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APPENDIX 8-D. INSTALLATION, MAINTENANCE, REPAIR COST DETERMINATION FOR FURNACE FANS

8-D.1 INTRODUCTION

This appendix provides further details about the derivation of installation, maintenance and repair costs for furnace fans. The installation cost is the price to the consumer of labor and materials (other than the cost of the actual product) needed to install a furnace product.

The Department of Energy (DOE) estimated installation, maintenance, and repair costs for furnaces based on RS Means, a well known and respected construction cost estimation method, as well as manufacturer literature and information from expert consultants. Table 8-D.1.1 offers an example of the cost calculation method. All labor costs are derived using the latest residential 2012 RS Means labor costs by crew type.[1] Replacement installation, maintenance, and repair cost tables include a trip charge, which is often charged by contractors and calculated to be equal to one half hour of labor per crew member. Labor hours (or person-hours) are based on RS Means data, expert data, or engineering judgment. Bare costs are all the costs without any markups. Material costs are based on RS Means data, expert data, or internet sources. The total includes overhead and profit (O&P), which is calculated using labor and material markups from RS Means. Values reported in this appendix are based on national average labor costs. The labor costs shown in the tables in this appendix are the national average values. In its analysis, DOE used regional labor costs to more accurately estimate installation costs by region. Section 8-D.5 describes the derivation of regional labor costs. DOE then applied the appropriate regional labor cost to each RECS sample household. The total costs include O&P. (Note that the unit "L.F." in the tables means "linear foot.")

Table 8-D.1.1 Example Cost Table

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Quantity	Total incl. O&P
				Material	Labor	Total		
Trip Charge	CREW1	0.5	-	0.00	23.00	23.00	1	35.00
Description of Installation Item	CREW1	0.5	Ea.	15.00	23.00	48.00	1	51.50
Total		1.0		15.00	46.00	71.00		**86.50**

8-D.2 INSTALLATION COST DETERMINATION

Furnace fans typical require the installer to check the airflow settings in heating, cooling, and/or constant circulation modes. For multi-stage equipment or more complex furnace fan designs may require additional installation costs at startup to check and adjust airflow. In addition, there are a fraction of installations that require a more labor intensive "quality installation" due to either local or state building codes or other building requirements. The fraction of household quality installations is assumed to be 20 percent based mainly on California building requirements. DOE also assumed that 35 percent of PSC and constant-torque BPM with single-stage controls do not require any installation costs. Finally, DOE assumes that a fraction of PSC motors have two-stage controls. The fraction by product class is based on number of models in the March 2013 AHRI directory. Table 8-D.2.1 shows the labor hour requirements for different motor and control types based on a consultant report.

Table 8-D.2.1 Labor Hours for Different Motor and Control Types based on a Consultant Report

Fan Motor Type	Control Type	Average Labor Hours	
		Normal	Quality Installation
PSC or Constant Torque BPM	Single-Stage	0.75	2.25
	Multi-Stage	1.25	2.5
Constant Air-Flow BPM	Single-Stage	1.25	2.25
	Multi-Stage	1.5	2.5

In addition if the household has cooling an additional 0.25 hour is added for a normal installation, 0.5 hour is added for a normal two-stage installation (if SEER>16), 0.75 hour is added for a quality installation, and 0.5 hour is added for a quality two-stage installation (if SEER>16). Table 8-D.2.2 shows an example installation cost of one hour using RS Means.

Table 8-D.2.2 One Hour Installation Cost Calculation (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Check blower airflow	Q9	1	Ea.	$0.00	$30.95	$30.95	$51.50

8-D.2.1 Summary of Furnace Fan Installation Costs

Table 8-D.2.3 shows the average total installation costs used in the analysis.

Table 8-D.2.3 Installation Costs for Furnace Fans (2012$)

Key Product Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**
	Baseline PSC	Improved PSC	Inverter-driven PSC	Constant-torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward-curved impeller
Non-weatherized, Non-condensing Gas Furnace Fan	$65	$65	$65	$65	$97	$113	$113
Non-weatherized, Condensing Gas Furnace Fan	$53	$53	$53	$53	$79	$92	$92
Weatherized Gas Furnace Fan	$29	$29	$29	$29	$44	$51	$51
Oil Furnace Fan	$33	$33	$33	$33	$56	$67	$67
Electric Furnace / Modular Blower Fan	$14	$14	$14	$14	$24	$28	$28
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	$29	$29	$29	$29	$44	$52	$52
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	$34	$34	$34	$34	$57	$68	$68
Manufactured Home Electric Furnace / Modular Blower Fan	$34	$34	$34	$34	$57	$68	$68

8-D.3 MAINTENANCE COST FOR FURNACE FANS

The maintenance cost is the routine annual cost to the consumer of maintaining equipment operation. It is the cost associated with general maintenance. The regular furnace maintenance generally includes checking the furnace fan. DOE assumes that this maintenance cost is the same at all efficiency levels.

DOE estimated labor hours and costs for annual maintenance was estimated using RS Means data (See Table 8-D.3.1).

Table 8-D.3.1 Maintenance Cost Calculation for Furnace Fans (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Check blower	Q1	0.042	Ea.	$0.00	$2.06	$2.06	$3.22

The frequency with which the maintenance occurs was derived from a 2008 consumer survey[2] on the frequency with which owners of different types of furnaces perform maintenance.

Table 8-D.3.2 Maintenance Fractions based on 2008 American Home Comfort Survey

Frequency of Maintenance	Assumed Frequency for Analysis	Fraction of Households	
		Oil Furnaces	Other Furnaces
Last maintenance within a year	Annual	71%	53%
Last maintenance within two years	Biannual	17%	17%
Last maintenance over 2 years	Every 5 years	7%	15%
Never	Never	5%	14%

8-D.4 REPAIR COST FOR FURNACE FANS

The repair cost is the cost to the consumer for replacing or repairing components in the furnace fan that have failed. DOE included motor replacement as a repair cost for a fraction of furnace fans. To estimate rates of fan failure, DOE developed a distribution of fan motor lifetime (expressed in operating hours) by motor size using data from DOE's analysis for small electric motors.[a] See Figure 8-D.4.1 for the furnace motor Weibull distribution, which indicates 30,000 hours as the mean operating hours. DOE then paired these data with the calculated number of annual operating hours for each sample furnace. Although DOE used the same motor lifetime for each fan efficiency level in terms of total operating hours, the lifetime in terms of years is lower for equipment with multi-stage controls (most commonly applied in higher efficiency furnace fan designs) due to increased operating hours. In addition, DOE included additional labor hours to repair constant-torque BPM and constant-airflow BPM motors, as well as higher equipment cost for the BPM motors. For the NOPR, DOE assumed that repair to electronics would occur for PSC with controls (7.5 percent of the time if the motor had not been replaced), constant-torque BPM motors (15 percent of the time if the motor had not been replaced), and especially constant-airflow BPM motors (30 percent of the time if the motor had not been replaced). DOE added an extra cost for the cases that require control updates for these efficiency levels. DOE also added the cost of replacing the PSC capacitor for a fraction of installations (See Figure 8-D.4.2 for the capacitor lifetime distribution based on manufacturer product literature). The PSC capacitor cost is only applied if the motor has not been repaired.

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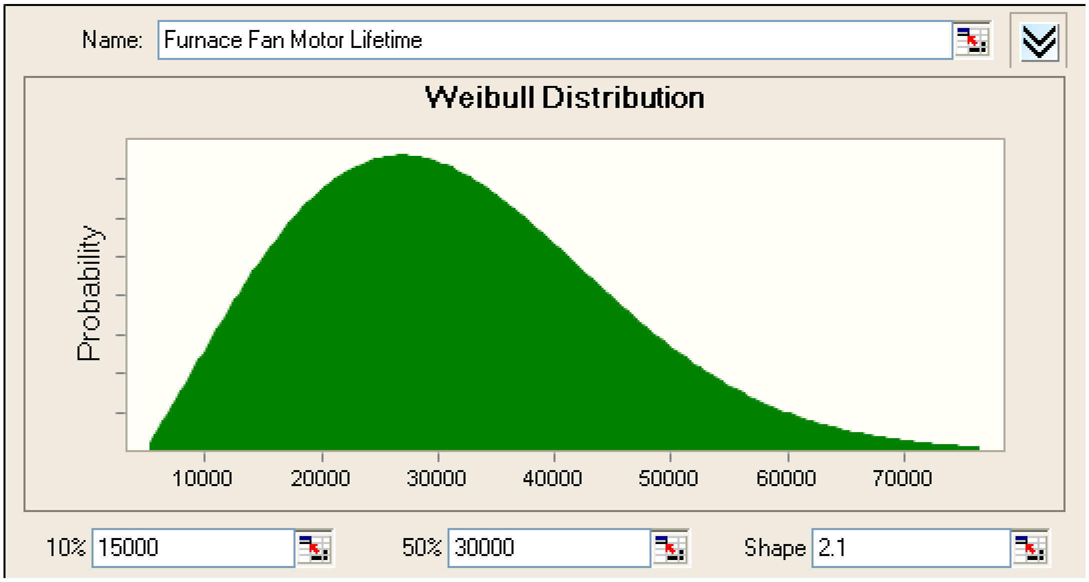
[a] http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html



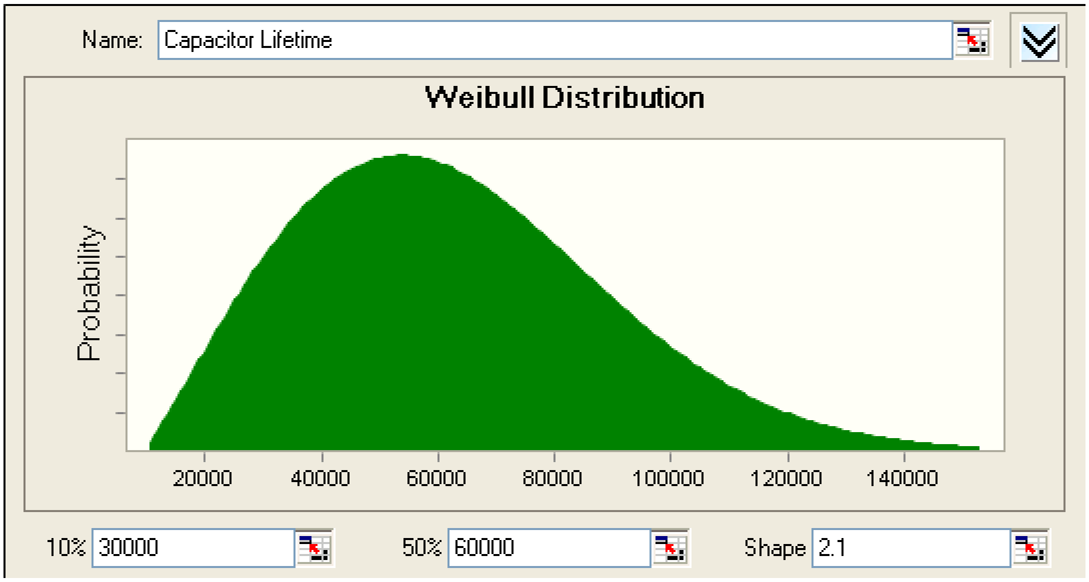
Name: Furnace Fan Motor Lifetime

10% 15000

50% 30000

Shape 2.1

Figure 8-D.4.1 Furnace Fan Lifetime Distribution in Operating Hours



Name: Capacitor Lifetime

10% 30000

50% 60000

Shape 2.1

Figure 8-D.4.2 Capacitor Distribution in Operating Hours

Motor costs were based on costs developed in the engineering analysis and marked up using the replacement markups developed in the markup analysis. DOE assumed that the motor cost does not apply if motor failure occurs during the furnace warranty period or if a service contract covers parts. Table 8-D.4.1 shows the warranty period assumptions based on manufacturer product literature. Table 8-D.4.2 shows the service contract assumptions based on a 2008 consumer survey.[2]

Table 8-D.4.1 Warranty Period Assumptions

Warranty Period	Fraction of Households
One year Labor and Parts	100%
5 years parts only	90%
10 year parts only	10%

Table 8-D.4.2 Service Contract Assumptions

Service Contract Types	Fraction of Households	
	Oil Furnaces	Other Furnaces
Total Package (Labor and Parts)	27%	15%
Annual Cleaning	11%	6%
None	62%	79%

DOE estimated repair costs at each considered level, based on *2012 RS Means Facility Repair and Maintenance Data*.[3] DOE accounts for regional differences in labor costs. DOE estimated labor hours and costs for repair using RS Means data (See Table 8-D.4.3 to Table 8-D.4.6). Repair costs where applied at the year of failure and a single household could incur multiple costs during the furnace lifetime. DOE assumed that the labor cost does not apply if motor failure occurs during the furnace warranty periods first year or if a service contract covers labor.

Table 8-D.4.3 Replace Motor Cost Calculation (Labor Only) for Furnace Fans (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Trip Charge	Q-1	0.5	Ea.	$0.00	$24.58	$24.58	$38.29
Replace Motor	Q-1	2.5	Ea.	$0.00	$122.88	$122.88	$191.44
Total							**$229.73**

Table 8-D.4.4 Replace Motor Cost Calculation (Labor Only) for Constant-Airflow BPM Furnace Fans (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Trip Charge	Q-1	0.5	Ea.	$0.00	$24.58	$24.58	$38.29
Replace Motor	Q-1	3.5	Ea.	$0.00	$172.03	$172.03	$268.01
Total							**$306.30**

Table 8-D.4.5 Repair Controls Cost Calculation (Labor Only) for Furnace Fans (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Trip Charge	Q-1	0.5	Ea.	$0.00	$24.58	$24.58	$38.29
Repair Controls	Q-1	1.5	Ea.	$0.00	$73.73	$73.73	$114.86
Total							**$153.15**

Table 8-D.4.6 Replace Capacitor Cost Calculation for Furnace Fans (National Average)

Description	Crew	Labor Hours	Unit	Bare Costs *(2012$)*			Total incl. O&P
				Material	Labor	Total	
Trip Charge	Q-1	0.5	Ea.	$0.00	$24.58	$24.58	$38.29
Replace Capacitor	Q-1	1	Ea.	$25.00	$49.15	$74.15	$104.08
Total							**$142.36**

8-D.4.1 Summary of Furnace Fan Repair Costs

Table 8-D.4.9 shows the average repair costs used in the analysis.

Table 8-D.4.7 Average Repair Year for Furnace Fans (2012$)

Key Product Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**
	Baseline PSC	Improved PSC	Inverter-driven PSC	Constant-torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward-curved impeller
Non-weatherized, Non-condensing Gas Furnace Fan	15.5	15.5	15.3	14.8	14.5	14.2	14.2
Non-weatherized, Condensing Gas Furnace Fan	16.3	16.3	16.0	15.4	14.8	14.5	14.5
Weatherized Gas Furnace Fan	15.5	15.5	15.4	15.0	14.5	14.3	14.3
Oil Furnace Fan	17.0	17.1	16.5	15.6	15.5	15.1	15.1
Electric Furnace / Modular Blower Fan	15.0	15.0	14.8	14.5	13.8	13.6	13.6
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	17.4	17.4	16.9	16.1	15.8	15.3	15.3
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	17.2	17.2	16.6	15.8	15.9	15.4	15.4
Manufactured Home Electric Furnace / Modular Blower Fan	16.1	16.1	15.8	15.4	15.0	14.7	14.7

Table 8-D.4.8 Fraction of Furnace Fan Households with a Repair Cost (2012$)

Key Product Class	0	1	2	3	4	5	6
	Baseline PSC	Improved PSC	Inverter-driven PSC	Constant-torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward-curved impeller
Non-weatherized, Non-condensing Gas Furnace Fan	42%	42%	45%	46%	51%	57%	57%
Non-weatherized, Condensing Gas Furnace Fan	41%	41%	44%	45%	53%	58%	58%
Weatherized Gas Furnace Fan	48%	48%	51%	51%	56%	60%	60%
Oil Furnace Fan	36%	36%	40%	43%	52%	59%	59%
Electric Furnace / Modular Blower Fan	45%	45%	48%	49%	54%	59%	59%
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	33%	33%	37%	39%	46%	53%	53%
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	31%	31%	35%	37%	45%	51%	51%
Manufactured Home Electric Furnace / Modular Blower Fan	40%	40%	44%	45%	49%	55%	55%

Table 8-D.4.9 Average Repair Cost for Furnace Fans (2012$)

Key Product Class	**0**	**1**	**2**	**3**	**4**	**5**	**6**
	Baseline PSC	Improved PSC	Inverter-driven PSC	Constant-torque BPM motor	Constant-torque BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage	Constant-airflow BPM motor + multi-stage + backward-curved impeller
Non-weatherized, Non-condensing Gas Furnace Fan	$369	$377	$391	$389	$451	$544	$565
Non-weatherized, Condensing Gas Furnace Fan	$382	$390	$401	$400	$463	$565	$587
Weatherized Gas Furnace Fan	$349	$358	$376	$380	$435	$537	$560
Oil Furnace Fan	$382	$392	$396	$382	$448	$551	$569
Electric Furnace / Modular Blower Fan	$287	$294	$311	$305	$313	$402	$422
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	$313	$320	$325	$315	$375	$452	$471
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	$327	$334	$333	$320	$386	$463	$481
Manufactured Home Electric Furnace / Modular Blower Fan	$242	$249	$264	$256	$267	$343	$361

8-D.5 REGIONAL MATERIAL AND LABOR COSTS

DOE used regional material and labor costs to more accurately estimate installation, maintenance, and repair costs by region. RS Means provides average national labor costs for different trade groups as shown in Table 8-D.5.1. Bare costs are given in RS Means, while labor costs including overhead and profit (O&P) are the bare costs multiplied by the RS Means markups by trade shown in Table 8-D.5.2.

Table 8-D.5.1 RS Means 2012 National Average Labor Costs by Crew

Crew Type	Crew Description	Laborers per Crew	Cost per Labor-Hour	
			Bare Costs	Incl. O&P*
Q9	1 sheet metal worker, 1 sheet metal worker apprentice	2	$30.95	$51.50
Q1	1 Plumber, 1 Plumber Apprentice	2	$49.15	$76.58

* Q&P includes markups in Table 8-A.8.2

Table 8-D.5.2 RS Means Labor Costs Markups by Trade (Residential)

Trade	Workers Comp.	Aver Fixed Overhead	Overhead	Profit	Total
Sheet Metal (Residential)	8.5%	17.9%	30.0%	10.0%	66.4%
Plumber (Repair/Remodel)	6.9%	17.9%	16.0%	15.0%	55.8%

RS Means also provides material and labor cost factors for 295 cities and towns in the U.S. To derive average labor cost values by state, DOE weighted the price factors by city or town population size using 2012 census data. DOE used the material and labor cost factors for cost associated with fire suppression, plumbing, and HVAC. Table 8-D.5.3 shows the final regional material and labor price factors used in the analysis by geographical area. The distribution of each RECS 2009 product class sample is different, so the average labor cost weighted by RECS 2009 sample weights is different from the RS Means national average (i.e., labor cost factor of 1.00).

Table 8-D.5.3 Material and Labor Cost Factors by Geographical Area

Geographical Area	Material	Labor
Connecticut, Maine, New Hampshire, Rhode Island, Vermont	1.00	0.99
Massachusetts	1.01	1.27
New York	1.03	1.60
New Jersey	1.00	1.24
Pennsylvania	0.98	1.16
Illinois	0.99	1.32
Indiana, Ohio	0.98	0.89
Michigan	0.96	1.01
Wisconsin	1.00	1.01
Iowa, Minnesota, North Dakota, South Dakota	1.01	0.96
Kansas, Nebraska	0.99	0.73
Missouri	0.99	0.98
Virginia	1.01	0.69
Delaware, District of Columbia, Maryland	0.99	0.87
Georgia	0.97	0.67
North Carolina, South Carolina	0.99	0.49
Florida	1.00	0.73
Alabama, Kentucky, Mississippi	0.97	0.71
Tennessee	0.98	0.68
Arkansas, Louisiana, Oklahoma	0.98	0.60
Texas	0.98	0.61
Colorado	1.01	0.82
Idaho, Montana, Utah, Wyoming	1.01	0.69
Arizona	0.97	0.74
Nevada, New Mexico	0.99	0.91
California	1.01	1.19
Oregon, Washington	1.01	0.98
Alaska	1.24	1.14
Hawaii	1.12	1.21
West Virginia	1.00	0.99

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APPENDIX 8-E. FURNACE FAN LIFETIME DETERMINATION

8-E.1 INTRODUCTION

DOE defines lifetime as the age when a product is retired from service. DOE used national survey data, along with manufacturer shipment data, to calculate the distribution of furnace fan lifetimes. Furnace fan lifetimes are considered to be equivalent to furnace lifetimes, so DOE modeled furnace fan lifetime based on estimated furnace lifetimes, which were developed for the recent HVAC rulemaking. DOE assumed that the lifetime of a fan is the same at different efficiency levels.

8-E.2 METHODOLOGY

DOE's lifetime methods are based on "Using national survey data to estimate lifetimes of residential appliances" paper.[1]

EIA's RECS[2] surveys occupied primary housing units, noting the presence of a range of appliances and placing the age of each appliance into several-year bins. The U.S. Census's *American Housing Survey* (AHS)[3] surveys all housing, including vacant and second homes. Using the AHS data allowed DOE to adjust the RECS data to reflect some appliance use outside of primary residences. AHS also has a larger sample size, with correspondingly smaller sampling error. By combining these survey results with the known history of appliance shipments (collected from manufacturer trade associations) DOE estimated the fraction of appliances of a given age still in operation. This survival function, which DOE assumed has the form of a cumulative Weibull distribution, provides an estimate of the average and median appliance lifetime.

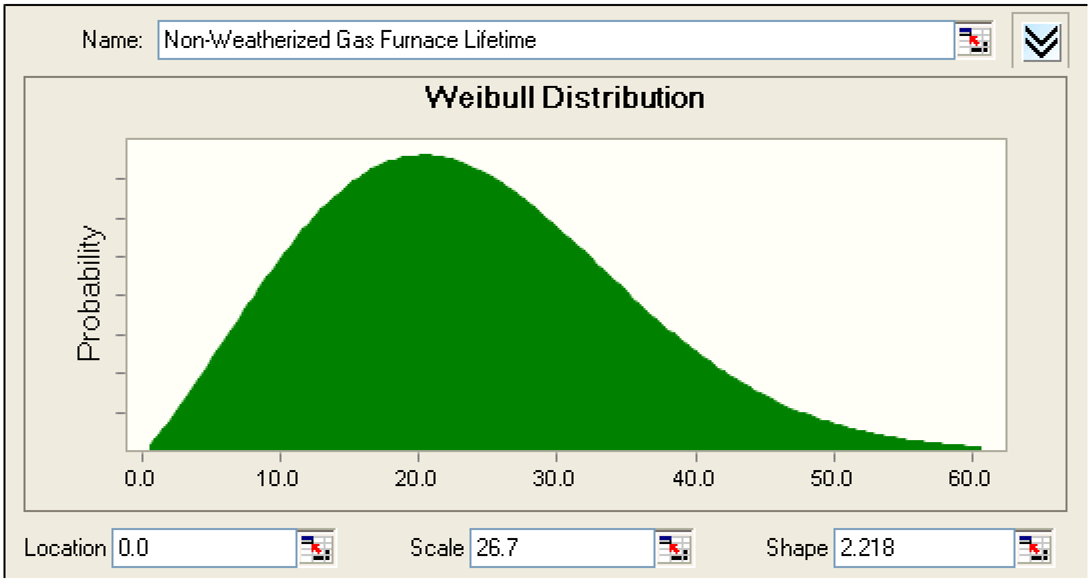
The Weibull distribution is a probability distribution function commonly used to measure failure rates.[4] Its form is similar to an exponential distribution, which would model a fixed failure rate, except that it allows for a failure rate that changes over time in a particular fashion. The cumulative distribution takes the form:

$$P(x) = e^{-\left(\frac{x-\theta}{\alpha}\right)^{\beta}} \quad \text{for } x > \theta \text{ and } P(x) = 1 \text{ for } x \le \theta,$$

Where:

$P(x)$ = probability that the appliance is still in use at age x,
x = appliance age,
α = the scale parameter, which is the decay length in an exponential distribution,
β = the shape parameter, which determines the way in which the failure rate changes in time, and
θ = the delay parameter, which allows for a delay before any failures occur.

When $\beta = 1$, the failure rate is constant over time, and this distribution takes the form of a cumulative exponential distribution. For the case of appliances, β is commonly greater than 1, which results from a rising failure rate as the appliance ages. A plot of a Weibull distribution (DOE's calculated furnace fan survival function) is shown as Figure 8-E.2.1.


Name: Non-Weatherized Gas Furnace Lifetime

Location 0.0

Scale 26.7

Shape 2.218

Figure 8-E.2.1 Lifetime Distribution for Non-Weatherized Gas Furnaces

The RECS survey is DOE's primary resource for furnace ages. For several appliances, including furnaces, the survey asks respondents to place the appliance's age into one of these bins:

- less than 2 years;
- 2 to 4 years;
- 5 to 9 years;
- 10 to 19 years and
- more than 20 years.

The RECS survey has been conducted every 3 or 4 years for the last several decades. For this analysis, DOE used the surveys conducted in 1990, 1993, 1997, 2001, and 2005. The AHS survey is conducted every other year, and DOE used the surveys conducted from 1991 to 2007. DOE used the AHS count of housing units with furnaces to scale the RECS data to better match the total installed stock. DOE used the surveys' household-level micro-data to count households with shared or multiple furnaces. Households that did not know the age of their appliances were allocated among the remaining age bins according to the distribution of respondents who did report their appliance age.

DOE used RECS appliance age data, AHS total installed stock data, and the history of appliance shipments to generate an estimate of the survival function. For example, DOE summed the total shipments from 5 to 9 years prior to the RECS survey, and compared this number with the number of units of those ages still in use, to calculate one approximation of the surviving appliance fraction within that age bin. The AHS total stock acts as an "all ages" bin. By combining the age bins from five RECS surveys and nine AHS surveys with shipments data, DOE had enough data to build a fit to a Weibull distribution and find the parameters (α, β, θ) that best approximate the surviving units, using a least-squares method. Because the first two (youngest) RECS bin data tend to have a large scatter relative to the shipments in those years, DOE combined the RECS and shipments data in the first two bins. Generally, appliances do not tend to fail in large numbers during this period, so combining bins does not appreciably lower the accuracy of the shape of the distribution. DOE weighted each bin's contribution to the sum of squares by the inverse of the variance in the survey results, which controls for the changes in sample size between RECS bins, between RECS and AHS, and within each survey over time.[4] RECS and AHS have complicated error models; DOE used only the error due to finite sample size to determine the variance used to weight each data point's contribution. The error due to sampling is less than 1% for AHS survey data and is typically about 5% for RECS age bins. The equation for the sum of squares DOE minimized is therefore:

$$\sum_{i} \frac{\left(\boldsymbol{RECS_i - Surv_i}\right)^2}{\sigma^2_{i,RECS}} + \sum_{j} \frac{\left(\boldsymbol{AHS_j - Surv_j}\right)^2}{\sigma^2_{j,AHS}}$$

Where:

i = the identifier for a bin from a single RECS,
j = the identifier for a single AHS survey,
$RECS_i$ = the number of appliances reported by RECS in bin i,
AHS_j = the number of appliances reported by AHS in survey year j,
$Surv_i$ = the number of surviving appliances in bin i predicted by the Weibull distribution applied to the number of appliances shipped (a function of α, β, and θ),
$\sigma_{i,RECS}$ = the standard error (square root of the variance) of the RECS data point for bin i, and
$\sigma_{j,AHS}$ = the standard error (square root of the variance) of the AHS data point for year j.

DOE adjusted the RECS and AHS survey data in several ways to place it on an even footing with the historical shipment data. In particular, DOE adjusted for the fact that the RECS survey is scaled to July of its reference year, the AHS survey is conducted in the middle portion of the year, and shipment data is provided for each calendar year. Adjustments included:

- DOE modeled the additional retirement of older appliances and their replacement by new ones that took place in the latter half of the survey year (after a given respondent had been surveyed), using the survival function. This had the effect of moving households from the older RECS age bins to the youngest age bin.

- For appliances installed directly in new construction, such as furnaces, DOE added units to the youngest RECS age bin and to the AHS total stock to represent half of the new construction for the final year of the survey, which were known to have installed the appliance type in question, using data from the U.S. Census for new construction starts.

Assumptions

DOE's lifetime-calculation technique depends on several assumptions:

- Appliance lifetime can be modeled by a survival function. In particular, a Weibull distribution is an appropriate survival function.
- The appliance survival function does not change over time.
- The survival function is independent of other household factors (such as household size, region, etc.) as well as product class (within furnaces).
- The age bin for the appliance as reported by the RECS respondent is correct.
- The historical shipment data is correct.
- The Weibull delay parameter, θ, is limited to between 1 and 5 years.

Three of these assumptions are of particular importance. The first is the assumption that a Weibull distribution is the correct distribution to use for appliance retirement rates. This distribution is the standard distribution for use in lifetime analysis, but it is not guaranteed to reflect actual consumer behavior. The second assumption is that consumer behavior and mechanical appliance lifetime have not changed over time. This assumption required DOE to treat all data from different RECS surveys on an equal footing. Using only recent surveys (to potentially better reflect recent consumer behavior and appliance lifetime) would result in attempted least-squares fits using a small number of data points, leading to large statistical uncertainty.

DOE limited the delay parameter to between 1 and 5 years to reflect the range of common appliance warranties. A delay of less than 1 year would imply that some appliances fail or are replaced within their initial year of use, a period during which they are commonly covered by parts and labor warranties. A delay of greater than 5 years implies that no appliances are replaced for some length of time after the end of the longest standard warranty. Fits with $\theta > 5$ also commonly show nonsensical behavior with sharp changes in consumer behavior or appliance survival immediately following the "delay" period.

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APPENDIX 8-F. DISTRIBUTIONS USED FOR DISCOUNT RATES

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8-F.1 INTRODUCTION

The Department of Energy (DOE) derived discount rates for the life-cycle cost (LCC) analysis using data on interest or return rates for various types of debt and equity. To account for variation among households in rates for each of the types, DOE sampled a rate for each household from a distribution of rates for each debt and equity type. This appendix describes the distributions used.

8-F.2 DISTRIBUTION OF MORTGAGE INTEREST RATES

Figure 8-F.2.1 shows the distribution of real interest rates for new home mortgages. The data source DOE used for mortgage interest rates is the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.[1] Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

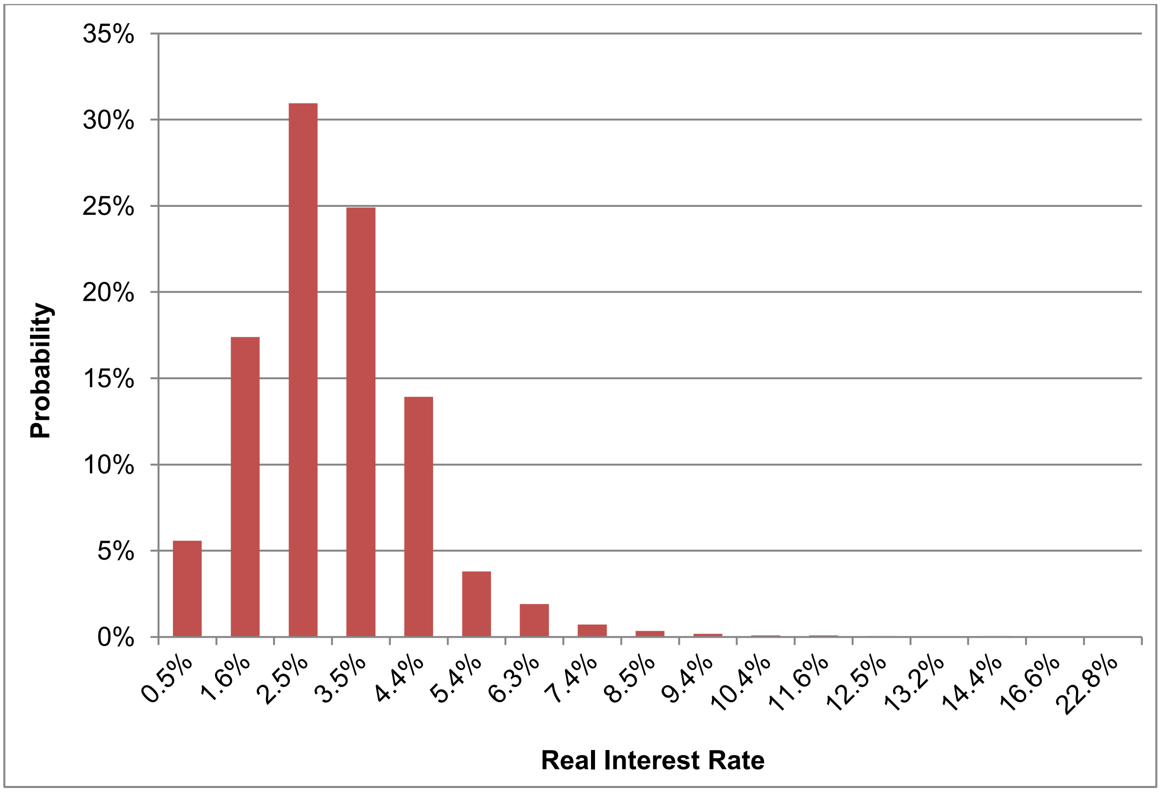

Figure 8-F.2.1 Distribution of New Home Mortgage Interest Rates

8-F.3 DISTRIBUTION OF RATES FOR DEBT CLASSES CONSIDERED FOR REPLACEMENT PRODUCTS

Figure 8-F.3.1 through Figure 8-F.3.5 show the distribution of real interest rates for different types of debt used to finance replacement clothes dryers and room air conditioners. The data source for the interest rates for home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.[1] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year. For home equity loans, DOE calculated effective interest rates in a similar manner as for mortgage rates, because interest on such loans is tax deductible.

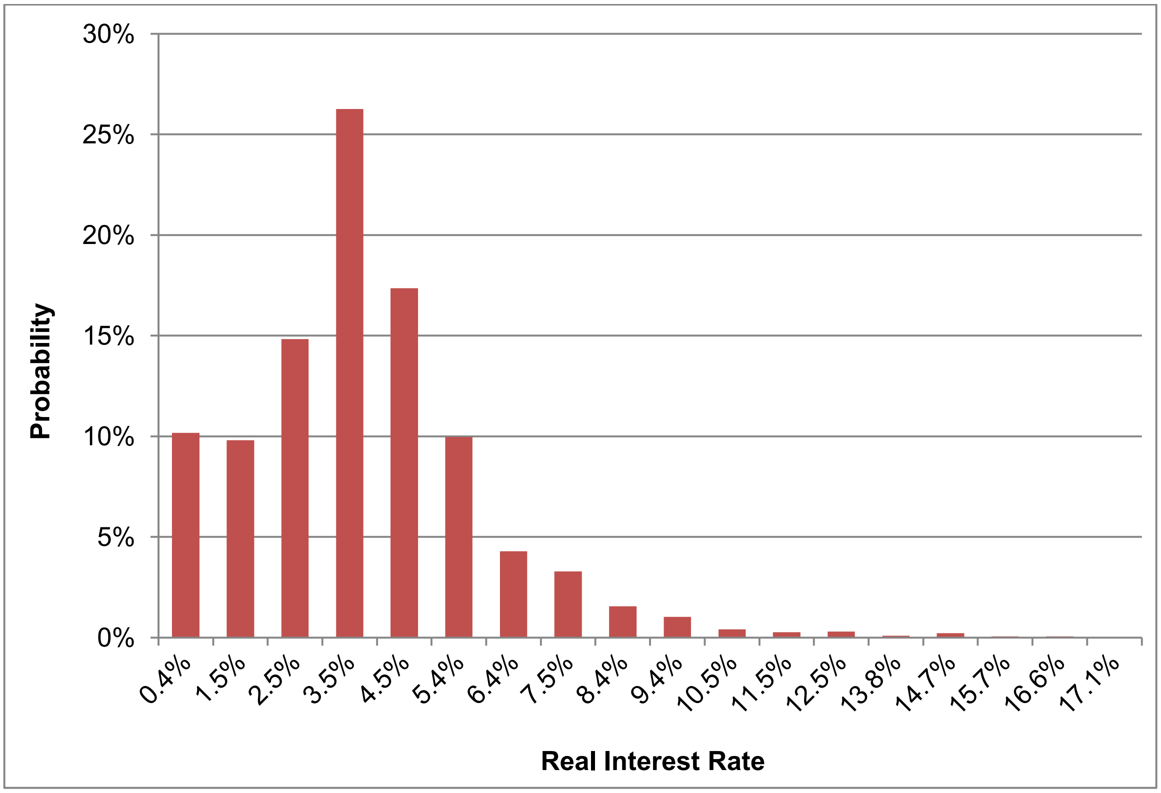

Figure 8-F.3.1 Distribution of Home Equity Loan Interest Rates

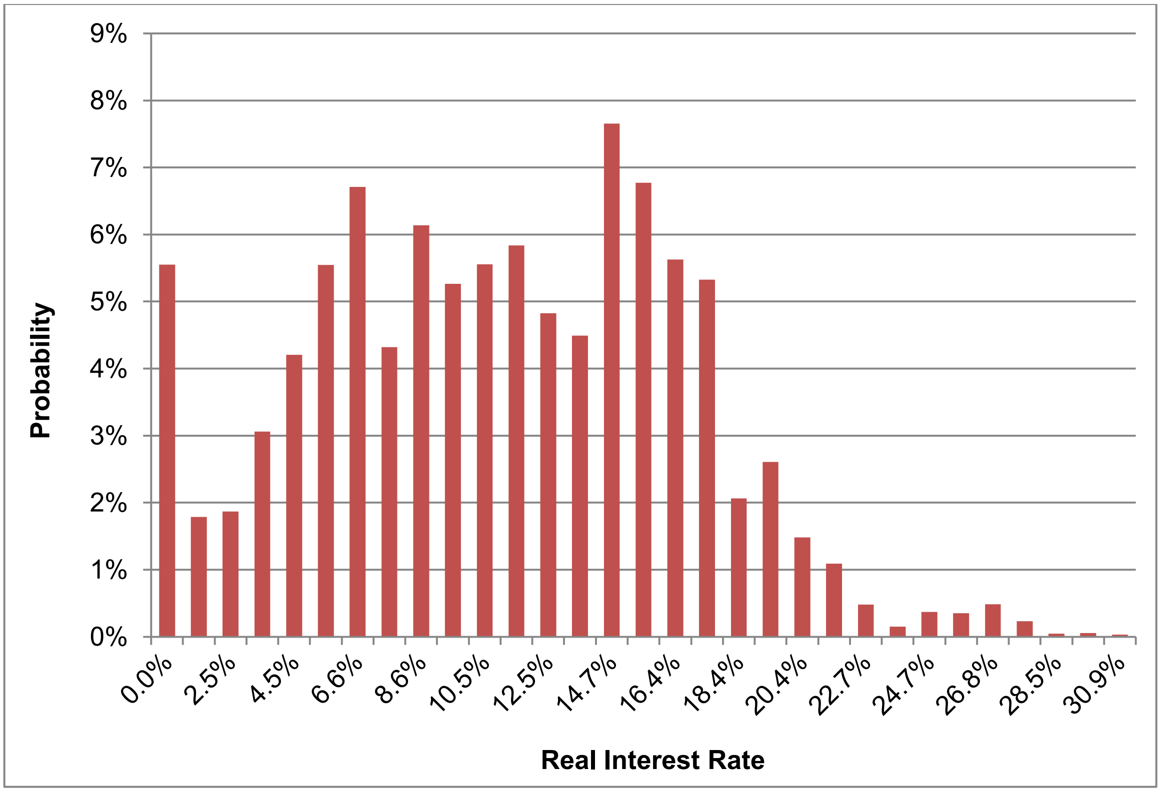

Figure 8-F.3.2 Distribution of Credit Card Interest Rates

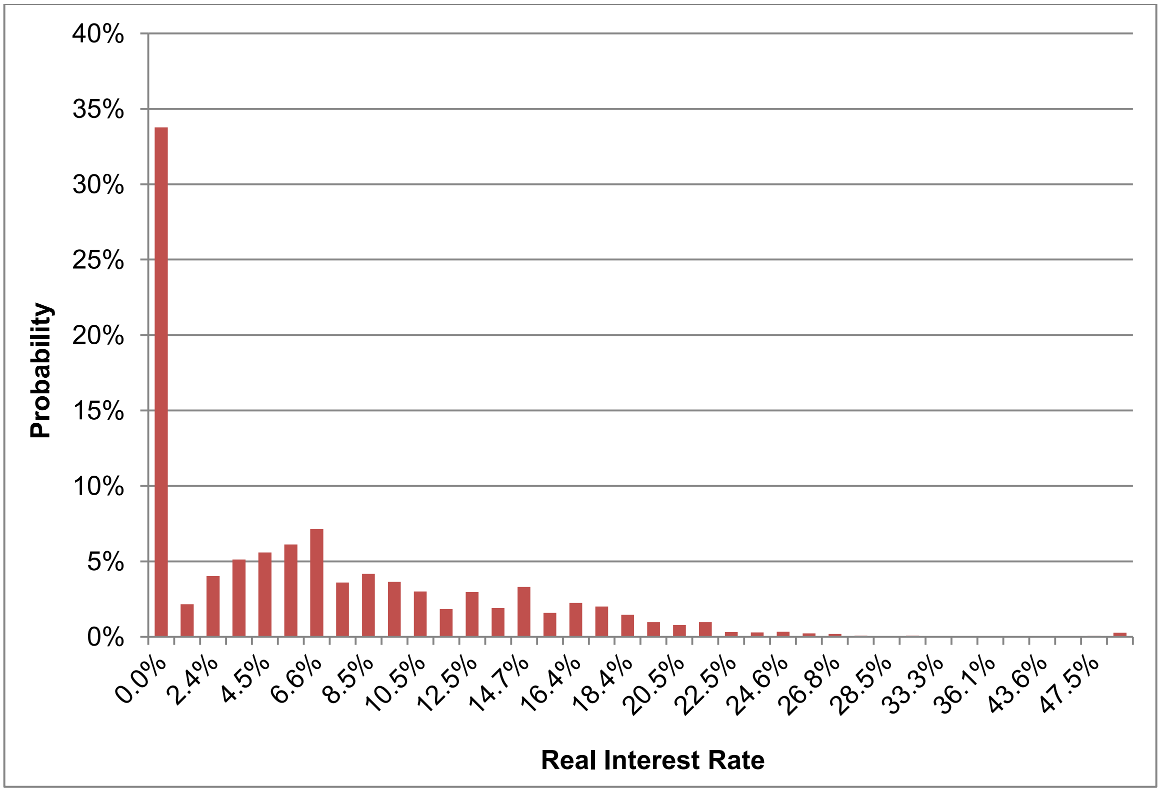

Figure 8-F.3.3 Distribution of Installment Loan Interest Rates

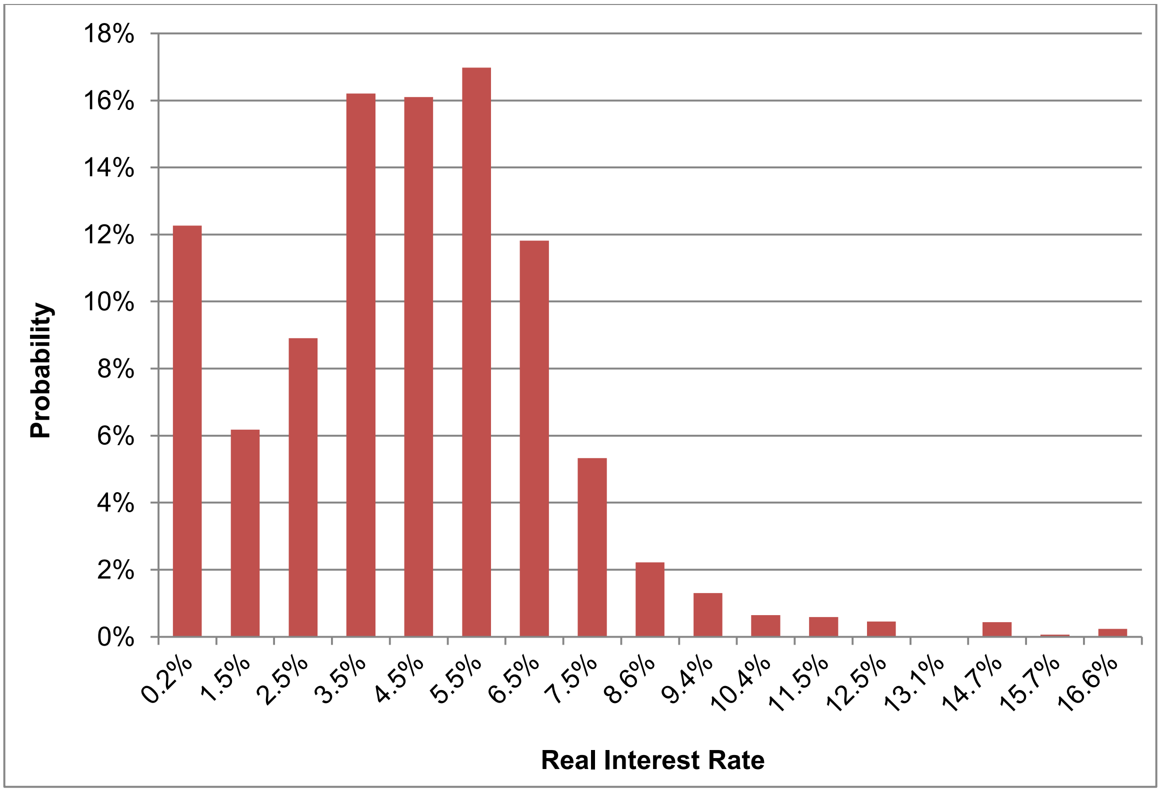

Figure 8-F.3.4 Distribution of Other Residence Loan Interest Rates

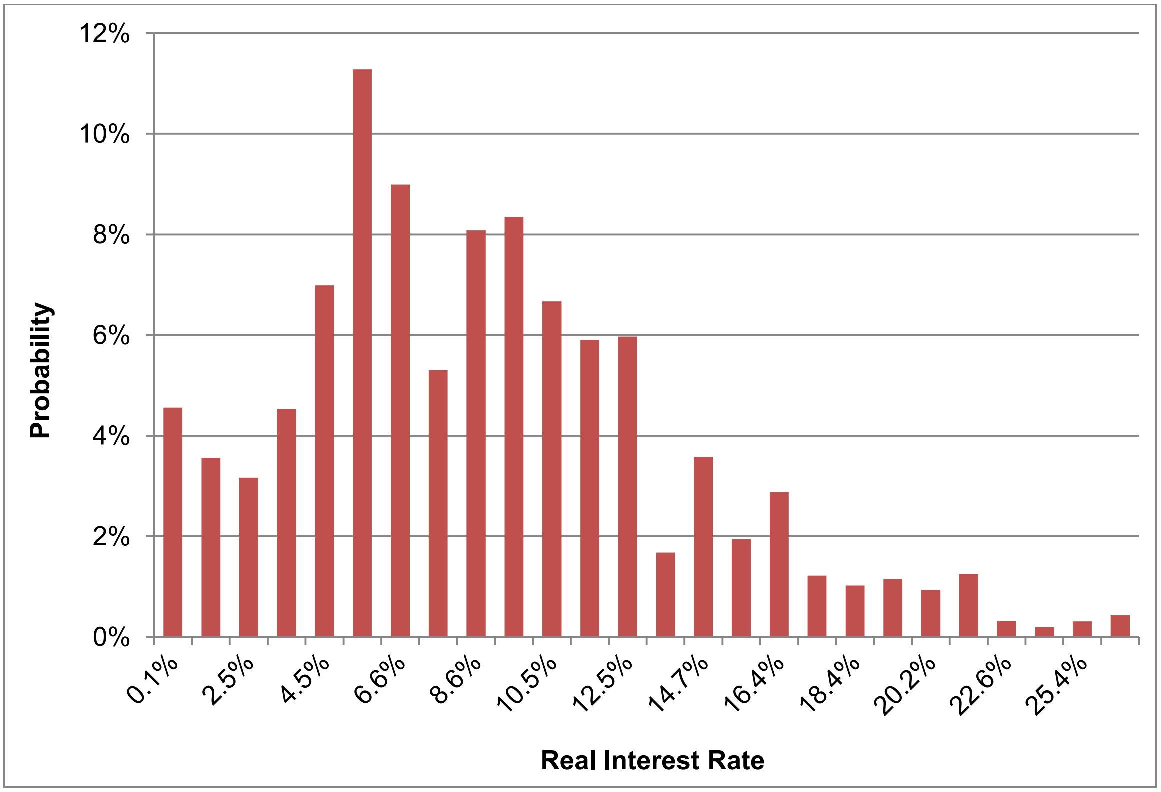

Figure 8-F.3.5 Distribution of Other Lines of Credit Loan Interest Rates

8-F.4 DISTRIBUTION OF RATES FOR EQUITY CLASSES CONSIDERED FOR REPLACEMENT PRODUCTS

Figure 8-F.4.1 through Figure 8-F.4.6 show the distribution of real interest rates for different types of equity used to finance replacement products. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data. The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and AAA corporate bonds[4] are from Federal Reserve Board time-series data covering 1977 to 2012. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984 to 2012.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 from 1977 to 2012.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year from 1977 to 2012. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

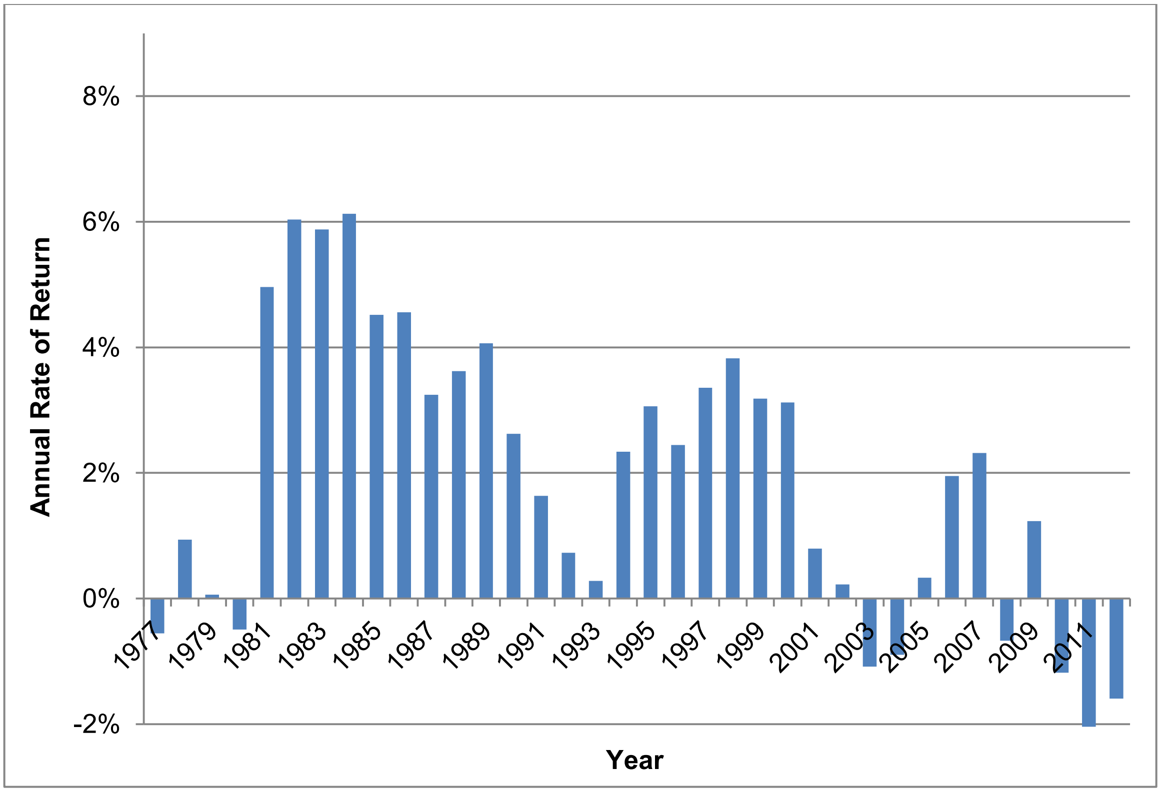

Figure 8-F.4.1 Distribution of Annual Rate of Return on CDs

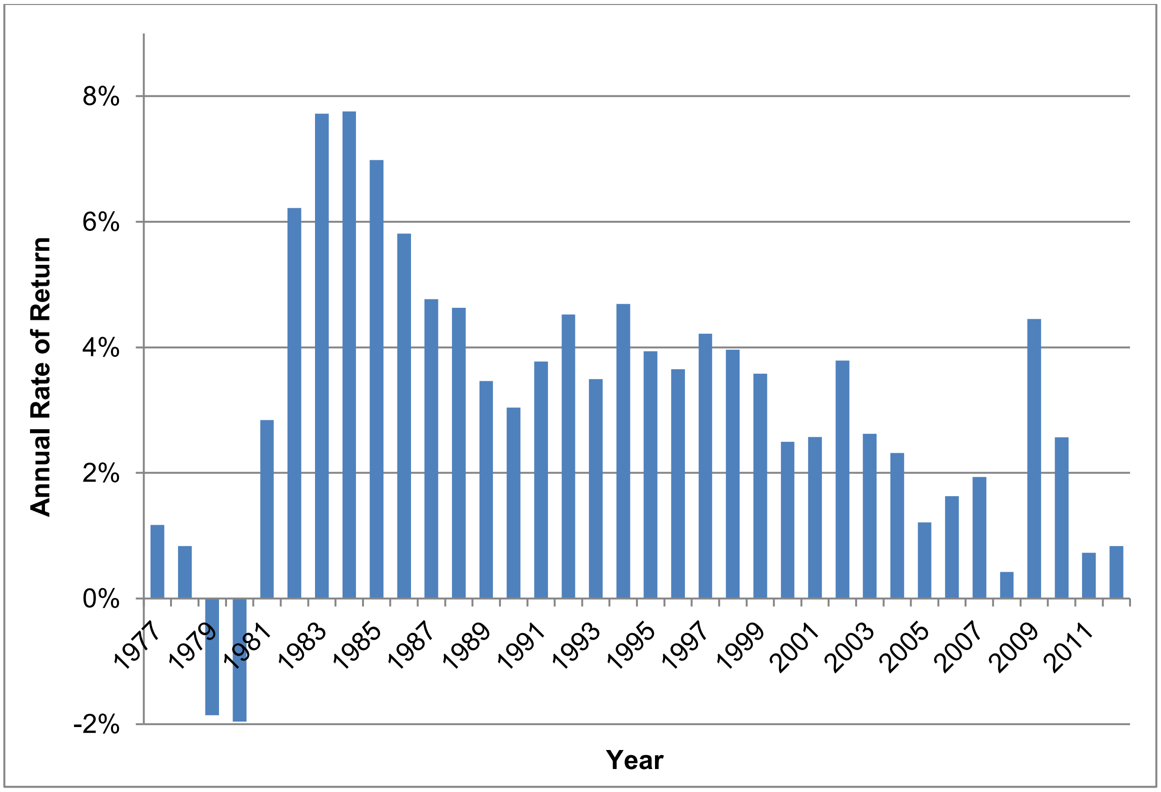

Figure 8-F.4.2 Distribution of Annual Rate of Return on Savings Bonds

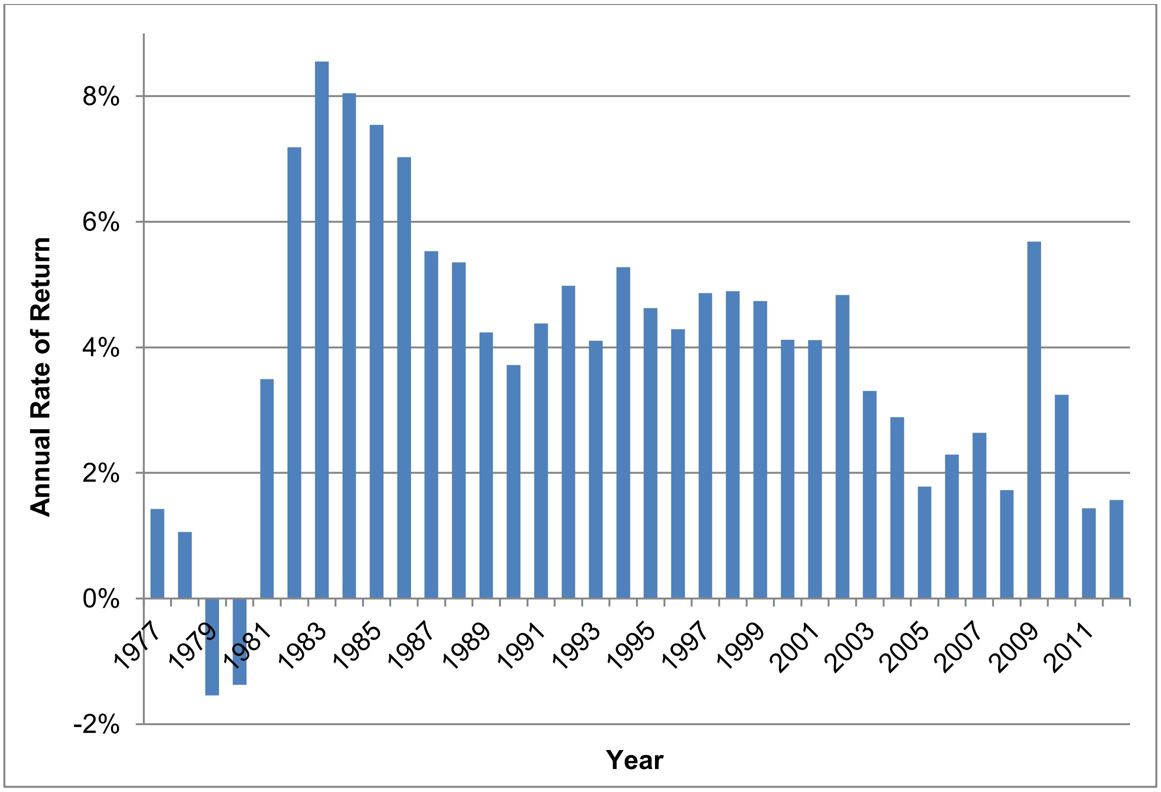

Figure 8-F.4.3 **Distribution of Annual Rate of Return on Corporate AAA Bonds**

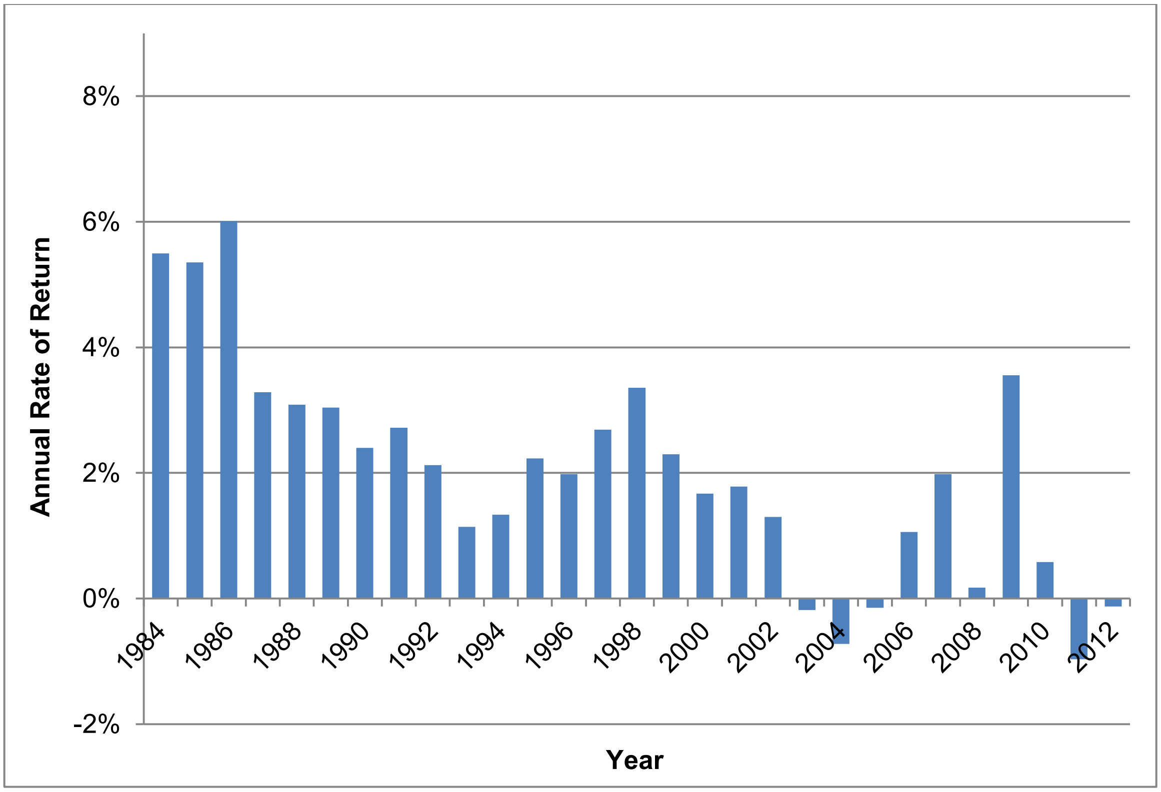

Figure 8-F.4.4 **Distribution of Annual Rate of Savings Accounts**

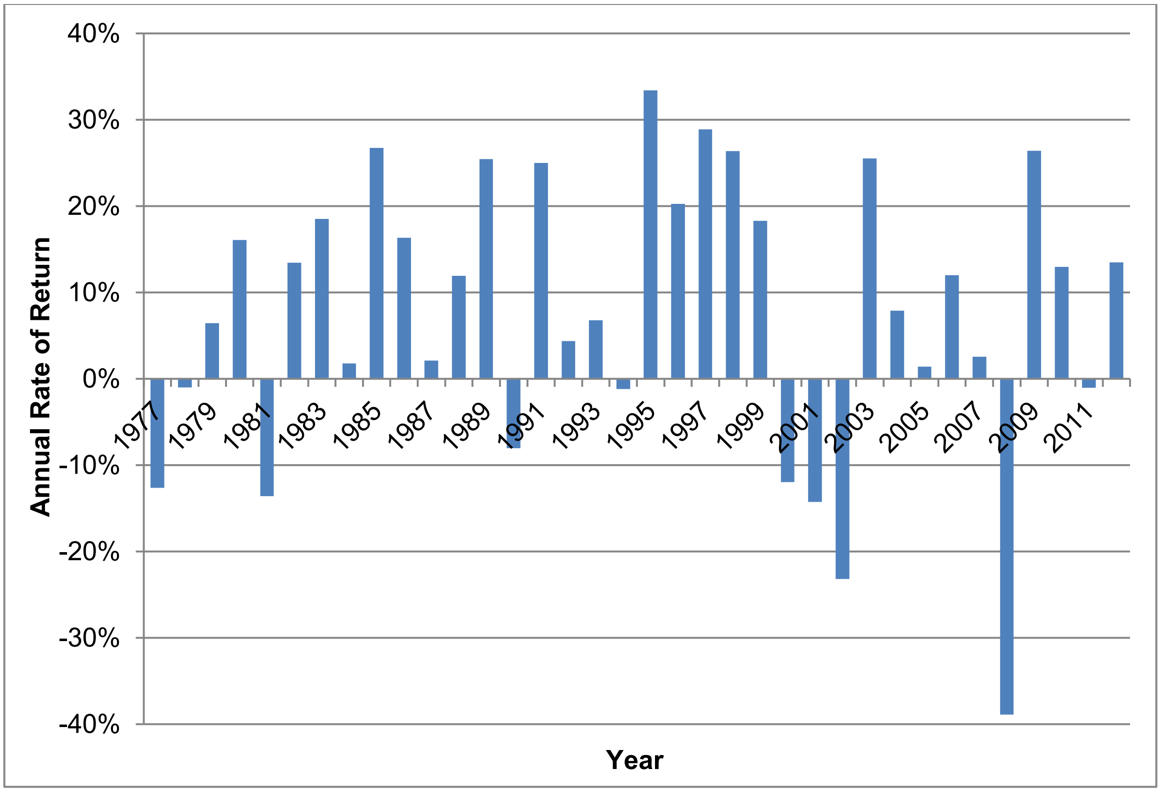

Figure 8-F.4.5 **Distribution of Annual Rate of Return on S&P 500**

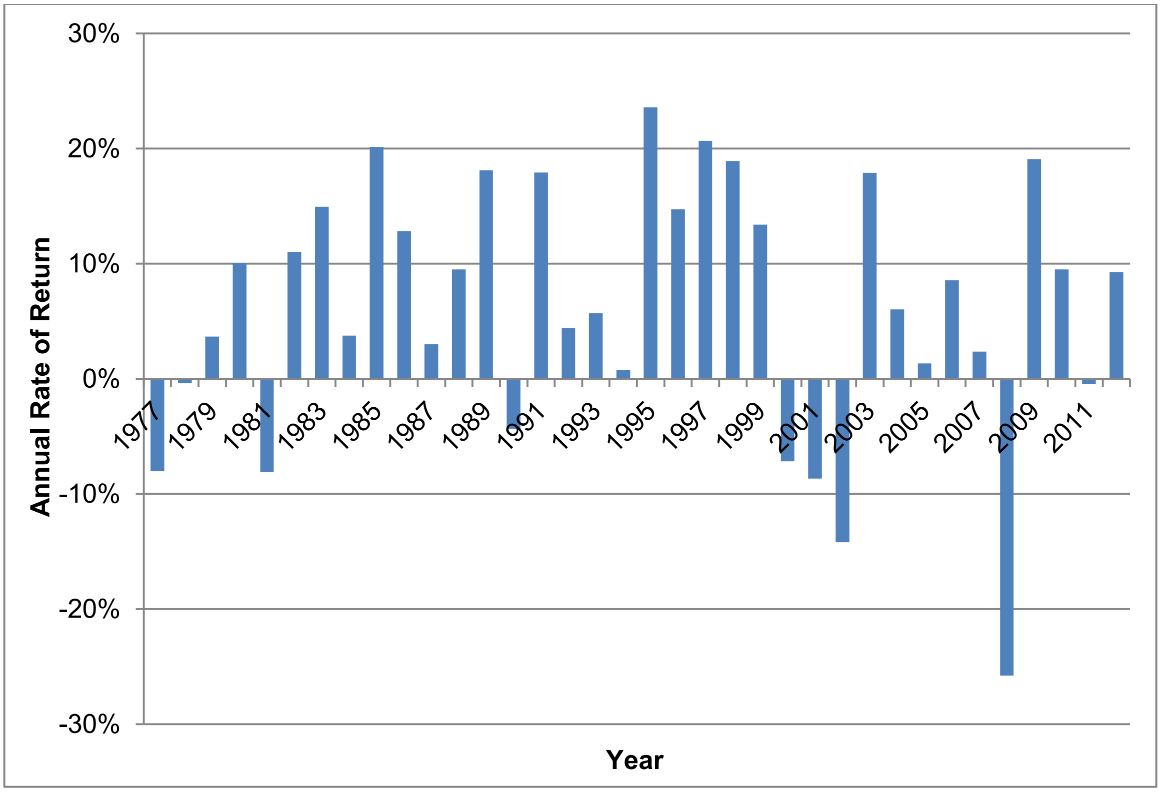

Figure 8-F.4.6 **Distribution of Annual Rate of Return on Mutual Funds**

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APPENDIX 8-G. LIFE-CYCLE COST ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR FURNACE FANS

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8-G.1 INTRODUCTION

This appendix presents life-cycle cost (LCC) results using energy price projections from alternative economic growth scenarios. The scenarios are based on the High Economic Growth case and the Low Economic Growth case from Energy Information Administration's (EIA's) *Annual Energy Outlook 2012* (*AEO2012*).[1]

This appendix describes the High and Low Economic Growth scenarios in further detail. See appendix 8-A for details about how to generate LCC results for High Economic Growth and Low Economic Growth scenarios using the LCC spreadsheet.

8-G.2 DESCRIPTION OF HIGH AND LOW ECONOMIC SCENARIOS

To generate LCC results reported in chapter 8, DOE uses the Reference case energy price projections from *AEO2012*. The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For *AEO2012*, EIA explored the impacts of alternative assumptions in other scenarios with different macroeconomic growth rates, world oil prices, rates of technology progress, and policy changes.

To reflect uncertainty in the projection of U.S. economic growth, EIA's *AEO2012* uses High and Low Economic Growth scenarios to project the possible impacts of alternative economic growth assumptions on energy markets. The High Economic Growth scenario incorporates population, labor force and productivity growth rates that are higher than the Reference scenario, while these values are lower for the Low Economic Growth scenario. Economic output as measured by real GDP increases by 2.5 percent per year from 2010 through 2035 in the Reference case, 3.0 percent in the Low Economic Growth scenario, and 2.0 percent in the High Economic Grow scenario.[2]

Energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario, except for electricity prices for the period between 2012 and 2027. The energy price forecasts affect the operating cost savings at different efficiency levels. Figure 8-G.1.1 to Figure 8-G.1.4 show the national price trends for the Reference, High Economic Growth, and Low Economic Growth scenarios to illustrate the general price trends. To estimate energy prices after 2035 in the high and low scenarios, DOE used the growth rate between 2020 and 2035. In these graphs price trends after 2035 are presented with a dashed line, since they are not part of *AEO2012* projections.

Since *AEO 2012* provides the price trends by census division, each sampled household is then matched to the appropriate census division price trend. See appendix 8-C for details about how energy price trends by census division are applied in the LCC analysis.

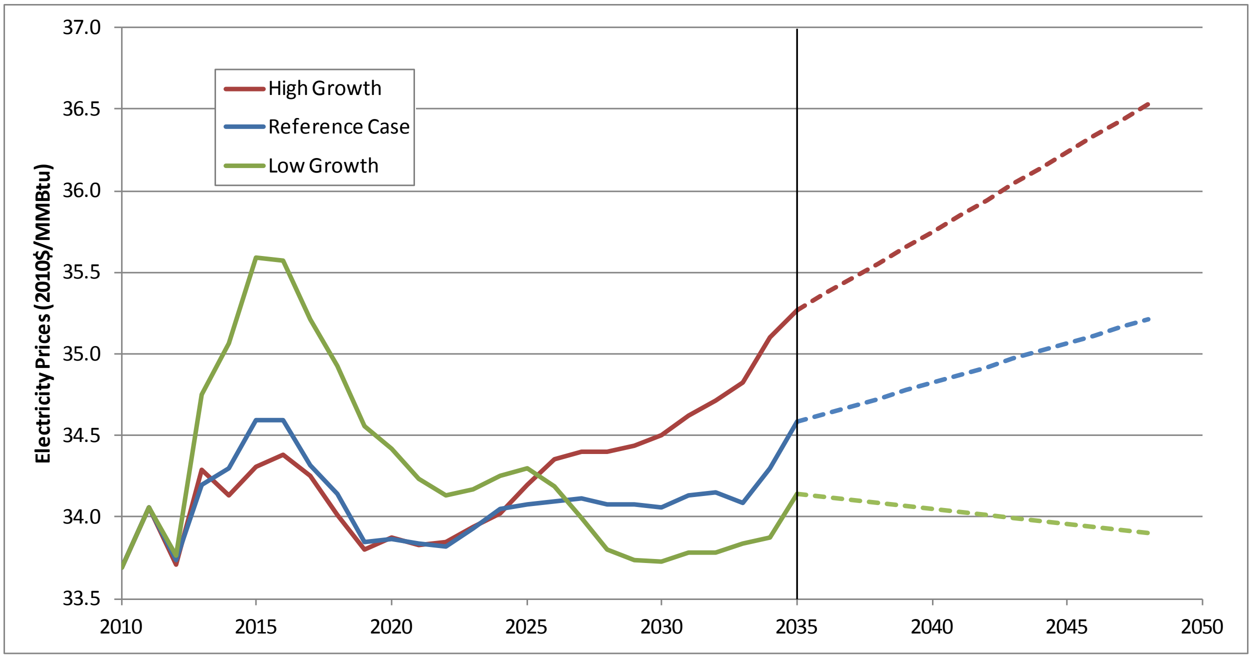

Figure 8-G.2.1 Electricity Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)

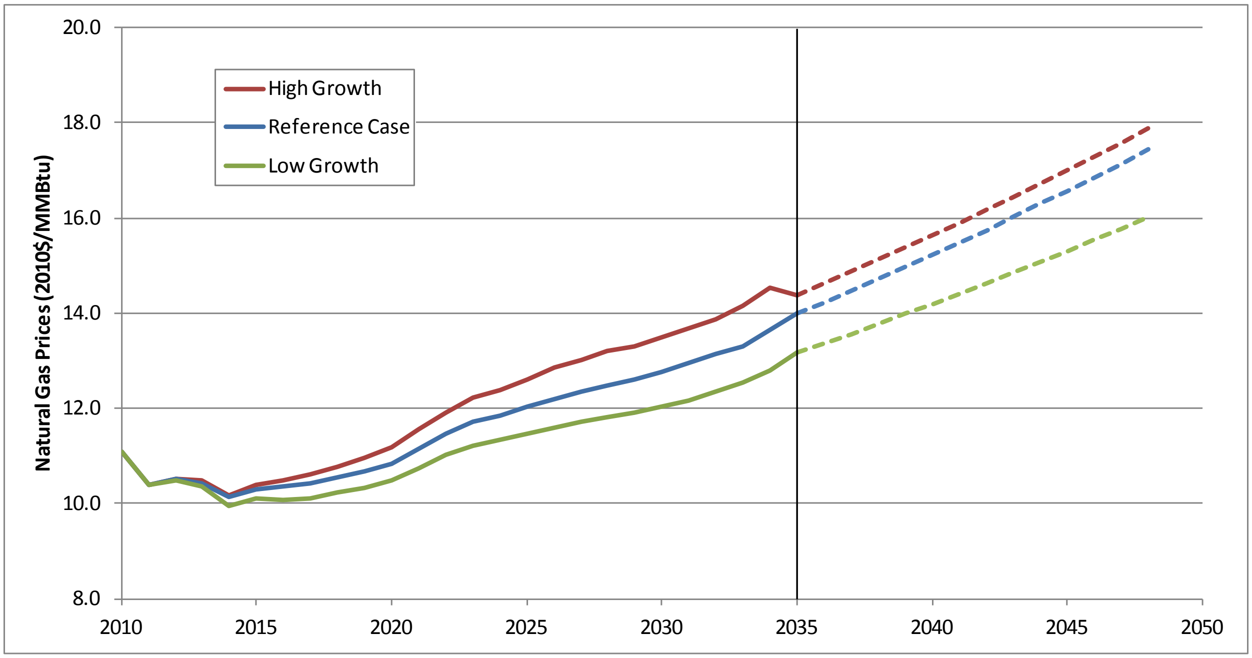

Figure 8-G.2.2 Natural Gas Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)

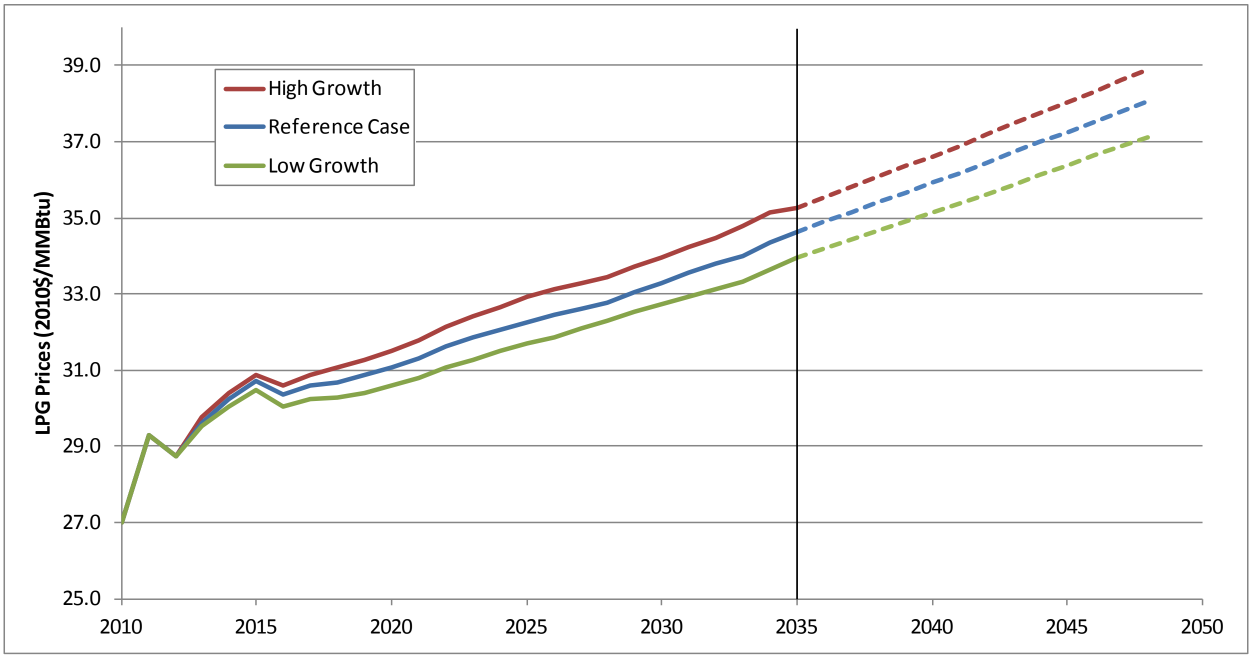

Figure 8-G.2.3 LPG Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)

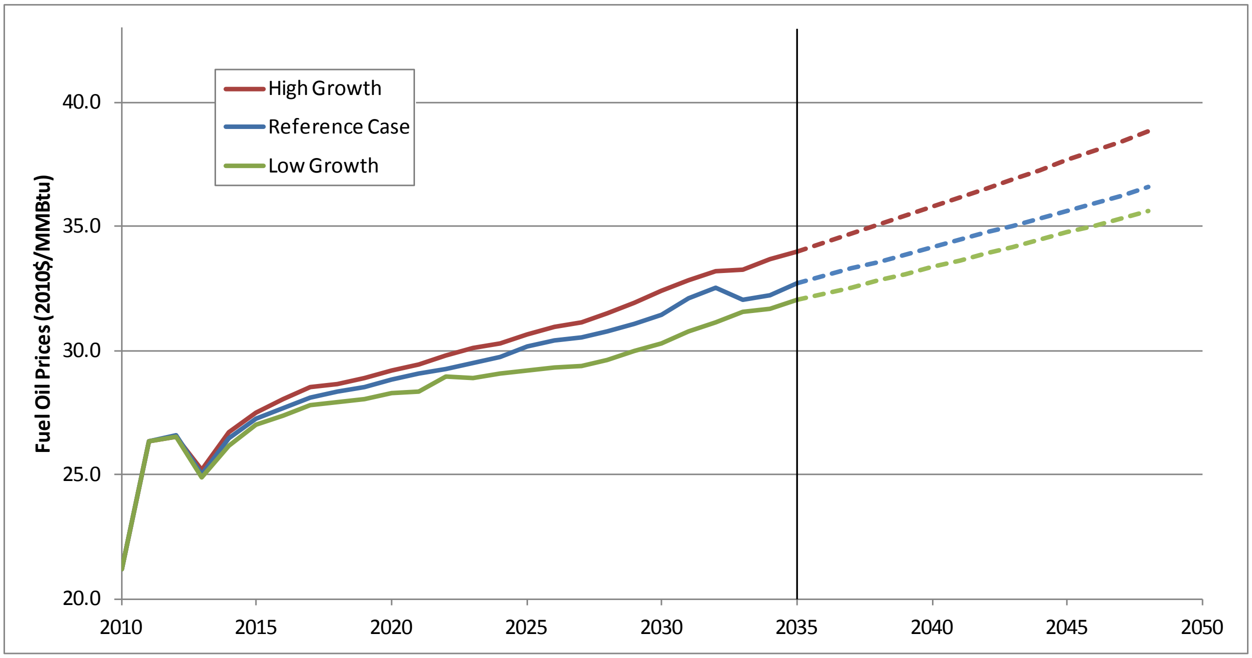

Figure 8-G.2.4 Fuel Oil Price Forecasts for Reference Case and High and Low Economic Growth Scenarios (National)

8-G.3 RESULTS

Table 8-G.3.1 and Table 8-G.3.2 summarizes the LCC and PBP results for High-Economic Growth and Low Economic Growth scenarios. Table 8-G.3.3 compares average LCC savings and median payback for these scenarios to the Reference case. The LCC and PBP results from the Reference, High-Economic Growth, and Low Economic Growth scenarios are similar. High-Economic Growth LCC and PBP savings are slightly higher compared to Reference and Low Economic Growth scenarios. Low Economic Growth savings are sometimes slightly higher or lower compared to Reference case.

Table 8-G.3.1 LCC and PBB Results for High Economic Growth Scenario

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
NWGFnc	Baseline	$343	$2,171	$2,514	$0	0%	100%	0%	---
	1	$354	$1,966	$2,320	$65	2%	68%	29%	1.4
	2	$403	$1,668	$2,071	$256	25%	25%	50%	4.0
	3	$414	$1,407	$1,821	$447	18%	25%	57%	2.7
	4	$496	$1,289	$1,784	$481	33%	14%	53%	5.4
	5	$662	$1,349	$2,011	$281	53%	12%	35%	11.5
	6	$697	$1,275	$1,972	$320	58%	0%	42%	11.2
NWGFc	Baseline	$339	$2,291	$2,630	$0	0%	100%	0%	---
	1	$351	$2,096	$2,446	$49	1%	75%	24%	1.3
	2	$398	$1,799	$2,197	$206	21%	41%	38%	4.1
	3	$408	$1,528	$1,936	$366	10%	41%	49%	2.7
	4	$490	$1,434	$1,924	$378	24%	34%	42%	5.4
	5	$658	$1,508	$2,165	$206	45%	29%	27%	11.7
	6	$692	$1,434	$2,126	$245	57%	0%	43%	11.0
WGF	Baseline	$329	$1,968	$2,297	$0	0%	100%	0%	---
	1	$340	$1,781	$2,121	$35	0%	81%	18%	1.3
	2	$387	$1,568	$1,955	$105	13%	56%	31%	5.0
	3	$397	$1,292	$1,689	$231	7%	56%	37%	2.7
	4	$476	$1,184	$1,660	$252	25%	33%	41%	6.4
	5	$636	$1,305	$1,941	$43	51%	27%	22%	15.6
	6	$670	$1,242	$1,912	$72	63%	0%	37%	13.5
OF	Baseline	$387	$2,586	$2,974	$0	0%	100%	0%	---
	1	$404	$2,434	$2,838	$40	12%	71%	18%	5.5
	2	$470	$2,080	$2,550	$250	46%	28%	26%	12.1
	3	$482	$1,933	$2,415	$350	43%	28%	29%	6.9
	4	$570	$1,868	$2,438	$333	49%	28%	23%	11.9
	5	$798	$1,922	$2,720	$128	58%	28%	14%	27.0
	6	$833	$1,874	$2,707	$140	79%	0%	21%	25.0

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
EF	Baseline	$241	$1,213	$1,454	$0	0%	100%	0%	---
	1	$252	$1,114	$1,365	$21	5%	73%	21%	2.4
	2	$295	$965	$1,260	$85	28%	37%	35%	6.2
	3	$294	$839	$1,133	$163	20%	37%	42%	3.2
	4	$315	$780	$1,095	$188	27%	25%	48%	3.6
	5	$450	$864	$1,314	$21	51%	25%	23%	12.9
	6	$482	$833	$1,315	$21	68%	0%	32%	13.5
MHGFnc	Baseline	$254	$1,159	$1,414	$0	0%	100%	0%	---
	1	$265	$1,085	$1,350	$27	13%	56%	32%	3.3
	2	$310	$968	$1,277	$99	62%	0%	38%	10.7
	3	$315	$913	$1,229	$148	58%	0%	42%	7.1
	4	$391	$888	$1,279	$98	70%	0%	30%	13.1
	5	$537	$938	$1,475	-$98	84%	0%	16%	26.3
	6	$569	$920	$1,489	-$113	84%	0%	16%	26.7
MHGFc	Baseline	$271	$1,373	$1,645	$0	0%	100%	0%	---
	1	$282	$1,279	$1,561	$27	7%	68%	25%	2.7
	2	$326	$1,138	$1,464	$98	42%	29%	28%	10.5
	3	$334	$1,053	$1,387	$155	39%	29%	32%	6.4
	4	$410	$1,019	$1,430	$115	68%	4%	28%	14.8
	5	$564	$1,066	$1,631	-$78	82%	4%	14%	34.2
	6	$597	$1,038	$1,635	-$82	84%	0%	16%	32.2
MHEF	Baseline	$192	$671	$863	$0	0%	100%	0%	---
	1	$202	$615	$817	$15	8%	71%	21%	2.5
	2	$243	$567	$810	$20	37%	38%	25%	10.1
	3	$241	$504	$745	$66	28%	38%	35%	4.4
	4	$259	$469	$728	$80	34%	26%	40%	4.6
	5	$382	$544	$926	-$68	59%	26%	15%	16.8
	6	$412	$530	$942	-$84	82%	0%	18%	17.0

Table 8-G.3.2 LCC and PBB Results for Low Economic Growth Scenario

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
NWGFnc	Baseline	$343	$2,142	$2,484	$0	0%	100%	0%	---
	1	$354	$1,937	$2,292	$65	2%	68%	30%	1.3
	2	$403	$1,644	$2,047	$253	25%	25%	50%	3.9
	3	$414	$1,382	$1,796	$444	18%	25%	57%	2.6
	4	$496	$1,265	$1,761	$476	32%	14%	53%	5.3
	5	$662	$1,325	$1,987	$277	53%	12%	35%	11.3
	6	$697	$1,252	$1,949	$315	58%	0%	42%	11.0
NWGFc	Baseline	$339	$2,228	$2,568	$0	0%	100%	0%	---

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
	1	$351	$2,037	$2,388	$48	1%	75%	24%	1.3
	2	$398	$1,750	$2,148	$200	21%	41%	38%	4.0
	3	$408	$1,483	$1,891	$357	10%	41%	49%	2.7
	4	$490	$1,393	$1,882	$366	24%	34%	42%	5.2
	5	$658	$1,467	$2,125	$194	45%	29%	26%	11.4
	6	$692	$1,394	$2,087	$231	57%	0%	43%	10.9
WGF	Baseline	$329	$1,940	$2,269	$0	0%	100%	0%	---
	1	$340	$1,754	$2,094	$35	0%	81%	18%	1.2
	2	$387	$1,544	$1,931	$104	12%	56%	31%	4.9
	3	$397	$1,270	$1,667	$229	6%	56%	37%	2.6
	4	$476	$1,163	$1,639	$248	25%	33%	41%	6.2
	5	$636	$1,283	$1,919	$40	51%	27%	22%	15.1
	6	$670	$1,221	$1,891	$69	63%	0%	37%	12.7
OF	Baseline	$387	$2,514	$2,902	$0	0%	100%	0%	---
	1	$404	$2,364	$2,768	$40	11%	71%	18%	5.5
	2	$470	$2,020	$2,490	$242	46%	28%	26%	12.2
	3	$482	$1,872	$2,354	$342	43%	28%	29%	7.1
	4	$570	$1,809	$2,379	$325	49%	28%	23%	12.2
	5	$798	$1,864	$2,662	$118	58%	28%	14%	27.5
	6	$833	$1,817	$2,650	$130	79%	0%	21%	25.6
EF	Baseline	$241	$1,195	$1,436	$0	0%	100%	0%	---
	1	$252	$1,097	$1,348	$21	5%	73%	21%	2.4
	2	$295	$950	$1,246	$84	28%	37%	34%	6.0
	3	$294	$826	$1,120	$161	20%	37%	42%	3.1
	4	$315	$768	$1,082	$185	27%	25%	48%	3.5
	5	$450	$851	$1,301	$19	51%	25%	23%	12.6
	6	$482	$821	$1,303	$17	68%	0%	32%	13.0
MHGFnc	Baseline	$254	$1,134	$1,388	$0	0%	100%	0%	---
	1	$265	$1,060	$1,325	$26	12%	56%	32%	2.7
	2	$310	$946	$1,256	$96	62%	0%	38%	10.4
	3	$315	$891	$1,206	$146	57%	0%	43%	6.7
	4	$391	$866	$1,257	$95	70%	0%	30%	12.6
	5	$537	$917	$1,454	-$102	84%	0%	16%	25.4
	6	$569	$899	$1,468	-$116	84%	0%	16%	26.0
MHGFc	Baseline	$271	$1,337	$1,608	$0	0%	100%	0%	---
	1	$282	$1,244	$1,526	$26	7%	68%	26%	2.7
	2	$326	$1,108	$1,434	$94	43%	29%	28%	9.5
	3	$334	$1,024	$1,358	$150	38%	29%	32%	6.3

	Efficiency Level	**Life-Cycle Cost (2012$)**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
		Average Installed Cost	**Average Discounted Operating Cost**	**Average LCC**	**Average Savings (2012$)**	**% of Households with**			
						Net Cost	**No Impact**	**Net Benefit**	
	4	$410	$991	$1,402	$109	68%	4%	28%	14.6
	5	$564	$1,039	$1,604	-$85	82%	4%	14%	33.8
	6	$597	$1,012	$1,608	-$89	84%	0%	16%	31.8
MHEF	Baseline	$192	$663	$855	$0	0%	100%	0%	---
	1	$202	$608	$810	$14	8%	71%	21%	2.5
	2	$243	$561	$804	$20	37%	38%	25%	9.9
	3	$241	$499	$739	$65	28%	38%	35%	4.3
	4	$259	$464	$723	$78	34%	26%	40%	4.5
	5	$382	$538	$921	-$70	59%	26%	15%	16.4
	6	$412	$525	$937	-$86	82%	0%	18%	16.4

Table 8-G.3.3 Comparison of Average LCC Savings and Median Payback Period Results for Reference Case and High and Low Economic Growth Scenarios

	Efficiency Level	Average LCC Savings *2012$*			Median Payback Period *Years*		
		High Growth	**Low Growth**	**Reference Case**	**High Growth**	**Low Growth**	**Reference Case**
NWGFnc	1	$65	$65	$64	1.4	1.3	1.3
	2	$256	$253	$253	4.0	3.9	4.0
	3	$447	$444	$442	2.7	2.6	2.7
	4	$481	$476	$474	5.4	5.3	5.4
	5	$281	$277	$275	11.5	11.3	11.5
	6	$320	$315	$313	11.2	11.0	11.2
NWGFc	1	$49	$48	$49	1.3	1.3	1.4
	2	$206	$200	$203	4.1	4.0	4.1
	3	$366	$357	$361	2.7	2.7	2.7
	4	$378	$366	$371	5.4	5.2	5.4
	5	$206	$194	$199	11.7	11.4	11.7
	6	$245	$231	$238	11.0	10.9	11.0
WGF	1	$35	$35	$35	1.3	1.2	1.3
	2	$105	$104	$104	5.0	4.9	4.9
	3	$231	$229	$228	2.7	2.6	2.7
	4	$252	$248	$247	6.4	6.2	6.4
	5	$43	$40	$39	15.6	15.1	15.5
	6	$72	$69	$67	13.5	12.7	13.3
OF	1	$40	$40	$40	5.5	5.5	5.5
	2	$250	$242	$245	12.1	12.2	12.3
	3	$350	$342	$344	6.9	7.1	7.0
	4	$333	$325	$326	11.9	12.2	12.1
	5	$128	$118	$120	27.0	27.5	27.5
	6	$140	$130	$132	25.0	25.6	25.4
EF	1	$21	$21	$21	2.4	2.4	2.4
	2	$85	$84	$84	6.2	6.0	6.2
	3	$163	$161	$160	3.2	3.1	3.2
	4	$188	$185	$185	3.6	3.5	3.5
	5	$21	$19	$18	12.9	12.6	12.8
	6	$21	$17	$17	13.5	13.0	13.4

	Efficiency Level	**Average LCC Savings** *2012$*			**Median Payback Period** *Years*		
		High Growth	**Low Growth**	**Reference Case**	**High Growth**	**Low Growth**	**Reference Case**
MHGFnc	1	$27	$26	$26	3.3	2.7	3.3
	2	$99	$96	$97	10.7	10.4	10.7
	3	$148	$146	$146	7.1	6.7	7.0
	4	$98	$95	$95	13.1	12.6	13.1
	5	-$98	-$102	-$102	26.3	25.4	26.2
	6	-$113	-$116	-$116	26.7	26.0	26.7
MHGFc	1	$27	$26	$27	2.7	2.7	2.7
	2	$98	$94	$96	10.5	9.5	10.5
	3	$155	$150	$152	6.4	6.3	6.5
	4	$115	$109	$111	14.8	14.6	14.8
	5	-$78	-$85	-$82	34.2	33.8	34.3
	6	-$82	-$89	-$86	32.2	31.8	32.2
MHEF	1	$15	$14	$14	2.5	2.5	2.5
	2	$20	$20	$20	10.1	9.9	10.0
	3	$66	$65	$64	4.4	4.3	4.3
	4	$80	$78	$78	4.6	4.5	4.6
	5	-$68	-$70	-$70	16.8	16.4	16.8
	6	-$84	-$86	-$86	17.0	16.4	17.1

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1. Energy Information Administration, *Annual Energy Outlook 2012 with Projections to 2035*, 2012. Washington, DC. <http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf>

2. Energy Information Administration, *Macroeconomic Activity Module for Annual Energy Outlook 2012*, 2012. Washington, DC. <http://www.eia.gov/forecasts/aeo/assumptions/pdf/macroeconomic.pdf>

APPENDIX 8-H. LIFE-CYCLE COST ANALYSIS USING ALTERNATIVE CONSTANT CIRCULATION USE SCENARIOS FOR FURNACE FANS

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APPENDIX 8-H. LIFE-CYCLE COST ANALYSIS USING ALTERNATIVE CONSTANT CIRCULATION USE SCENARIOS FOR FURNACE FANS

8-H.1 INTRODUCTION

This appendix presents LCC results using alternative constant circulation use scenarios.

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8-H.2 METHODOLOGY

The amount of constant-circulation hours is based on data from two surveys, which are also used for the furnace fan test procedure.[a] One survey was conducted by researchers in Wisconsin in 2003.[2] The second survey was conducted by the Center for Energy and the Environment (CEE) in Minnesota, the results of which were provided by CEE in a written comment that is included in the docket for the furnace fan test procedure.[3] DOE combined both studies by adding the number of respondents and derived fractions of households in each constant circulation use category, as shown in Table 8-H.2.1. The total share of households using some type of constant circulation equals 31 percent.

DOE estimated a value for average number of fan constant-circulation hours for each constant circulation use category, similar to what is assumed in the furnace fan test procedure. For “no constant circulation” responses, DOE assumed zero constant-circulation hours. For “year-round” responses, DOE assumed 100 percent of non-heating or cooling furnace fan operating hours, which DOE calculated by subtracting furnace fan heating and cooling operating hours for each sample household from the total annual hours (8,760). For “during heating season” responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For “during cooling season” responses, DOE assumed 15 percent of non-heating or cooling furnace fan operating hours. For “other (some constant circulation)” responses, DOE assumed 5 percent of non-heating or cooling furnace fan operating hours.

Similar to what was done for the test procedure, DOE did not use these data directly, because it believes they are not representative of consumer practices for the U.S. as a whole. In Wisconsin and Minnesota, many homes have low air infiltration, and there is a high awareness of indoor air quality issues, which leads to significant use of constant circulation. To account for this, DOE developed separate regional fractions that took into account information from manufacturer product literature and regional climate conditions. Furnace fan manufacturer literature states that constant circulation fan operation is not recommended for humid climates. Therefore, DOE assumed that the fraction using each constant circulation type in the South Hot

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[a] A recent national study was published by Decision Analyst in September 2013, which shows similar constant circulation use as was estimated by DOE in this analysis.[1]

Humid region[b] would only be 10 percent of what was reported in the Wisconsin and Minnesota studies (*i.e.*, 3.1 percent compared to 31 percent in the studies). For the rest of the country (North and South Hot Dry regions), DOE assumed that the fraction using constant circulation would be half of what was reported in the Wisconsin and Minnesota studies (*i.e.*, 15.5 percent compared to 31 percent in the studies). On average, an estimated 11 percent of U.S. households use some type of constant circulation. The fraction using year-round constant circulation is 5 percent.

Table 8-H.2.1 Results from Constant-Circulation Use Studies and Estimated National Constant-Circulation Practices

How Often is Constant Circulation Fan Used?	Assumed Average Number of Hours	Combined Data from Studies		Estimated North and South-Hot Dry Region Shares for LCC Analysis	Estimated South-Hot Humid Region Shares for LCC Analysis
		Number of Households	Percentage (%)		
No constant fan	0	69	68%	84%	97%
Year-round	7290	14	14%	7%	1%
During heating season	1097	4	4%	2%	0.4%
During cooling season	541	4	4%	2%	0.4%
Other (some constant fan)	365	10	10%	5%	1%
Total	--	101	100%	100%	100%

To take into account the sensitivity of these assumptions on the energy use results, DOE developed two sensitivity scenarios in addition to the default scenario used in the analysis and in DOE's furnace fan test procedure.

The default scenario (scenario 1) assumes 50% of the Wisconsin and Minnesota survey constant fan use for the North and South Hot Dry regions, and 10% in the South Hot Humid region. The second scenario assumes 50% of the Wisconsin and Minnesota survey constant fan use for the North region, 25% for the South Hot Dry region, and 10% in the South Hot Humid region. The third scenario assumes 25% of the Wisconsin and Minnesota survey constant fan use for the North and South Hot Dry regions, and 5% in the South Hot Humid region.

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[b] Regions as defined in the Furnace and Central Air Conditioner Final Rule[4]: North (Alaska, Colorado, Connecticut, Idaho, Illinois, Indiana, Iowa, Kansas, Maine, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Jersey, New York, North Dakota, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Utah, Vermont, Washington, West Virginia, Wisconsin, and Wyoming), South Hot Dry (Arizona, California, Nevada, and New Mexico), and South Hot Humid (Alabama, Arkansas, Delaware, Florida, Georgia, Hawaii, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia, and the District of Columbia).

Table 8-H.2.2 Constant Circulation Furnace Fan Scenarios

Scenario	Fraction of Households using Constant Circulation
1	11%
2	9%
3	5%

8-H.3 RESULTS

Table 8-H.3.1 Life Cycle Cost Results, Scenario 1 (Test Procedure Assumptions: 50% of Survey in North & South, Hot Dry; 10% in South Hot Humid)

Product Class	Efficiency Level	Life-Cycle Cost *2012$*			Average Life-Cycle Cost Savings *2012$*	% of Households that Experience			Median Payback Period *years*
		Installed Cost	Operating Cost*	LCC		Net Cost	No Impact	Net Benefit	
Non-weatherized, Non-condensing Gas Furnace Fan	0	$343	$2,146	$2,489	$0	0%	100%	0%	---
	1	$354	$1,943	$2,297	$64	2%	68%	30%	1.3
	2	$403	$1,649	$2,052	$253	25%	25%	50%	4.0
	3	$414	$1,389	$1,803	$442	18%	25%	57%	2.7
	4	$496	$1,273	$1,769	$474	33%	14%	53%	5.4
	5	$662	$1,333	$1,995	$275	53%	12%	35%	11.5
	6	$697	$1,260	$1,957	$313	58%	0%	42%	11.2
Non-weatherized, Condensing Gas Furnace Fan	0	$339	$2,259	$2,598	$0	0%	100%	0%	---
	1	$351	$2,066	$2,417	$49	1%	75%	24%	1.4
	2	$398	$1,775	$2,173	$203	21%	41%	38%	4.1
	3	$408	$1,506	$1,914	$361	10%	41%	49%	2.7
	4	$490	$1,414	$1,904	$371	24%	34%	42%	5.4
	5	$658	$1,488	$2,146	$199	45%	29%	27%	11.7
	6	$692	$1,415	$2,107	$238	57%	0%	43%	11.0
Weatherized Gas Furnace Fan	0	$329	$1,944	$2,273	$0	0%	100%	0%	---
	1	$340	$1,759	$2,099	$35	0%	81%	18%	1.3
	2	$387	$1,549	$1,936	$104	13%	56%	31%	4.9
	3	$397	$1,276	$1,673	$228	7%	56%	37%	2.7
	4	$476	$1,170	$1,645	$247	25%	33%	41%	6.4
	5	$636	$1,290	$1,926	$39	51%	27%	22%	15.5
	6	$670	$1,228	$1,898	$67	63%	0%	37%	13.3
Oil Furnace	0	$387	$2,540	$2,927	$0	0%	100%	0%	---
	1	$404	$2,389	$2,794	$40	12%	71%	18%	5.5
	2	$470	$2,042	$2,512	$245	46%	28%	26%	12.3

Product Class	**Efficiency Level**	**Life-Cycle Cost** *2012$*			**Average Life-Cycle Cost Savings** *2012$*	**% of Households that Experience**			**Median Payback Period** *years*
		Installed Cost	**Operating Cost***	**LCC**		**Net Cost**	**No Impact**	**Net Benefit**	
	3	$482	$1,896	$2,378	$344	43%	28%	29%	7.0
	4	$570	$1,833	$2,402	$326	49%	28%	23%	12.1
	5	$798	$1,887	$2,685	$120	58%	28%	14%	27.5
	6	$833	$1,840	$2,673	$132	79%	0%	21%	25.4
Electric Furnace / Modular Blower Fan	0	$241	$1,198	$1,439	$0	0%	100%	0%	---
	1	$252	$1,100	$1,352	$21	5%	73%	21%	2.4
	2	$295	$954	$1,249	$84	28%	37%	34%	6.2
	3	$294	$830	$1,124	$160	20%	37%	42%	3.2
	4	$315	$771	$1,086	$185	27%	25%	48%	3.5
	5	$450	$855	$1,305	$18	52%	25%	23%	12.8
	6	$482	$824	$1,306	$17	68%	0%	32%	13.4
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	0	$254	$1,144	$1,398	$0	0%	100%	0%	---
	1	$265	$1,070	$1,335	$26	13%	56%	32%	3.3
	2	$310	$955	$1,265	$97	62%	0%	38%	10.7
	3	$315	$901	$1,216	$146	58%	0%	42%	7.0
	4	$391	$876	$1,267	$95	70%	0%	30%	13.1
	5	$537	$927	$1,464	-$102	85%	0%	15%	26.2
	6	$569	$909	$1,478	-$116	85%	0%	15%	26.7
Manufactured Home Non-Weatherized, Condensing Gas Furnaces	0	$271	$1,355	$1,626	$0	0%	100%	0%	---
	1	$282	$1,261	$1,543	$27	7%	68%	26%	2.7
	2	$326	$1,123	$1,449	$96	43%	29%	28%	10.5
	3	$334	$1,039	$1,373	$152	38%	29%	32%	6.5
	4	$410	$1,005	$1,416	$111	68%	4%	27%	14.8
	5	$564	$1,053	$1,618	-$82	82%	4%	14%	34.3
	6	$597	$1,025	$1,622	-$86	84%	0%	16%	32.2
Manufactured Home Electric Furnace /Modular Blower	0	$192	$663	$855	$0	0%	100%	0%	---
	1	$202	$608	$810	$14	8%	71%	21%	2.5
	2	$243	$561	$804	$20	37%	38%	25%	10.0
	3	$241	$499	$739	$64	28%	38%	34%	4.3
	4	$259	$464	$723	$78	34%	26%	40%	4.6
	5	$382	$539	$921	-$70	59%	26%	15%	16.8
	6	$412	$525	$937	-$86	82%	0%	18%	17.1

Table 8-H.3.2 Life Cycle Cost Results, Scenario 2 (50% of Survey in North; 25% in South Hot Dry; 10% in South Hot Humid)

Product Class	Efficiency Level	Life-Cycle Cost *2012$*			Average LCC Savings *2012$*	% of Households that Experience			Median Payback Period *years*
		Installed Cost	Operating Cost*	LCC		Net Cost	No Impact	Net Benefit	
Non-weatherized, Non-condensing Gas Furnace Fan	0	$343	$1,916	$2,259	$0	0%	100%	0%	---
	1	$354	$1,735	$2,089	$59	2%	68%	29%	1.4
	2	$403	$1,520	$1,923	$189	27%	25%	48%	4.3
	3	$414	$1,283	$1,696	$362	19%	25%	56%	2.9
	4	$496	$1,185	$1,681	$376	34%	14%	51%	5.8
	5	$662	$1,250	$1,912	$173	55%	12%	33%	12.4
	6	$697	$1,184	$1,881	$204	60%	0%	40%	11.8
Non-weatherized, Condensing Gas Furnace Fan	0	$339	$1,944	$2,283	$0	0%	100%	0%	---
	1	$351	$1,782	$2,133	$41	1%	75%	24%	1.4
	2	$398	$1,596	$1,995	$127	22%	41%	37%	4.5
	3	$408	$1,359	$1,767	$266	11%	41%	48%	2.9
	4	$490	$1,296	$1,785	$256	25%	34%	40%	5.8
	5	$658	$1,376	$2,034	$78	47%	29%	24%	12.6
	6	$692	$1,313	$2,005	$107	60%	0%	40%	11.4
Weatherized Gas Furnace Fan	0	$329	$1,787	$2,115	$0	0%	100%	0%	---
	1	$340	$1,616	$1,956	$32	0%	81%	18%	1.3
	2	$387	$1,464	$1,851	$80	13%	56%	31%	5.3
	3	$397	$1,202	$1,599	$200	7%	56%	37%	2.7
	4	$476	$1,109	$1,584	$212	26%	33%	40%	6.6
	5	$636	$1,235	$1,871	$1	52%	27%	21%	16.3
	6	$670	$1,177	$1,848	$24	65%	0%	35%	14.3
Oil Furnace	0	$387	$2,059	$2,446	$0	0%	100%	0%	---
	1	$404	$1,955	$2,359	$26	13%	71%	17%	5.8
	2	$470	$1,772	$2,242	$115	50%	28%	22%	15.8
	3	$482	$1,675	$2,157	$177	47%	28%	25%	8.6
	4	$570	$1,653	$2,223	$129	53%	28%	19%	14.9
	5	$798	$1,716	$2,514	-$82	62%	28%	10%	33.1
	6	$833	$1,684	$2,517	-$84	84%	0%	16%	31.8
Electric Furnace / Modular Blower Fan	0	$241	$1,098	$1,339	$0	0%	100%	0%	---
	1	$252	$1,009	$1,260	$18	5%	73%	21%	2.5
	2	$295	$898	$1,193	$59	29%	37%	33%	6.7
	3	$294	$783	$1,077	$130	21%	37%	41%	3.3
	4	$315	$734	$1,049	$147	28%	25%	46%	3.7
	5	$450	$819	$1,269	-$20	53%	25%	21%	13.6
	6	$482	$791	$1,273	-$24	70%	0%	30%	14.5
Manufactured	0	$254	$960	$1,215	$0	0%	100%	0%	---

Product Class	Efficiency Level	Life-Cycle Cost *2012$*			Average LCC Savings *2012$*	% of Households that Experience			Median Payback Period *years*
		Installed Cost	Operating Cost*	LCC		Net Cost	No Impact	Net Benefit	
Home Non-Weatherized, Non-Condensing Gas Furnaces	1	$265	$904	$1,169	$20	13%	56%	31%	3.4
	2	$310	$843	$1,152	$37	65%	0%	35%	11.2
	3	$315	$805	$1,120	$69	61%	0%	39%	7.8
	4	$391	$798	$1,189	$0	74%	0%	26%	14.3
	5	$537	$852	$1,388	-$199	88%	0%	12%	29.3
	6	$569	$838	$1,408	-$218	88%	0%	12%	29.5
Manufactured Home Non-Weatherized, Condensing Gas Furnaces	0	$271	$1,111	$1,382	$0	0%	100%	0%	---
	1	$282	$1,040	$1,322	$21	7%	68%	25%	3.4
	2	$326	$971	$1,297	$39	45%	29%	25%	11.2
	3	$334	$910	$1,244	$78	41%	29%	29%	7.4
	4	$410	$900	$1,310	$15	73%	4%	23%	16.3
	5	$564	$951	$1,515	-$181	86%	4%	10%	38.7
	6	$597	$930	$1,526	-$193	89%	0%	11%	35.7
Manufactured Home Electric Furnace /Modular Blower	0	$192	$628	$820	$0	0%	100%	0%	---
	1	$202	$576	$778	$14	8%	71%	21%	2.5
	2	$243	$540	$783	$13	38%	38%	24%	10.2
	3	$241	$480	$721	$56	28%	38%	34%	4.4
	4	$259	$448	$708	$68	35%	26%	39%	4.7
	5	$382	$523	$905	-$80	60%	26%	14%	17.1
	6	$412	$510	$922	-$97	83%	0%	17%	17.5

Table 8-H.3.3 Life Cycle Cost Results, Scenario 3 (25% of Survey in North & South Hot Dry; 5% in South Hot Humid)

Product Class	Efficiency Level	Life-Cycle Cost *2012$*			Average LCC Savings *2012$*	% of Households that Experience			Median Payback Period *years*
		Installed Cost	Operating Cost*	LCC		Net Cost	No Impact	Net Benefit	
Non-weatherized, Non-condensing Gas Furnace Fan	0	$343	$2,066	$2,409	$0	0%	100%	0%	---
	1	$354	$1,870	$2,225	$63	2%	68%	30%	1.4
	2	$403	$1,605	$2,008	$232	26%	25%	49%	4.1
	3	$414	$1,353	$1,767	$417	19%	25%	56%	2.7
	4	$496	$1,243	$1,739	$442	34%	14%	52%	5.5
	5	$662	$1,306	$1,968	$241	54%	12%	35%	11.7
	6	$697	$1,235	$1,932	$276	59%	0%	41%	11.4
Non-weatherized, Condensing Gas Furnace Fan	0	$339	$2,236	$2,575	$0	0%	100%	0%	---
	1	$351	$2,045	$2,396	$48	1%	75%	24%	1.4
	2	$398	$1,762	$2,161	$195	21%	41%	38%	4.1
	3	$408	$1,496	$1,904	$352	10%	41%	49%	2.7
	4	$490	$1,406	$1,896	$360	24%	34%	42%	5.4
	5	$658	$1,480	$2,138	$187	45%	29%	26%	11.7
	6	$692	$1,408	$2,100	$225	57%	0%	43%	11.0
Weatherized Gas Furnace Fan	0	$329	$1,855	$2,184	$0	0%	100%	0%	---
	1	$340	$1,678	$2,018	$33	0%	81%	18%	1.3
	2	$387	$1,501	$1,888	$85	13%	56%	31%	5.1
	3	$397	$1,234	$1,631	$207	7%	56%	37%	2.7
	4	$476	$1,135	$1,611	$221	26%	33%	41%	6.5
	5	$636	$1,259	$1,895	$10	51%	27%	21%	16.0
	6	$670	$1,199	$1,870	$36	64%	0%	36%	13.8
Oil Furnace	0	$387	$2,523	$2,911	$0	0%	100%	0%	---
	1	$404	$2,375	$2,779	$39	12%	71%	18%	5.5
	2	$470	$2,032	$2,502	$240	47%	28%	25%	12.5
	3	$482	$1,888	$2,370	$338	44%	28%	28%	7.1
	4	$570	$1,826	$2,396	$319	49%	28%	23%	12.2
	5	$798	$1,881	$2,679	$113	58%	28%	14%	27.6
	6	$833	$1,835	$2,667	$125	79%	0%	21%	25.7
Electric Furnace / Modular Blower Fan	0	$241	$1,177	$1,418	$0	0%	100%	0%	---
	1	$252	$1,081	$1,332	$21	5%	73%	21%	2.4
	2	$295	$942	$1,237	$79	28%	37%	34%	6.2
	3	$294	$820	$1,114	$154	21%	37%	42%	3.2
	4	$315	$763	$1,078	$177	27%	25%	47%	3.6
	5	$450	$847	$1,298	$11	52%	25%	22%	13.0
	6	$482	$818	$1,300	$9	68%	0%	31%	13.7

Product Class	Efficiency Level	Life-Cycle Cost *2012$*			Average LCC Savings *2012$*	% of Households that Experience			Median Payback Period *years*
		Installed Cost	**Operating Cost***	**LCC**		**Net Cost**	**No Impact**	**Net Benefit**	
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	0	$254	$1,106	$1,361	$0	0%	100%	0%	---
	1	$265	$1,036	$1,301	$25	13%	56%	32%	3.4
	2	$310	$933	$1,243	$84	63%	0%	37%	10.9
	3	$315	$882	$1,197	$129	59%	0%	41%	7.2
	4	$391	$860	$1,251	$75	71%	0%	29%	13.4
	5	$537	$912	$1,449	-$123	86%	0%	15%	27.0
	6	$569	$895	$1,464	-$138	85%	0%	15%	27.4
Manufactured Home Non-Weatherized, Condensing Gas Furnaces	0	$271	$1,332	$1,603	$0	0%	100%	0%	---
	1	$282	$1,241	$1,523	$26	7%	68%	25%	2.7
	2	$326	$1,110	$1,437	$90	43%	29%	28%	10.7
	3	$334	$1,027	$1,361	$145	39%	29%	32%	6.6
	4	$410	$996	$1,407	$102	69%	4%	27%	15.0
	5	$564	$1,045	$1,609	-$92	82%	4%	14%	34.6
	6	$597	$1,017	$1,614	-$96	85%	0%	15%	32.5
Manufactured Home Electric Furnace /Modular Blower	0	$192	$660	$853	$0	0%	100%	0%	---
	1	$202	$606	$808	$14	8%	71%	21%	2.5
	2	$243	$559	$802	$19	37%	38%	25%	10.1
	3	$241	$498	$738	$64	28%	38%	34%	4.3
	4	$259	$463	$722	$77	34%	26%	40%	4.6
	5	$382	$537	$920	-$70	59%	26%	15%	16.8
	6	$412	$524	$936	-$87	82%	0%	18%	17.1

Table 8-H.3.4 Comparison of Average LCC Savings and Median Payback Period Results for Constant Circulation Assumptions

Product Class	Efficiency Level	Average LCC Savings *2012$*			Median Payback Period *Years*		
		Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Non-weatherized, Non-condensing Gas Furnace Fan	1	$64	$59	$63	1.3	1.4	1.4
	2	$253	$189	$232	4.0	4.3	4.1
	3	$442	$362	$417	2.7	2.9	2.7
	4	$474	$376	$442	5.4	5.8	5.5
	5	$275	$173	$241	11.5	12.4	11.7
	6	$313	$204	$276	11.2	11.8	11.4
Non-weatherized, Condensing Gas Furnace Fan	1	$49	$41	$48	1.4	1.4	1.4
	2	$203	$127	$195	4.1	4.5	4.1
	3	$361	$266	$352	2.7	2.9	2.7
	4	$371	$256	$360	5.4	5.8	5.4
	5	$199	$78	$187	11.7	12.6	11.7
	6	$238	$107	$225	11.0	11.4	11.0
Weatherized Gas Furnace Fan	1	$35	$32	$33	1.3	1.3	1.3
	2	$104	$80	$85	4.9	5.3	5.1
	3	$228	$200	$207	2.7	2.7	2.7
	4	$247	$212	$221	6.4	6.6	6.5
	5	$39	$1	$10	15.5	16.3	16.0
	6	$67	$24	$36	13.3	14.3	13.8
Oil Furnace	1	$40	$26	$39	5.5	5.8	5.5
	2	$245	$115	$240	12.3	15.8	12.5
	3	$344	$177	$338	7.0	8.6	7.1
	4	$326	$129	$319	12.1	14.9	12.2
	5	$120	-$82	$113	27.5	33.1	27.6
	6	$132	-$84	$125	25.4	31.8	25.7
Electric Furnace / Modular Blower Fan	1	$21	$18	$21	2.4	2.5	2.4
	2	$84	$59	$79	6.2	6.7	6.2
	3	$160	$130	$154	3.2	3.3	3.2
	4	$185	$147	$177	3.5	3.7	3.6
	5	$18	-$20	$11	12.8	13.6	13.0
	6	$17	-$24	$9	13.4	14.5	13.7
Manufactured Home Non-Weatherized, Non-Condensing Gas Furnaces	1	$26	$20	$25	3.3	3.4	3.4
	2	$97	$37	$84	10.7	11.2	10.9
	3	$146	$69	$129	7.0	7.8	7.2
	4	$95	$0	$75	13.1	14.3	13.4
	5	-$102	-$199	-$123	26.2	29.3	27.0
	6	-$116	-$218	-$138	26.7	29.5	27.4

Product Class	**Efficiency Level**	**Average LCC Savings** *2012$*			**Median Payback Period** *Years*		
		Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Manufactured Home Non-Weatherized, Condensing Gas Furnaces	1	$27	$21	$26	2.7	3.4	2.7
	2	$96	$39	$90	10.5	11.2	10.7
	3	$152	$78	$145	6.5	7.4	6.6
	4	$111	$15	$102	14.8	16.3	15.0
	5	-$82	-$181	-$92	34.3	38.7	34.6
	6	-$86	-$193	-$96	32.2	35.7	32.5
Manufactured Home Electric Furnace /Modular Blower	1	$14	$14	$14	2.5	2.5	2.5
	2	$20	$13	$19	10.0	10.2	10.1
	3	$64	$56	$64	4.3	4.4	4.3
	4	$78	$68	$77	4.6	4.7	4.6
	5	-$70	-$80	-$70	16.8	17.1	16.8
	6	-$86	-$97	-$87	17.1	17.5	17.1

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CHAPTER 9. SHIPMENTS ANALYSIS

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CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

Estimates of future product shipments are a necessary input to calculations of the national energy savings (NES) and net present value (NPV), as well as to the manufacturer impact analysis (MIA). This chapter describes the data and methods the U.S. Department of Energy (DOE) used to forecast annual product shipments and presents results for furnace fan product classes being considered in this analysis.

The shipments model divides the shipments of furnace fans into specific market segments. The model starts from a historical base year and calculates, for each year of the analysis period, both shipments and retirements by market segment. This approach produces an estimate of the total equipment stock, broken down by age or vintage, in each year of the analysis period. The product stock distribution is calculated for the base case and for each efficiency level of each product class. The stock distribution is used in the national impact analysis (NIA) to estimate the total costs and benefits associated with each efficiency level.

The vast majority of furnace fans are shipped pre-installed in furnaces, so DOE estimated furnace fan shipments by projecting shipments of those products.

The shipments model was developed as a Microsoft Excel spreadsheet that is accessible on DOE's Appliance and Commercial Equipment Standards website (http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41). Appendix 10-A discusses how to access and utilize the shipments model spreadsheet, which is integrated into the spreadsheet for the NIA. This chapter explains how the shipments model is constructed and provides some summary output. The rest of section 9.1 describes the methodological approach.

9.1.1 Definition of Market Segments for the Shipments Analysis

The furnace fan shipments model considers three product placement channels (hereafter referred to as "channels") as follows:

1. New housing: a certain fraction of new buildings are assumed to acquire furnaces in the year of construction. This fraction is defined as the new construction saturation, which varies by year, by region, and by product type.

2. Existing owners (replacements): these are defined as existing buildings with furnaces installed. This category receives new shipments when existing equipment is replaced.

3. New owners: these are defined as existing buildings that acquire furnaces for the first time during the analysis period. The new owners primarily consist of households that have central air conditioning alone or central air conditioning and electric heating and choose to install a gas furnace.

9.1.2 Fundamental Model Equations

The fundamental dependent variable in the shipments model is the equipment stock, which is represented as a function of analysis year (indexed by *j)*, and equipment vintage or age (the equipment age is noted as *a,* and is equal to the analysis year minus the vintage). The stock function is adjusted in each year of the analysis period by new shipments coming in and broken or demolished equipment being taken out.

For existing stock:

$$\boldsymbol{Stock_p(j,a) = Stock_p(j-1,a-1) - Rem_p(j,a)}$$

and for new units:

$$\boldsymbol{Stock_p(j,a=1) = Ship_p(j-1).}$$

Where:

$Stock_p(j, a)$ = number of units of product class *p* and age *a* in analysis year *j,*

$Rem_p(j, a)$ = number of units of product class *p* and age *a* removed in analysis year *j,* and

$Ship_p(j)$ = number of units of product class *p* shipped in year *j*.

Shipments are directed to one of the three channels:

$$\boldsymbol{Ship_p(j) = Rpl_p(j) + NC_p(j) + NO_p(j)}$$

Where:

$Rpl_p(j)$ = number of units of product *p* replaced in year *j*, which depends on removals,

$NC_p(j)$ = number of units installed in new construction of product *p* in year *j*, and

$NO_p(j)$ = number of units shipped to "new owners" of product *p* in year *j*.

Removals due to equipment failure contains two terms. In the first, a survival function $f_p(a)$ is used to represent the probability that a unit of age *a* will survive in a given year; equivalently, the probability that this unit will fail is 1-$f_p(a)$. The second term is the extended repair stock that has been in use for six years following the repair date. Total removals in the base case are then:

$$\boldsymbol{Rem_p(j,a) = \lfloor 1 - f_p(a) \rfloor \times Stock_p(j,a) + ER\_Stock_p(j,a2=6)}$$

Where:

$a2$ = number of years since the equipment was repaired[a], and
$ER\_Stock_p(j, a2)$ = number of extended-repair units of product p replaced in year j.

9.2 DATA INPUTS AND SUPPORTING CALCULATIONS

9.2.1 Historical Shipments and Calculation of Replacement Shipments

9.2.1.1 Historical Shipments

DOE used historical shipments data (i.e., domestic shipments and imports) to populate its shipments model for furnace fan equipment. As part of its data submittal to DOE's 2011 furnace standards rulemaking, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) provided historical shipments data over the 2005-2009 time period disaggregated into three categories: (1) non-weatherized gas and manufactured home gas furnaces, (2) oil-fired furnaces, and (3) weatherized gas furnaces.[2] Historical shipments for 1972-2005, except for weatherized gas furnace shipments, were also provided by AHRI[b] from previous data submittals to Lawrence Berkeley National Laboratory (LBNL).[2, 3]

DOE disaggregated manufactured home gas furnace shipments from the gas furnace total by using a combination of data from the U.S. Census [4] and American Housing Survey (AHS).[5] DOE used a similar method to determine manufactured home electric furnace shipments. For electric furnaces, DOE used the historical estimates calculated in DOE's 2011 furnace standards rulemaking. For weatherized gas furnaces, DOE used the 2005-2009 data provided by AHRI together with historical packaged central air conditioner shipments. In addition, DOE obtained national shipments of gas furnaces[c] and oil-fired furnaces from 2010-2012 from AHRI's website.[d]

Disaggregated condensing and non-condensing gas furnace shipments by region were available from 1992 to 2009, and these data were used to estimate shipments by region before 1992.

Figure 9.2.1 summarizes the historical shipments data that DOE assembled.

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[a] Based on data available from Decision Analyst consumer survey of HVAC equipment owners, DOE was able to estimate that consumers expect a major repair to extend the lifetime of the equipment by around 6 years.[1]

[b] Previously known as Gas Appliance Manufacturers Association (GAMA).

[c] Combined non-weatherized gas and manufactured home gas furnace shipments.

[d] Both annual and monthly shipments from: http://www.ahrinet.org/statistics.aspx.

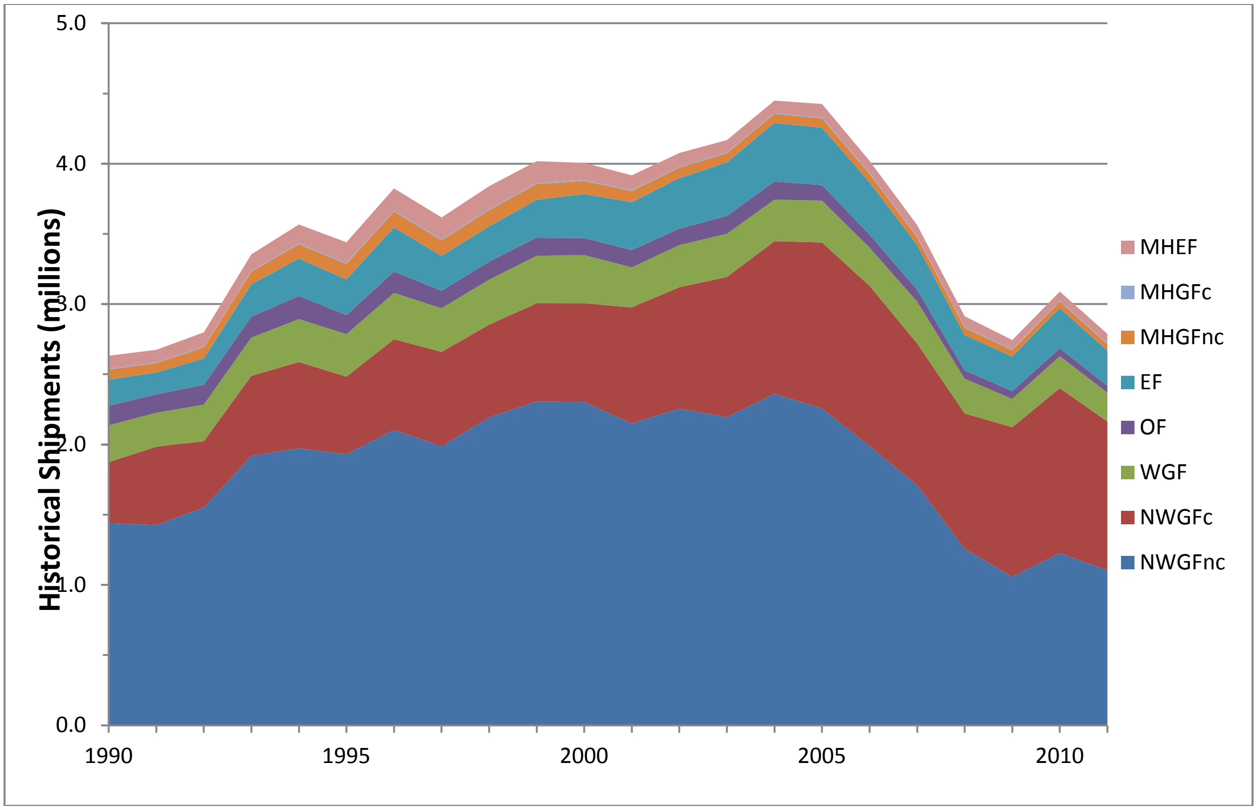

Figure 9.2.1 **Historical Shipments of HVAC Products with Furnace Fans**

9.2.1.2 Replacement Shipments

When an equipment unit fails, it is removed from the stock. The following retirement function $r_p(a)$ is used to represent the probability that a unit will be broken at age a.

$$Rem_p(j) = \sum_a r_a(a) \times Stock_p(j,a)$$

Retirement functions and product lifetimes are discussed in more detail in chapter 8.

In each year, equipment is removed from demolished buildings. As represented by the following expression, the shipments model assumes that the saturation of the equipment in the demolished buildings is the same as that of the overall population.

$$D(j) = H\_Stock(j-1) + H\_Starts(j) - H\_Stock(j)$$

$$Dem(j) = D(j) \times sat(p, j-1)$$

Where:

$H\_Stock\,(j)$ = number of housing units in analysis year j,
$H\_Starts(j)$ = number of new housing units in year j,

D(j) = number of demolished buildings,
Dem (j) = number of equipment units demolished in analysis year *j,* and
sat(p,j) = saturation of equipment of product class p for all buildings in year j.

The shipments model assumes that units that are taken from demolished buildings, *Dem(j)*, are included in the mix of broken units $Rem_p\ (j)$. In addition for non-weatherized gas furnaces, the shipments model takes into account early replacements *ERpl (j)* shipments that occurred in the past.[e] Since demolished units do not need to be replaced and early replacement units were already replaced, they are deducted from $Rem_p(j)$ when calculating the required replacements, as represented by the following expression..

$$Rpl_p(j) = \mathrm{Re}\,m_p(j) - Dem(j) - ERpl(j)$$

9.2.2 Shipments to New Housing

DOE multiplied new construction market saturations by forecasts of new housing units to estimate shipments to the new construction channel. On a product class basis, the determination of shipments to new construction is represented by the following expression:

$$\boldsymbol{NC_p(j) = NC\_Starts(j) \times NC\_Sat_p(j)}$$

Where:

NC_Starts (j) = number of new housing starts in year *j,* and
NC_Sat(j) = new housing saturation for product class p and year *j.*

DOE determined new construction housing starts by using recorded data through 2008[6, 7] and projections from the DOE-Energy Information Administration (EIA)'s *Annual Energy Outlook 2012* (*AEO2012*).[8]

DOE developed new housing furnace type market saturations from *Characteristics of New Housing* data from the U.S. Census Bureau[8] and Energy Information Administration's *2009 Residential Energy Consumption Survey* (RECS 2009).[9] DOE used historical new housing saturations for each furnace type to project future saturations for each class. DOE used a 10-year average (2000-2009) from RECS 2009 data to estimate future saturations for non-weatherized and weatherized gas furnaces (39.8% in South and 62.7% in North), oil furnaces (0.1% in South

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[e] Based on historical shipment data and the retirement function, there are a large amount of shipments that cannot be explained as being replacement, new owners, or new construction from 1998-2010 for non-condensing gas furnaces. DOE assumes that a fraction of these shipments are early replacements between 1998 to 2010 due to extensive retrofits and higher efficiency incentives. To model this DOE assumed, that 10% of replacement shipments that would have occurred between 2007-2009 occurred ten years earlier between 1998-2000 as early replacements, 15% of replacement shipments that would have occurred between 2010-2014 occurred ten years earlier between 2001-2005 as early replacements, and 30% of replacement shipments that would have occurred between 2015-2019 occurred ten years earlier between 2006-2010 as early replacements.

and 1.5% in North), electric furnace (36.1% in South and 10.5% in North), manufactured home gas furnaces (8.3% in South and 66.7% in North), and manufactured home electric furnaces (50.5% in South and 2.1% in North). Based on the census data it was determined that only 31% of "electric furnaces" in RECS are actually electric furnaces without a heat pump. Therefore, DOE used a 31% fraction of the saturations estimated using RECS 2009 data (i.e., 11.3% in South and 3.3% in North for electric furnaces).

9.2.3 Shipments to New Owners

The third market segment consists of new owners of products in a given product class, and also includes an adjustment for switching to a different product class. In most cases, new owners consist of households that have central air conditioning alone, or central air conditioning and electric heating, and choose to install a gas furnace to augment or replace their existing equipment.

DOE estimated historical shipments to this market segment using the following equation:

$$A(j) = Shipment(j) - (RU(j) + NU(j))$$

Where:
j = year where historical shipment data is available
$A(j)$ = new owners (if positive) or adjustment for switching (if negative) for year j,
$Shipment(j)$ = historical shipment in year j,
$RU(j)$ = estimated replacement units in year j,
$NU(j)$ = new units for new homes in year j,

First, DOE calculated the historical shipments for this market segment as the non-negative difference between historical shipments and new construction and replacement shipments calculated using the methods described above. Most of the shipments in this segment occurred from 1998-2008 period for non-weatherized gas furnaces due to a large number of retrofit projects. DOE assumed that this market segment would likely be much smaller and decreasing in the future. For this analysis, DOE projected the shipments to this market segment to be zero after 2019 for all product classes.

9.2.4 Forecasting Condensing and Non-Condensing Market Shares

For non-weatherized gas and manufactured home gas furnaces, the future condensing and non-condensing market shares need to be projected. For both the South and North regions, condensing furnaces are currently not required, but some consumers choose to purchase them anyway. DOE used the historical shipments data to estimate condensing furnace market share in 2019 as 31.9% in South and 75.0% in North). It used this information to project condensing furnace market share up to 2048 (46.4% in South and 97.2% in North). This projection is similar to that used in DOE's 2011 furnace standards rulemaking.[10]

9.3 IMPACT OF STANDARDS ON SHIPMENTS

As detailed in chapter 10, DOE created trial standard levels (TSLs) that combine specific efficiency levels across product classes. Table 9.3.1 shows the TSLs DOE analyzed.

Table 9.3.1 Trial Standard Levels for Furnace Fans (Efficiency Level)

	Trial Standard Level					
Product Class	**1**	**2**	**3**	**4**	**5**	**6**
NWGFnc	1	3	3	4	4	6
NWGFc	1	3	3	4	4	6
WGF	1	3	3	4	4	6
OF	1	1	3	1	3	6
EF	1	3	3	4	4	6
MHGFnc	1	1	3	1	3	6
MHGFc	1	1	3	1	3	6
MHEF	1	1	3	4	4	6

For replacements, consumer purchase decisions are influenced by the purchase price and operating cost of equipment, and therefore will likely be different in the base case and under different trial standard levels (TSLs). These decisions are modeled by estimating the purchase price elasticity for furnaces. The purchase price elasticity is defined as the change in the percentage of consumers acquiring a furnace divided by a change in the *relative price* (defined below) for that equipment. This elasticity and information obtained from the life-cycle cost (LCC) and payback period (PBP) analysis on the change in purchase price and operating costs under different TSLs are used in the shipments model to estimate the change in shipments.

9.3.2 Purchase Price Elasticity

DOE conducted a literature review and an analysis of appliance price and efficiency data to estimate the combined effects on product shipments from increases in product purchase price, decreases in product operating costs, and changes to household income. Appendix 9-A provides a detailed explanation of the methodology DOE used to quantify the impacts from these variables.

Existing studies of appliance markets suggest that the demand for appliances is price-inelastic. Other information in the literature suggests that appliances are a normal good, so that rising incomes increase the demand for appliances, and that consumer behavior reflects relatively high implicit discount rates[f] when comparing appliance prices and appliance operating costs.

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[f] A high implicit discount rate with regard to operating costs suggests that consumers put a low economic value on the operating cost savings realized from more-efficient appliances. In other words, consumers are much more concerned with higher purchase prices.

DOE used the available data for the period 1980-2002 on large appliance purchases to evaluate broad market trends and conduct simple regression analyses. These data indicate that there has been a rise in appliance shipments and a decline in appliance purchase price and operating costs over the time period. Household income has also risen during this time. Because purchase decisions are sensitive to income, as well as to potential savings in the operating cost of the appliance, DOE combined the available economic information into one variable, termed the *relative price*. This variable was used in a regression analysis to parameterize historical market trends. The relative price is defined with the following expression:

$$\boldsymbol{RP} = \frac{\boldsymbol{TP}}{\boldsymbol{Income}} = \frac{\boldsymbol{PP} + \boldsymbol{PVOC}}{\boldsymbol{Income}}$$

Where:

RP = relative price,
TP = total price,
$Income$ = household income,
PP = appliance purchase price, and
$PVOC$ = present value of operating cost.

In the above equation, DOE used real prices, as opposed to nominal, and an implicit discount rate of 37 percent to estimate the present value of operating costs. The rate of 37 percent is based on a survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[11]

DOE's regression analysis suggests that the relative price elasticity of demand, averaged over the three appliances, is -0.34. This implies that a relative price increase of 10 percent results in a 3.4 percent decrease in shipments. Note that the relative price elasticity incorporates the impacts from purchase price, operating cost, and household income, so the impact from any single effect can be mitigated by changes in the other two effects.

The relative price elasticity of -0.34 is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using simple statistical analysis. More importantly, the measure is based on an assumption that economic variables, including purchase price, operating costs, and household income, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but DOE did not account for them in this analysis. Despite these uncertainties, DOE believes that its estimate of the relative price elasticity of demand provides a reasonable assessment of the impact that purchase price, operating cost, and household income have on product shipments.

Because DOE's forecasts of shipments and national impacts attributable to standards is calculated for a lengthy time period, it needed to consider how the *relative price* elasticity is affected after a new standard takes effect. DOE considered the *relative price* elasticity, described above, to be a short-term value. It was unable to identify sources specific to household durable goods, such as appliances, to indicate how short-run and long-run price elasticities differ. Therefore, to estimate how the *relative price* elasticity changes over time, DOE relied on a study pertaining to automobiles.[12] This study shows that the automobile price elasticity of demand changes in the years following a purchase price change, becoming smaller (more inelastic) until it reaches a terminal value around the tenth year after the price change. Table 9.3.2 shows the relative change in the price elasticity of demand for automobiles over time. DOE developed a time series of relative price elasticities based on the relative change in the automobile price elasticity of demand. For years not shown in Table 9.3.2, DOE performed a linear interpolation to obtain the relative price elasticity.

Table 9.3.2 Change in Relative Price Elasticity Following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

9.3.3 Impact from Increase in Relative Price

Using the relative price elasticity, DOE was able to estimate the impact of the increase in relative price from a particular TSL. The impact, as shown in the equation below, is expressed as a percentage drop in market share for each year, dMS^p_j, which is applied in the decision for replacement versus extended repair.

$$dMS_j^p = \left[1 - \left(\frac{RP\_std_p(j)}{RP\_base_p(j)}\right)\right] \times e_{RP}(j)$$

Where:

dMS^p_j = percentage market share drop for class *p,* year *j*,
$RP\_std_p(j)$= relative price in the standards case for product class *p,* year *j*,
$RP_p(j)$= relative price in the base case for product class *p,* year *j*, and
$e_{RP}(j)$ = relative price elasticity in year *j*.

Because the percentage change in the cost of furnaces due to potential furnace fan standards is relatively small, DOE assumed that the new construction market is unaffected by changes in either the total installed cost or operating costs of the equipment. That is, home builders are not likely to choose to not install a furnace if the installed cost rises by a small amount.

To model the impact of the increase in relative price from a particular TSL on furnace shipments, DOE assumed consumers affected by an increase in total installed cost would repair their equipment rather than replace it, extending the life of the product by six years. When the extended repaired units fail after six more years, they will be replaced with new ones.

The model calculates, for each year after the standard, the relative percentage market drop, dMS^p_j, due to the equipment price increase. The extended repair is only applicable to failed equipment that is purchased before 2019.

The number of failed furnaces that will be repaired instead of being replaced is calculated as follows:

$$XR_i = \sum_a \mathrm{Re}\, m(j,a) \times dMS_i^p \qquad for\,(j-a) < 2018$$

$$Rpl(j) = \sum_a Re\, m(\,j, a\,) - XR_i + XR_{j-6} - Dem(j)$$

Where:

dMS^p_j = percentage market share drop for class p, year j,
a = age of equipment,
j = year,
$Rem(j,a)$ = retiring units in year j of age a,
XR_j = extended repair units, year j,
$Rpl(j)$ = replacement units in year j, and
$Dem\ (j)$ = number of units gone with demolished buildings in analysis year j.

9.4 RESULTS

Figure 9.4.1 shows the historic and projected shipments of HVAC products with furnace fans by product class.

Figure 9.4.2 shows total projected shipments of HVAC products with furnace fans in the base case and under each standards case. Because the elasticity is modeled as a delayed replacement of a furnace, the forecast for the TSLs shows a decline in the early years, but an increase in later years once the delayed replacements are finally made. Recall that the elasticity parameter decreases over time, so the impact of the standards on shipments diminishes.

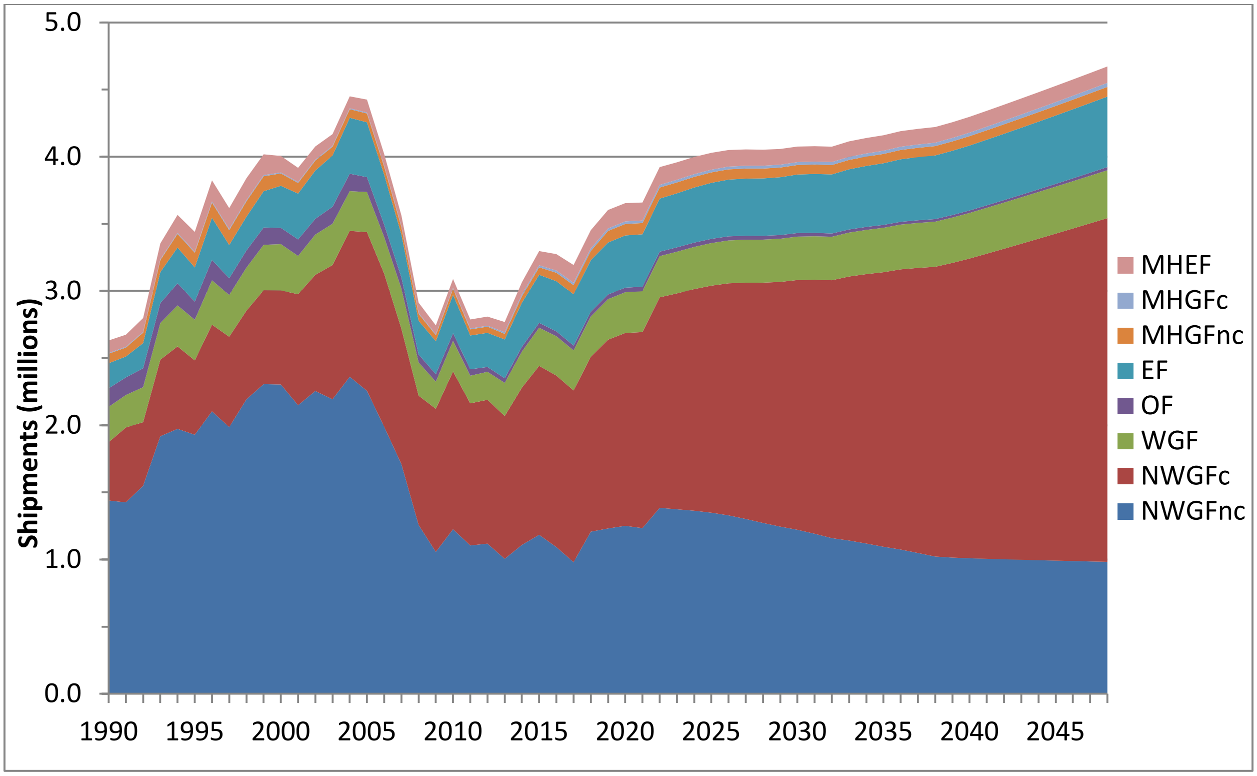

Figure 9.4.1 Historic and Projected Base Case Shipments of HVAC Products With Furnaces Fans by Product Class

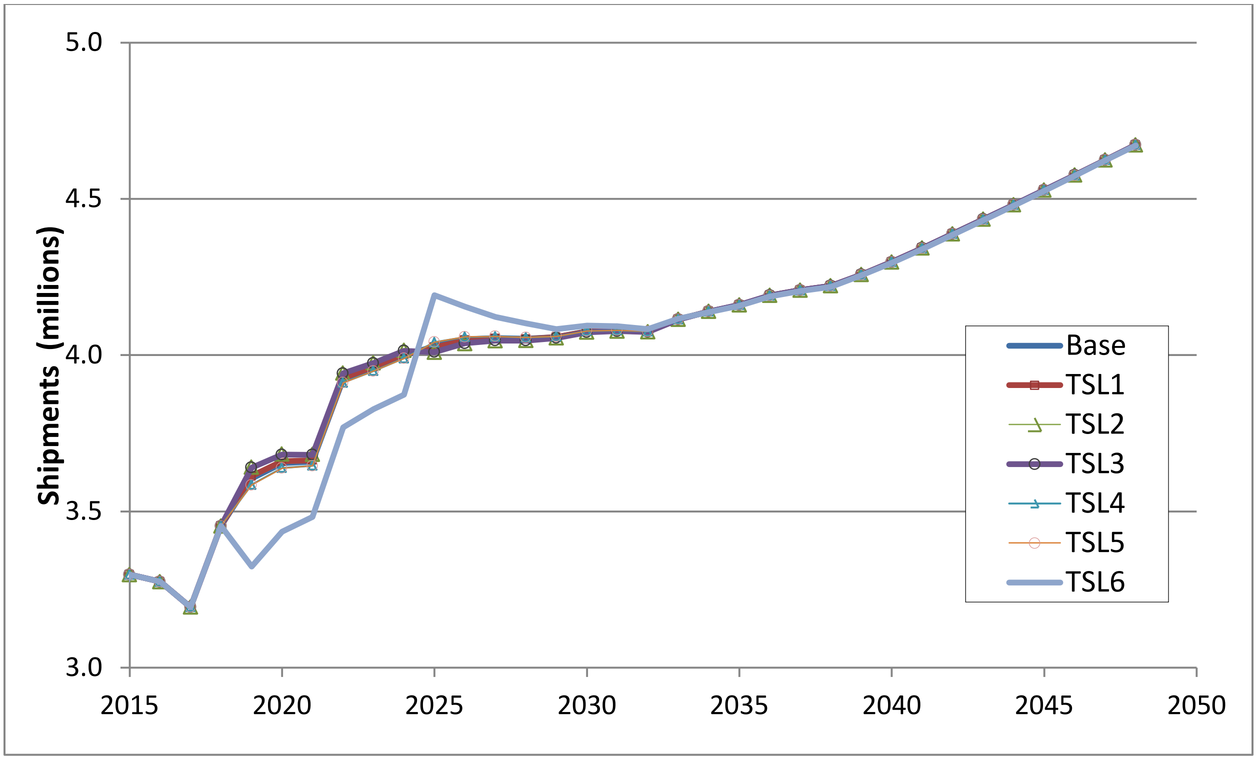

Figure 9.4.2 **Total Projected Shipments of HVAC Products With Furnaces Fans in the Base Case and Each Standards Case**

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APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

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APPENDIX 9-A. RELATIVE PRICE ELASTICITY OF DEMAND FOR APPLIANCES

9-A.1 INTRODUCTION

This appendix summarizes DOE's study of the price elasticity of demand for home appliances, including refrigerators, clothes washers and dishwashers. DOE chose this particular set of appliances because of the availability of data to determine a price elasticity. Section 9-A.2 reviews the existing economics literature describing the impact of economic variables on the sale of durable goods. Section 9-A.3 describes the market for home appliances and the changes that have occurred over the past 20 years. In section 9-A.4, DOE summarizes the results of its regression analysis and presents estimates of the price elasticity of demand for the three appliances. In section 9-A.5, DOE presents development of an 'effective' purchase price elasticity. DOE's interpretation of its results is presented in section 9-A.6. Finally, section 9-A.7 describes the data used in DOE's analysis.

9-A.2 LITERATURE REVIEW

Relatively few studies measure the impact of price, income and efficiency on the sale of household appliances. This section briefly reviews the literature that describes the likely importance of these variables on the purchase of household appliances.

9-A.2.1 Price

DOE reviewed many studies that sought to measure the impact of price on sales in a dynamic market. One study of the automobile market prior to 1970 finds the price elasticity of demand to decline over time. The author explains this as the result of buyers delaying purchases after a price increase but eventually making the purchase (Table 9A.2.1).[1] A contrasting study of household white goods also prior to 1970, finds the elasticity of demand to increase over time as more price-conscious buyers enter the market.[2] An analysis of refrigerator market survey data finds that consumer purchase probability decreases with survey asking price.[3] Estimates of the price elasticity of demand for different brands of the same product tend to vary. A review of 41 studies of the impact of price on market share found the average price elasticity to be -1.75.[4] The average estimate of price elasticity of demand reported in these studies is -0.33 in the appliance market and -0.47 in the combined automobile and appliance markets.

9-A.2.2 Income

Higher income households are more likely to own household appliance.[5] The impact of income on appliance shipments is explored in two econometric studies of the automobile and appliance markets.[1, 2] The average income elasticity of demand is 0.50 in the appliance study cited in the literature review, much larger in the automobile study (Table 9-A.2.1).

9-A.2.3 Appliance Efficiency and Discount Rates

Many studies estimate the impact of appliance efficiency on consumers' choice of appliance. Typically, this impact is summarized by the implicit discount rate; that is, the rate consumers use to compare future savings in appliance operating costs against a higher initial purchase price of an appliance. One early and much cited study concludes that consumers use a 20 percent implicit discount rate when purchasing room air conditioners (Table 9-A.2.1).[6] A survey of several studies of different appliances suggests that the consumer implicit discount rate has a broad range and averages about 37 percent.[7]

Table 9-A.2.1 Estimates of the Impact of Price, Income and Efficiency on Automobile and Appliance Sales

Durable Good	Price Elasticity	Income Elasticity	Brand Price Elasticity	Implicit Discount Rate	Model	Data Years	Time Period
Automobiles[1]	-1.07	3.08	-	-	Linear Regression, stock adjustment	-	Short run
Automobiles[1]	-0.36	1.02	-	-	Linear Regression, stock adjustment	-	Long run
Clothes Dryers[2]	-0.14	0.26	-	-	Cobb-Douglas, diffusion	1947-1961	Mixed
Room Air Conditioners[2]	-0.37[8]	0.45	-	-	Cobb-Douglas, diffusion	1946-1962	Mixed
Dishwashers[2]	-0.42	0.79	-	-	Cobb-Douglas, diffusion	1947-1968	Mixed
Refrigerators[3]	-0.37	-	-	39%	Logit probability, survey data	1997	Short run
Various[4]	-	-	-1.76[9]	-	Multiplicative regression	-	Mixed
Room Air Conditioners[5]	-	-	-1.72	-	Non-linear diffusion	1949-1961	Short run
Clothes Dryers[5]	-	-	-1.32	-	Non-linear diffusion	1963-1970	Short run
Room Air Conditioners[6]	-	-	-	20%	Qualitative choice, survey data	-	-
Household Appliances[7]	-	-	-	37%[10]	Assorted	-	-

Sources: [1] S. Hymens. 1971; [2] P. Golder and G. Tellis, 1998; [3] D. Revelt and K. Train, 1997; [4] G. Tellis, 1988; [5] D. Jain and R. Rao; [6] J. Hausman; [7] K. Train, 1985.

Notes: [8] Logit probability results are not directly comparable to other elasticity estimates in this table.
[9] Average brand price elasticity across 41 studies.
[10] Averaged across several household appliance studies referenced in this work.

9-A.3 VARIABLES DESCRIBING THE MARKET FOR REFRIGERATORS, CLOTHES WASHERS, AND DISHWASHERS

In this section DOE evaluates variables that appear to account for refrigerator, clothes washer and dishwasher shipments, including physical household/appliance variables and economic variables.

9-A.3.1 Physical Household/Appliance Variables

Several variables influence the sale of refrigerators, clothes washers and dishwashers. The most important for explaining appliance sales trends are the annual number of new households formed (housing starts) and the number of appliances reaching the end of their operating life (replacements). Housing starts influence sales because new homes are often provided with, or soon receive, new appliances, including dishwashers and refrigerators. Replacements are correlated with sales because new appliances are typically purchased when old ones wear out. In principle, if households maintain a fixed number of appliances, shipments should equal housing starts plus appliance replacements.

9-A.3.2 Economic variables

Appliance price, appliance operating cost and household income are important economic variables affecting shipments. Low prices and costs encourage household appliance purchases and a rise in income increases householder ability to purchase appliances. In principle, changes in economic variables should explain changes in the number of appliances per household.

During a 1980–2002 study period, annual shipments grew 69 percent for clothes washers, 81 percent for refrigerators and 105 percent for dishwashers (Table 9-A.3.1). This rising shipments trend is explained in part by housing starts, which increased 6 percent and by appliance replacements, which rose between 49 percent and 90 percent, depending on the appliance, over the period (Table 9-A.3.1).[a] For mature markets such as these, replacements exceed appliance sales associated with new housing construction.

Table 9-A.3.1 Physical Household/Appliance Variables

	Shipments[1] (millions)			Housing Starts[2] (millions)			Replacements[3] (millions)		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	5.124	9.264	81%	1.723	1.822	6%	3.93	5.84	49%
Clothes Washers	4.426	7.492	69%	1.723	1.822	6%	3.66	5.50	50%
Dishwashers	2.738	5.605	105%	1.723	1.822	6%	1.99	3.79	90%

[1] Shipments: Number of units sold. **Sources:** AHAM Fact Book and Appliance Magazine.

[2] Housing Starts: Annual number of new homes constructed. **Source:** U.S. Census.

[3] Replacements: Average of annual lagged shipments, with lag equal to expected appliance operating life, ± 5 years.

Shipments increased somewhat more rapidly than housing starts and replacements. This is shown by comparing the beginning and end points of lines that represent “starts plus replacements” (uppermost solid line in Figure 9-A.3.1) and “shipments” (diamond linked line in Figure 9-A.3.1). In 1980 the “shipment” line begins below the “starts plus replacements” line. In 2002, the “shipments” line ends above the “starts plus replacements” line. This more rapid

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[a] Appliance replacements are determined from the expected operating life of refrigerators (19 years), clothes washers (14 years), and dishwashers (12 years) and from past shipments. Replacements are further discussed in section 9-A.3. The dishwasher lifetime used in this analysis does not match the dishwasher used in the primary analysis.

increase in shipments, compared to housing starts plus replacements, suggests that the appliance per household ratio increased over the study period.

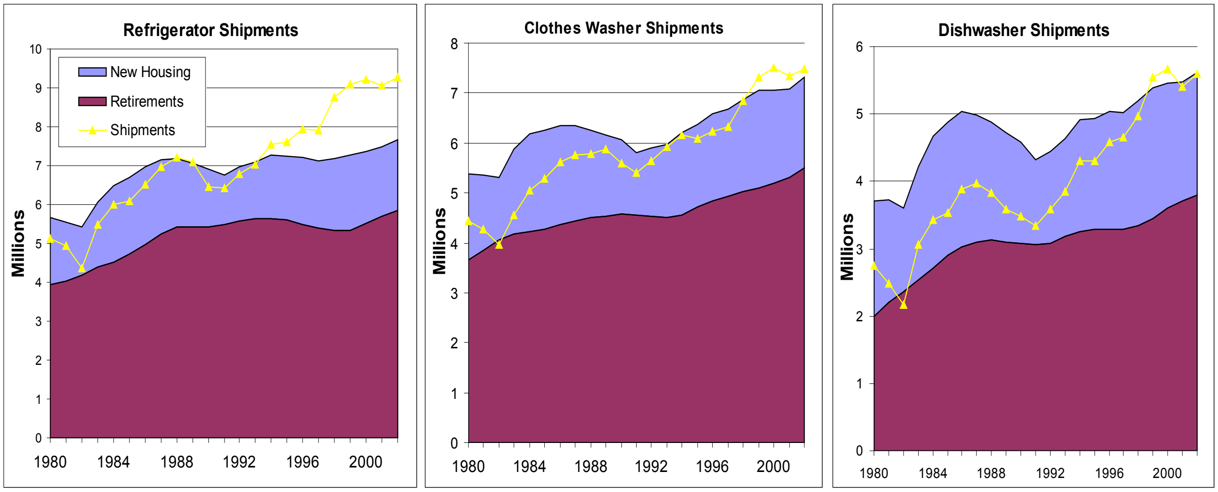

Figure 9-A.3.1 Trends in Appliance Shipment, Housing Starts and Replacements

Economic variables, including price, cost and income, may explain this increase in appliances per household. Over the period, appliance prices decreased 40 percent to 50 percent, operating costs fell between 33 percent and 72 percent, and median household income rose 16 percent (Table 9-A.3.2).

Table 9-A.3.2 Economic Variables

	Price[1] (1999$)			**Operating Cost[2] (1999$)**			**Household Income[3] (1999$)**		
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**
Refrigerators	1208	726	-40%	333	94	-72%	37,447	43,381	16%
Clothes Washers	779	392	-50%	262	175	-33%	37,447	43,381	16%
Dishwashers	713	369	-48%	183	95	-48%	37,447	43,381	16%

[1] Price: Shipment weighted retail sales price. **Sources:** AHAM Fact Book and Appliance Magazine.
[2] Operating Cost: Annual electricity price times electricity consumption. **Source:** AHAM Fact Book.
[3] Income: Mean Household income. **Source:** U.S. Census.

9-A.4 REGRESSION ANALYSIS OF VARIABLES AFFECTING APPLIANCE SHIPMENTS

Few data are available to estimate the impact of economic variables on the demand for appliances. Industry operating cost data is incomplete—appliance energy use data are available for only 12 years of the 1980-2002 study period. Industry price data are also incomplete—available for only 8 years of the study period for each of the appliances.

The lack of data suggests that regression analysis can at best evaluate broad data trends, utilizing relatively few explanatory variables. This section begins by describing broad trends apparent in the economic and physical household data sets and then specifies a simple regression model to measure these trends, making assumptions to minimize the number of explanatory variables. Finally, results of the regression analysis are presented along with an estimate of the price elasticity of demand for appliances. In section 9-A.4.5, DOE presents the results of regression analysis performed with more complex models, which are used to test assumptions underlying the simple model. These results support the specification of the simple model and the price elasticity of appliance demand estimated with that model.

9-A.4.1 Broad Trends

In this section DOE reviews trends in the physical household and economic data sets and posits a simple approach for estimating the price elasticity of appliance demand. As noted above, the physical household variables (housing starts and appliance replacements) explain most of the variability in appliance shipments during the study period (1980-2002).[b] DOE assumes the rest of the variability in shipments (referred to as "residual shipments") is explained by economic variables. Below, DOE presents a tabular method for measuring price elasticities.

To illustrate this tabular approach, DOE defines two new variables—residual shipments and total price. Residual shipments are defined as the difference between shipments and physical household demand (starts plus replacements). Total price, represented by the following equation, is defined as appliance price plus the present value of lifetime appliance operating cost:[c]

$$TP = PP + PVOC$$

where:

TP = Total price,
PP = Appliance purchase price, and
$PVOC$ = Present value of operating cost.

Over the study period, residual shipments increased in proportion to total shipments by 30 percent for refrigerators, 19 percent for clothes washers, and 23 percent for dishwashers. At the same time, total prices declined 47 percent, 45 percent and 48 percent for refrigerators, clothes washers, and dishwashers, respectively. Assuming that total price explains the entire change in per household appliance usage, a rough estimate is calculated of the total price elasticity of demand equal to -0.48 for refrigerators, -0.32 for clothes washers and -0.37 for dishwashers (Table 9-A.4.1).

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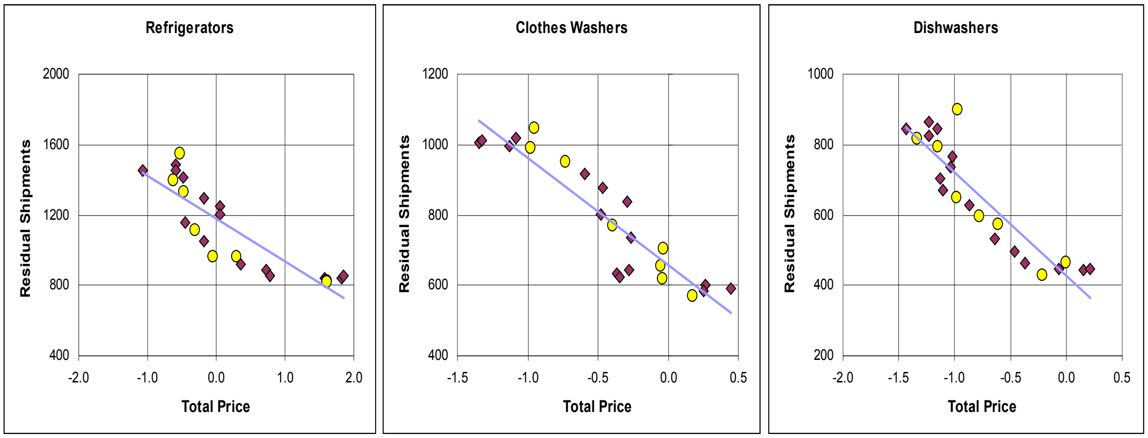
[b] A log regression of the form: Shipments = a + b • Housing Starts + c • Retirements, indicates that these two variables explain 89 percent of the variation in refrigerator shipments, 97 percent of the variation in clothes washer shipments, and 97 percent of the variation in dishwasher shipments.

[c] Present value operating cost is calculated assuming a 19-year operating life for refrigerators, 14-year operating life for clothes washers, and a 12-year operating life for dishwashers. A 37 percent discount rate is used to sum annual operating costs into a present value operating cost.

Table 9-A.4.1 Estimate of Total Price Elasticity of Demand

	Residual Shipments (millions)				Total Price (1999$)			
Appliance	**1980**	**2002**	**Difference**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.5	1.6	2.1	30%	1541	820	-61%	-0.48
Clothes Washers	-1.0	0.2	1.1	19%	1042	567	-59%	-0.32
Dishwashers	-1.0	-0.01	1.0	23%	896	464	-64%	-0.37

The negative correlation between total price and residual shipments suggested by these negative price elasticities is illustrated in a graph of residual shipments on the y-axis and total price on the x-axis (Figure 9-A.4.1).



Yellow points are observed price data; red points are interpolated price data.

Figure 9-A.4.1 Residual Shipments and Appliance Price

Household income rose during the study period, making it easier for households to purchase appliances. Assuming that a rise in income has a similar impact on shipments as a decline in price, the impact of income is incorporated by defining a third variable, termed *relative* price, which is calculated as total price divided by household income and represented by the following equation.[d]

$$RP = \frac{TP}{Income}$$

where:

RP = Relative price,
TP = Total price, and
Income = Household income.

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[d] Recall that the income elasticity of demand cited in the literature review is 0.50 and the price elasticity of demand cited in the review averages -0.35. This suggests that combining the effects of income and price will yield an elasticity less negative than price elasticity alone.

The percent decline in *relative* price for the three appliances divided by the percent decline in residual shipments suggests a rough estimate of *relative* price elasticity equal to -0.40 for refrigerators, -0.26 for clothes washers and -0.30 for dishwashers (Table 9-A.4.2).

Table 9-A.4.2 Tabular Estimate of Relative Price Elasticity of Appliance Demand

	Residual Shipments (millions)			Relative Price (1999$)			
Appliance	**1980**	**2002**	**Change**	**1980**	**2002**	**Change**	**Elasticity**
Refrigerators	-0.532	1.597	30%	0.041	0.019	-74%	-0.40
Clothes Washers	-0.953	0.174	19%	0.028	0.013	-72%	-0.26
Dishwashers	-0.974	-0.005	23%	0.024	0.011	-76%	-0.30

9-A.4.2 Specification of Model

The limited price data suggest it is appropriate to use a simple regression model to estimate the impact of economic variables on shipments, using few explanatory variables. The following equation, chosen for this analysis, includes one physical household variable (housing starts plus replacements) and one *relative* price variable (the sum of purchase price plus operating cost, divided by income).

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor} \qquad \textbf{Eq. 9A.1}$$

where:

Ship = Quantity of appliance sold,
RP = Relative price,
Starts = Number of new homes, and
Rplc = Number of appliances at the end of their operating life.

The natural logs are taken of all variables so that the estimated coefficients for each variable in the model may be interpreted as the percent change in shipments associated with the percent change in the variable. Thus, the coefficient *b* in this model is interpreted as the *relative* price elasticity of demand for the three appliances.

DOE used the following combined regression equation to estimate an average price elasticity of demand across the three appliances, using pooled data in a single regression. A combined regression specification is justified, given the limited data available and the similarity in price and shipment behavior across appliances (see Figure 9-A.4.1). Thus, the model represented by the combined regression equation is considered the basic model in DOE's analysis of appliance shipments.

$$\boldsymbol{Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor + d \times CW + e \times DW} \qquad \textbf{Eq. 9A.2}$$

where:

CW = Quantity of clothes washers sold, and

$DW =$ Quantify of dishwashers sold.

9-A.4.3 Discussion of Model

The most important assumption used to specify this model is that changes in economic variables over the study period—income, price, and operating cost—are responsible for all observed growth in residual appliance shipments. In other words, DOE assumes no impact from other possible factors, such as changing consumer preferences or increases in the quality of appliances. This assumption seems unlikely, but without additional data, the impact of this assumption on the price elasticity of demand cannot be measured. DOE effectively assumes that changes in consumer preferences and appliance characteristics, while affecting which models are purchased, have relatively little impact on the total number of appliances purchased in a year.

Three additional assumptions used to specify this model deserve comment. The *relative* price variable is specified in the model, assuming that (1) the correct implicit discount rate is used to combine appliance price and operating cost and that (2) rising income has the same impact on shipments as falling total price. The "starts + replacements" variable is specified, assuming (3) that starts and replacements have similar impacts on shipments.

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations 9-A.1 and 9-A.2. The results of this analysis, presented in section 9-A.4.5, indicate that the elasticity of *relative* price is fairly insensitive to changes in the discount rate.

To investigate the second and third assumptions, DOE specified a regression model separating income from total price and replacements from starts, thereby adding two additional explanatory variables to the basic model as shown in the following equation:

$$Ship = a + b \times TP + c \times Incone + d \times Start + e \times Rplc + f \times CW + g \times DW \qquad \textbf{Eq. 9A.3}$$

The results of the regression analysis of this model are presented in section 9-A.4.5. These results suggest that the elasticity of total price (coefficient *b*) is relatively insensitive to changes in the treatment of income and "starts + replacements" in the model.

9-A.4.4 Analysis Results

The following sections describe results of analyses using both the individual and combined models for appliances and the effects of a lower consumer discount rate and disaggregated variables.

9-A.4.4.1 Individual Appliance Model

The individual appliance regression equations are specified in the following equation.

$$Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor$$

In regression analysis of this model, the elasticity of *relative* price (*b*) is estimated to be -0.40 for refrigerators, -0.31 for clothes washers and -0.32 for dishwashers (Table 9-A.4.3), averaging -0.35. These elasticities are similar to those reported in the literature survey for appliances (Table 9-A.2.1). They are remarkably similar to the price elasticity calculated using a tabular approach (Table 9-A.4.2).

The estimated coefficient associated with the "starts + replacements" variable is close to one. A coefficient equal to one for this variable would imply that, holding economic variables constant, shipments increase in direct proportion to an increase in "starts + replacements." The high R-squared values (above 95) and t-statistics (above 5) in the results provide a measure of confidence in this analysis, despite the very small data set.

Table 9-A.4.3 Individual Appliance Model Results

	Refrigerator		**Clothes Washer**		**Dishwasher**	
Variable	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**	**Coefficient**	**t-stat**
Intercept	-1.51	-7.26	-1.47	-8.23	-2.08	-16.78
Relative Price	-0.40	-6.60	-0.31	-5.69	-0.32	-7.03
Starts + Replacements	1.05	5.90	1.08	6.41	1.35	11.46
R^2	0.954		0.954		0.975	
Observations	23		23		23	

9-A.4.4.2 Combined Appliance Model

The combined appliance regression equation is specified in the following equation.

$$Ship = a + b \times RP + c \times \lfloor Starts + Rplc \rfloor + d \times CW + e \times DW$$

This regression analysis indicates that the model fits the existing shipments data well (high R-squared) and that the variables included in the model are statistically significant (Table 9-A.4.4). Estimated with this model, the elasticity of *relative* price is -0.34, close to the average value estimated in the individual appliance models (-0.35). It is also similar to elasticity estimates reported in the literature survey and calculated using the tabular approach in Table 9-A.4.2.

Table 9-A.4.4 Combined Appliance Model Result

Variable	**Coefficient**	**t-statistic**
Intercept	-1.60	-15.54
Relative Price	-0.34	-10.74
Starts + Replacements	1.21	13.95
CW	-0.20	-9.04
DW	-0.32	-6.58
R^2	0.983	
Observations	69	

9-A.4.5 Additional Regression Specifications and Results

As described in section 9-A.4.3, DOE used three assumptions to specify its appliance models. The first, made to aggregate appliance price and operating cost, is that the implicit price variable in the basic regression model is specified using a 37 percent implicit discount rate. The second states that the implicit price variable is defined assuming that rising income has the same impact on shipments as falling total price. The third states that the "starts + replacements" variable is defined assuming that housing starts have a similar impact on shipments as appliance replacements.

9-A.4.5.1 Lower Consumer Discount Rate

To investigate the first assumption about discount rates, DOE calculated "present value operating cost" using a 20 percent implicit discount rate and performed a second regression analysis based on the models described in equations 9-A.1 and 9-A.2. The estimated coefficient associated with the *relative* price variable in these regressions is almost identical to the coefficients estimated for the same variable based on a 37 percent implicit discount rate. The elasticity of *relative* price calculated using a 20 percent discount rate is -0.33 in the combined regression and averages -0.35 for the three appliances (Table 9-A.4.5). The elasticity of price calculated using a 37 percent discount rate is -0.34 in the combined regression and averages -0.35 for the three appliances. DOE concludes from this analysis that the elasticity of *relative* price is fairly insensitive to changes in the discount rate.

Table 9-A.4.5 Combined and Individual Results, 20 percent discount rate

Three Appliances Variable	Coefficient	t-Stat
Intercept	-1.53	-14.61
Total Price / Income	-0.33	-10.69
Starts + Retirements	1.20	13.65
CW	-0.18	-8.69
DW	-0.32	-6.57
R^2	0.982	
Observations	69	

	Refrigerator		Clothes Washers		Dishwasher	
Variable	Coefficient	t-Stat	Coefficient	t-Stat	Coefficient	t-Stat
Intercept	-1.36	-6.26	-1.41	-7.49	-2.04	-17.23
Total Price / Income	-0.38	-6.50	-0.32	-5.29	-0.33	-7.30
Starts + Retirements	1.04	5.73	1.06	5.83	1.34	11.64
R^2		0.953		0.950		0.977
Observations		23		23		23

9-A.4.5.2 Disaggregated Variables

To investigate the second and third assumptions, DOE constructed a regression model that separates income from total price and replacements from starts, thus adding two additional explanatory variables to the basic model (as shown earlier as Eq. 9-A.3 and shown below).

$$Ship = a + b \times TP + c \times Income + d \times Start + e \times Rplc + f \times CW + g \times DW$$

The estimated coefficient associated with the total price variable in these regressions is almost identical to the coefficients estimated for the *relative* price variable reported above. The elasticity of total price in the above equation is -0.36 in the combined appliance regression and averages -0.35 for the three appliances (Table 9-A.4.6). The elasticity of *relative* price based on the model described in equation 9A.2 is -0.34 in the combined regression (Table 9-A.4.4) and averages -0.35 across the individual appliances (Table 9-A.4.3). DOE concludes that the price elasticity calculated in this analysis is relatively insensitive to the specification of household income and "starts + replacements" variables in the model.

Table 9-A.4.6 Disaggregated Regression Results, 37 percent discount rate

Three Appliances		
Variable	**Coefficient**	**t-Stat**
Intercept	-2.92	-1.26
Income	0.58	2.92
Total Price	-0.36	-7.06
Housing Starts	0.44	10.02
Retirements	0.62	8.12
CW	-0.24	-9.25
DW	-0.46	-7.68
R^2		0.985
Observations		69

	Refrigerator		**Clothes Washers**		**Dishwasher**	
Variable	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**	**Coefficient**	**t-Stat**
Intercept	-6.19	-2.24	-6.64	-1.63	1.00	0.23
Income	0.89	3.80	0.87	2.31	0.20	0.52
Total Price	-0.35	-5.48	-0.27	-2.51	-0.43	-5.18
Housing Starts	0.41	7.38	0.25	3.29	0.62	8.24
Retirements	0.56	6.06	0.56	2.09	0.65	5.86
R^2		0.984		0.958		0.979
Observations		23		23		23

9-A.5 LONG RUN IMPACTS

As noted above in Table 9-A.2.1, the literature review provides price elasticities over short and long time periods, also referred to as short run and long run price elasticities. As noted in the first two rows of Table 9-A.2.1, one source (i.e., Hymans) shows that the price elasticity of demand is significantly different over the short run and long run for automobiles.[1] Because DOE's forecasts of shipments and national impacts due to standards is over a 30-year time period, consideration must be given to how the *relative* price elasticity is affected once a new standard takes effect.

DOE considers the *relative* price elasticities determined above in section 9A.4 to be short run elastcities. DOE was unable to identify sources specific to household durable goods, such as appliances, to indicate how short run and long run price elasticities differ. Therefore, to estimate how the *relative* price elasticity changes over time, DOE relied on the Hymans study pertaining to automobiles. Based on the Hymans study, Table 9-A.5.1 shows how the automobile price elasticity of demand changes in the years following a purchase price change. With increasing years after the price change, the price elasticity becomes more inelastic until it reaches a terminal value around the tenth year after the price change.

Table 9-A.5.1 Change in Price Elasticity of Demand for Automobiles following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Price Elasticity of Demand	-1.20	-0.93	-0.75	-0.55	-0.42	-0.40
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33

Source: Hymans, 1971.

Based on the relative change in the automobile price elasticity of demand shown in Table 9-A.5.1, DOE developed a time series of *relative* price elasticities for home appliances. Table 9-A.5.2 presents the time series.

Table 9-A.5.2 Change in Relative Price Elasticity for Home Appliances following a Purchase Price Change

	Years Following Price Change					
	1	**2**	**3**	**5**	**10**	**20**
Relative Change in Elasticity to 1st year	1.00	0.78	0.63	0.46	0.35	0.33
Relative Price Elasticity	-0.34	-0.26	-0.21	-0.16	-0.12	-0.11

9-A.6 SUMMARY

This appendix describes the results of a literature search, tabular analysis, and regression analyses of the impact of price and other variables on appliance shipments. In the literature, DOE found only a few studies of appliance markets that are relevant to this analysis and no studies after 1980 using time series price and shipments data. The information that can be summarized from the literature suggests that the demand for appliances is price inelastic. Other information in the literature suggests that appliances are a normal good, such that rising incomes increase the demand for appliances. Finally, the literature suggests that consumers use relatively high implicit discount rates, when comparing appliance prices and appliance operating costs.

There are too few price and operating cost data available to perform complex analysis of dynamic changes in the appliance market. In this analysis, DOE used data available for refrigerators, clothes washers, and dishwashers to evaluate broad market trends and perform simple regression analysis.

These data indicate an increase in appliance shipments and a decline in appliance price and operating cost over the study period 1980-2002. Household income has also risen during this time. To simplify the analysis, DOE combined the available economic information into one variable, termed *relative* price, and used that variable in a tabular analysis of market trends and a regression analysis.

DOE's tabular analysis of trends in the number of appliances per household suggests that the price elasticity of demand for the three appliances is inelastic. Our regression analysis of these same variables suggests that the *relative* price elasticity of demand is -0.34. The price elasticity is consistent with estimates in the literature. Nevertheless, DOE stresses that the measure is based on a small data set, using very simple statistical analysis. More important, the measure is based on an assumption that economic variables, including price, income and operating costs, explain most of the trend in appliances per household in the United States since 1980. Changes in appliance quality and consumer preferences may have occurred during this period, but they are not accounted for in this analysis.

9-A.7 DATA USED IN THE ANALYSIS

- **Appliance Shipments** are defined as the annual number of units shipped in millions. These data were collected from the Association of Home Appliance Manufacturers (AHAM)[8, 9] and Appliance Magazine[10] as annual values for each year, 1980–2002. AHAM was used for the period 1989–2002 while Appliance Magazine was used for the period 1980–1988.

- **Appliance Price** is defined as the shipments weighted retail sales price of the unit in 1999 dollars. Price values for 1980, 1985, 1986, 1991, 1993, 1994, 1998, and 2002 were collected from AHAM Fact Books.[11 1993, 1995, 2000, and 2003 #7452] Price values for other years were interpolated from these eight years of data.

- **Housing Starts** data were collected from the U.S. Census construction statistics (C25 reports) as annual values for each year, 1980–2002.[12]

- **Replacements**, driven by equipment retirements, are estimated with the assumption that some fraction of sales arise from consumers replacing equipment at the end of its useful life. Since each appliance has a different expected lifespan (19 years for refrigerators,[13] 14 years for clothes washers,[14] 12 years for dishwashers[15]), replacements are calculated differently for each appliance type. Replacements are estimated as the average of shipments 14–24 years previous for refrigerators, 9–19 years previous for clothes washers, and 7–17 years previous for dishwashers. Historical shipments data were collected from AHAM and Appliance Magazine.

- **Annual Electricity Consumption** (UEC) is defined as the energy consumption of the unit in kilowatt-hours. Electricity consumption depends on appliance capacity and efficiency. These data were provided by AHAM for 1980, 1990–1997 and 1999–2002.[9] Data were interpolated in the years for which data were not available.

- **Operating Cost** is the present value of the electricity consumption of an appliance over its expected lifespan. The lifespans of refrigerators, clothes washers and dishwashers are assumed to be 19, 14, and 12 years respectively. Discount rates of 20 percent[6] and 37 percent[16] were used, producing similar estimates of price elasticity. A study by Hausman recommended a discount rate of "about 20 percent" in its introduction and presented results ranging from 24.1 percent to 29 percent based on his calculations for room air conditioners. A study by Train suggests a range of implicit discount rates averaging 35 percent for appliances.

- **Income:** Median annual household income in 2003 dollars. These data were collected for each year, 1980–2002, from Table H-6 of the U.S. Census.[17]

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CHAPTER 10. NATIONAL IMPACT ANALYSES

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CHAPTER 10. NATIONAL IMPACT ANALYSES

10.1 INTRODUCTION

This chapter examines selected national impacts attributable to each trial standard level (TSL) considered for furnace fans. The results presented here include: (1) national energy savings (NES); (2) operating cost savings; (3) increased total installed costs; and (4) the net present value (NPV) of the difference between the value of operating cost savings and increased total installed costs.

The calculations were performed using a Microsoft Excel spreadsheet model, which is accessible on the Internet (http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41). The spreadsheet model, termed the National Impact Analysis (NIA) model, calculates energy savings and NPV for the nation and for each of the regions analyzed. The NIA model for furnace fans was based on the NIA model that DOE used in its 2011 rulemaking for furnaces.[1] Like the furnace NIA model, it splits the Nation into two regions: North and South. Details regarding and instructions for using the NIA model are provided in appendix 10-A.

The NIA model incorporates the shipments model that DOE used to forecast future purchases of furnace fans. Chapter 9 includes analysis of consumers' sensitivities to total installed cost, operating expense, and income (otherwise known as elasticities), and how DOE captured those elasticities within the NIA model.

10.2 FORECASTED EFFICIENCY TRENDS

A key component of the NIA is the energy efficiency forecasted over time for the base case (without new standards) and for each of the standards cases (with potential new standards).

10.2.1 Base and Standards Case Efficiencies in 2019

For each furnace fan product class, DOE developed a distribution of efficiencies in the base case for 2019 (the assumed compliance date for new standards), as described in chapter 8. In each standards case, DOE assumed a "roll-up" scenario to establish the efficiency distribution for 2019. Product efficiencies in the base case that did not meet the standard under consideration would "roll up" to meet the new standard level. All efficiency shares in the base case that were above the standard under consideration would not be affected. Table 10.2.1 to Table 10.2.4 present the efficiency distributions for the base case and standards cases for non-weatherized gas furnaces, weatherized gas furnaces, and electric furnaces. Each standards case refers to a standard at the corresponding efficiency level. For example, standards case 1 refers to the case with a standard at efficiency level 1.

Table 10.2.1 Non-weatherized, Non-condensing Gas Furnace Fans: Efficiency Distributions for the Base and Standards Cases in 2019

Efficiency Level	Market Share						
	Base Case	Standards Case					
		1	2	3	4	5	6
Baseline PSC	33%						
1-Improved PSC	43%	76%					
2-Inverter-driven PSC	0%	0%	76%				
3-Constant-torque BPM motor	10%	10%	10%	86%			
4-Constant-torque BPM motor + multi-stage	2%	2%	2%	2%	89%		
5-Constant airflow BPM motor + multi-stage	11%	11%	11%	11%	11%	100%	
6-Constant airflow BPM motor + multi-stage + backward-curved impeller	0%	0%	0%	0%	0%	0%	100%

Table 10.2.2 Non-weatherized, Condensing Gas Furnace Fans: Efficiency Distributions for the Base and Standards Cases in 2019

Efficiency Level	Market Share						
	Base Case	Standards Case					
		1	2	3	4	5	6
Baseline PSC	25%						
1-Improved PSC	34%	59%					
2-Inverter-driven PSC	0%	0%	59%				
3-Constant-torque BPM motor	7%	7%	7%	66%			
4-Constant-torque BPM motor + multi-stage	6%	6%	6%	6%	72%		
5-Constant airflow BPM motor + multi-stage	28%	28%	28%	28%	28%	100%	
6-Constant airflow BPM motor + multi-stage + backward-curved impeller	0%	0%	0%	0%	0%	0%	100%

Table 10.2.3 Weatherized Gas Furnace Fans: Efficiency Distributions for the Base and Standards Cases in 2019

Efficiency Level	Market Share						
	Base Case	Standards Case					
		1	2	3	4	5	6
Baseline PSC	19%						
1-Improved PSC	25%	43%					
2-Inverter-driven PSC	0%	0%	43%				
3-Constant-torque BPM motor	23%	23%	23%	67%			
4-Constant-torque BPM motor + multi-stage	6%	6%	6%	6%	73%		
5-Constant airflow BPM motor + multi-stage	27%	27%	27%	27%	27%	100%	
6-Constant airflow BPM motor + multi-stage + backward-curved impeller	0%	0%	0%	0%	0%	0%	100%

Table 10.2.4 Electric Furnace Fans: Efficiency Distributions for the Base and Standards Cases in 2019

Efficiency Level	Market Share						
	Base Case	Standards Case					
		1	2	3	4	5	6
Baseline PSC	30%						
1-Improved PSC	37%	67%					
2-Inverter-driven PSC	0%	0%	67%				
3-Constant-torque BPM motor	11%	11%	11%	78%			
4-Constant-torque BPM motor + multi-stage	0%	0%	0%	0%	78%		
5-Constant airflow BPM motor + multi-stage	22%	22%	22%	22%	22%	100%	
6-Constant airflow BPM motor + multi-stage + backward-curved impeller	0%	0%	0%	0%	0%	0%	100%

10.2.2 Forecasted Efficiency Trends After 2019

Trends in HVAC product efficiency due to either future standards or other incentives are a major factor driving furnace fan efficiency. However, it is uncertain to what extent incentives will play a role after 2019 and to what degree future standards for residential HVAC products will require high-efficiency furnace fans. For this analysis, based on stakeholder input[2, 3], DOE estimated a growth rate in the overall market share of fans with BPM motor reaching 35 percent in 2019 (see chapter 8 for discussion), growing to 45 percent by 2048 (Figure 10.2.1).[a]

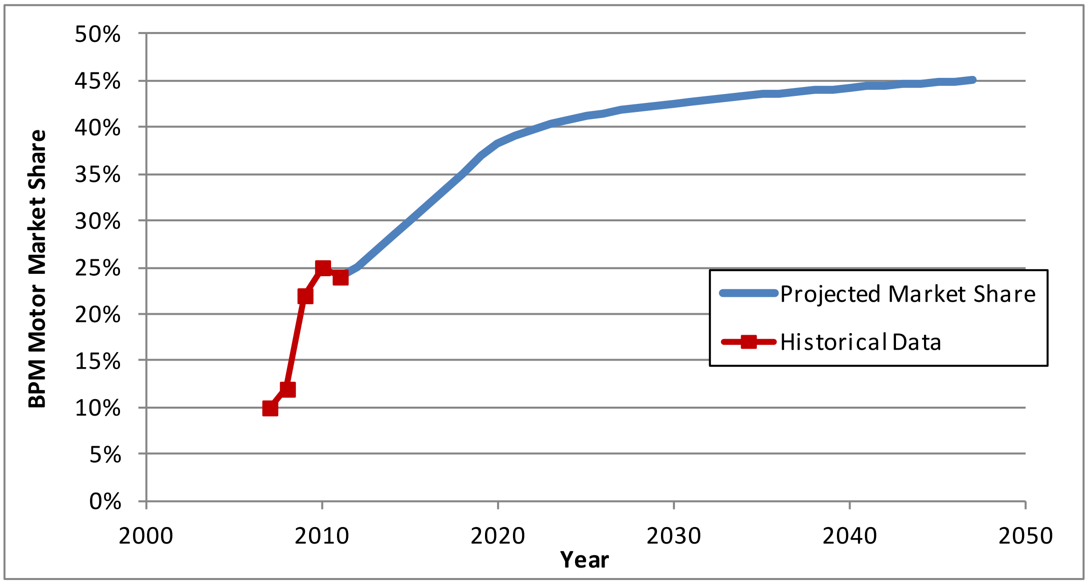

Figure 10.2.1 Projection of Base Case Market Share for BPM Motor Furnace Fans

For standards case 1 and 2, DOE applied the above described efficiency trend for the BPM motor market share. The difference between these standards cases and the base case is in the market shares of the various PSC designs. For standard cases 3 through 6, the overall BPM motor market share goes to 100 percent in 2019 and remains at that level. The shares of the specific BPM motor designs (i.e., constant-torque BPM, constant-torque BPM motor + multi-stage, constant-airflow BPM motor + multi-stage, and constant-airflow BPM motor + multi-stage + backward-curved impeller) remain at the levels shown in the tables above.

10.3 NATIONAL ENERGY SAVINGS

10.3.1 Definition

DOE calculates annual NES as the difference between two projections: a base case (without new standards) and a standards case (with new standards). The calculation of annual nation energy savings (NES_y) are represented by the following expressions.

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[a] Goodman estimated a value in the range of 40-50% by mid-century.

$$NES_y = AEC_{natl-base} - AEC_{natl-std}$$

Cumulative energy savings are the sum of each annual *NES* over the lifetime of products shipped in the period that extends from a standard's assumed compliance date for 30 years. This calculation is represented by the following equations for:

$$NES_{cum} = \sum NES_y$$

DOE calculated *AEC* by multiplying the number or stock of a given product (by vintage) by its unit energy consumption (also by vintage). The calculation of the national and each regional *AEC* is represented by the following equation:

$$AEC = \sum STOCK_V \times UEC_V$$

Where:

AEC = annual energy consumption each year for the Nation in quadrillion British thermal units (Btus)—quads—summed over vintages of the product stock, $STOCK_V$;

NES_y = national annual energy savings (quads);

NES_{cum} = national cumulative energy savings (quads);

$STOCK_V$ = stock of product (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption;

UEC_V = annual energy consumption per product in kilowatt-hours (kWh); electricity consumption is converted from site energy to power plant energy (quads) by applying a time-dependent conversion factor;

$natl$ = designates the quantity corresponding to the Nation;

$base$ = designates the quantity corresponding to the base case;

std = designates the quantity corresponding to the standards case;

y = year in the forecast; and

cum = cumulative over the forecast period; and

V = year in which the product was purchased as a new unit.

The stock of equipment depends on annual shipments and the lifetime of the given product. As described in chapter 9, DOE projected shipments for the base case and each standards case.

10.3.2 Inputs to Calculation

The inputs for calculating national and regional energy savings are:

- average annual energy consumption per unit (*UEC*),
- shipments,

- equipment stock ($STOCK_V$),
- annual energy consumption for the Nation (*AEC*), and
- power plant primary energy use factor (*src_conv*).

10.3.2.1 Annual Energy Consumption per Unit

For each product class, DOE presented the per-unit annual energy consumption as a function of product efficiency in chapter 7. Because the per-unit annual energy consumption is directly dependent on efficiency, DOE used the shipments-weighted energy efficiency of the base and standards cases presented in section 10.2, along with the annual energy use data presented in chapters 7 and 8, to estimate the shipment-weighted average annual per-unit energy consumption (UEC) under the base and standards cases.

As an example, Table 10.3.1 and Table 10.3.2 present the base case and standards case shipment-weighted annual UECs for non-weatherized gas furnace fans in 2019 (the assumed effective date of new standards). The tables show both the direct energy use of furnace fans and the additional furnace fuel use associated with higher-efficiency furnace fans. The values after 2019 change according to the projected efficiency trends.

Table 10.3.1 Non-weatherized, Non-condensing Gas Furnace Fans: Average Annual Energy Use for the Base and Standards Cases in 2019

	Base Case	Standards Case					
		1	2	3	4	5	6
Avg. Annual Elec Use (kWh)	863	814	720	602	539	539	486
Additional Fuel Use (MMBtu)	0.167	0.329	0.334	0.561	0.617	0.592	0.671

Table 10.3.2 Non-weatherized, Condensing Gas Furnace Fans: Average Annual Energy Use for the Base and Standards Cases in 2019

	Base Case	Standards Case					
		1	2	3	4	5	6
Avg. Annual Elec Use (kWh)	846	821	704	565	479	477	425
Additional Fuel Use (MMBtu)	0.291	0.208	0.215	0.446	0.522	0.499	0.557

The results in the above tables are not adjusted for the impact of the rebound effect discussed in chapter 8. In the NIA model, for those standards cases that require an inverter-driven PSC or BPM motor furnace fan (i.e., standard case 2 and above), DOE applied a rebound effect that varies by product class and by efficiency level. The rebound effect factors by product class and efficiency level are presented in Table 10.3.3. These factors are determined by calculating the additional electricity use that is required from a doubling of the use of continuous fan circulation compared to the average use assumed in chapter 8.[b]

Table 10.3.3 Rebound Factors for each Product Class and Efficiency Level

Product Class	Efficiency Level	Average National Rebound Factor
Non Weatherized Gas Furnace Non Condensing	0	0.0%
	1	0.0%
	2	39.0%
	3	18.9%
	4	12.4%
	5	11.0%
	6	8.9%
Non Weatherized Gas Furnaces Condensing	0	0.0%
	1	0.0%
	2	51.7%
	3	24.2%
	4	15.9%
	5	14.3%
	6	11.6%
Weatherized Gas Furnaces	0	0.0%
	1	0.0%
	2	33.9%
	3	16.5%
	4	10.8%
	5	9.0%
	6	7.3%
Oil Furnaces	0	0.0%
	1	0.0%
	2	30.2%
	3	14.7%
	4	9.8%
	5	8.6%
	6	7.1%
Electric Furnaces	0	0.0%
	1	0.0%
	2	32.7%
	3	16.9%
	4	10.6%
	5	9.1%
	6	7.3%

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[b] DOE reviewed an evaluation report from Wisconsin[4] that indicates that a considerable number of homeowners who purchase constant-airflow BPM furnaces significantly increase the frequency with which they operate their furnace fan subsequent to the installation of the constant-airflow BPM furnace. On average this report indicates that there is a doubling in the amount of continuous fan circulation use. DOE assumed that this doubling was the same for all types of furnace fans that had a significant decrease in energy use in the continuous fan circulation mode.

Product Class	Efficiency Level	Average National Rebound Factor
Manufactured Housing Gas Furnaces Non Condensing	0	0.0%
	1	0.0%
	2	34.0%
	3	17.0%
	4	10.8%
	5	9.4%
	6	7.8%
Manufactured Housing Gas Furnaces Condensing	0	0.0%
	1	0.0%
	2	39.8%
	3	19.2%
	4	12.5%
	5	11.3%
	6	9.3%
Manufactured Housing Electric Furnaces	0	0.0%
	1	0.0%
	2	31.0%
	3	17.5%
	4	10.5%
	5	8.5%
	6	6.9%

10.3.2.2 Shipments

DOE forecasted shipments for each product class under the base case and all standards cases. Several factors impact forecasted shipments, including total installed costs, operating cost, household income, and equipment lifetime. As noted earlier, the increased total installed cost of more efficient products causes some customers to forego product purchases. Consequently, shipments forecasted under the standards cases are lower than under the base case. DOE believes it would be inappropriate to count energy savings that result from reduced shipments due to standards, as described in chapter 9. Therefore, DOE did not calculate annual energy consumption for the base case using the base case shipments forecast. Instead, for each comparison of a standards case with the base case, DOE used shipments associated with that particular standards case. As a result, all of the calculated energy savings are due to higher energy efficiency in the standards case. Chapter 9 describes in detail the method DOE used to calculate and generate the shipments forecasts for each product class.

10.3.2.3 Equipment Stock

The stock of equipment in any given year depends on annual shipments and the lifetime of a given product class. The NIA model keeps track of the number of units shipped each year. The lifetime of a unit determines how many units shipped in previous years survive in the given year. DOE assumes that products have an increasing probability of retiring as they age. The probability of survival as a function of years since purchase is termed the survival function. Refer to chapter 8 for further details on the survival functions that DOE used in its analysis.

10.3.2.4 Annual Energy Consumption

For each product class, DOE calculated the total national site (*i.e.*, the energy consumed at the household or establishment) annual energy consumption (AEC). Annual energy consumption is the product of the AEC per unit [also termed the unit energy consumption (UEC)] and the number of units of each vintage. This method accounts for differences in UEC from year to year. The equation for determining annual energy consumption, presented in section 10.3.2, is repeated here.

$$AEC = \sum STOCK_V \times UEC_V$$

10.3.2.5 Site-to-Power Plant Energy Use Factor

DOE calculates primary energy savings (power plant consumption) from site energy savings by applying a factor to account for losses associated with the generation, transmission, and distribution of electricity. DOE derived annual average site-to-power plant factors based on the version of the National Energy Modeling System (NEMS) that corresponds to Energy Information Administration (EIA's) *Annual Energy Outlook 2012* (*AEO 2012*).[5] The factors change over time in response to projected changes in the types of power plants projected to provide electricity to the country. Figure 10.3.1 shows the site-to-power plant factors from 2019 to the end of the projection period. For years after 2035 (the last year in the *AEO*), DOE extrapolated the trend from 2025 to 2035.

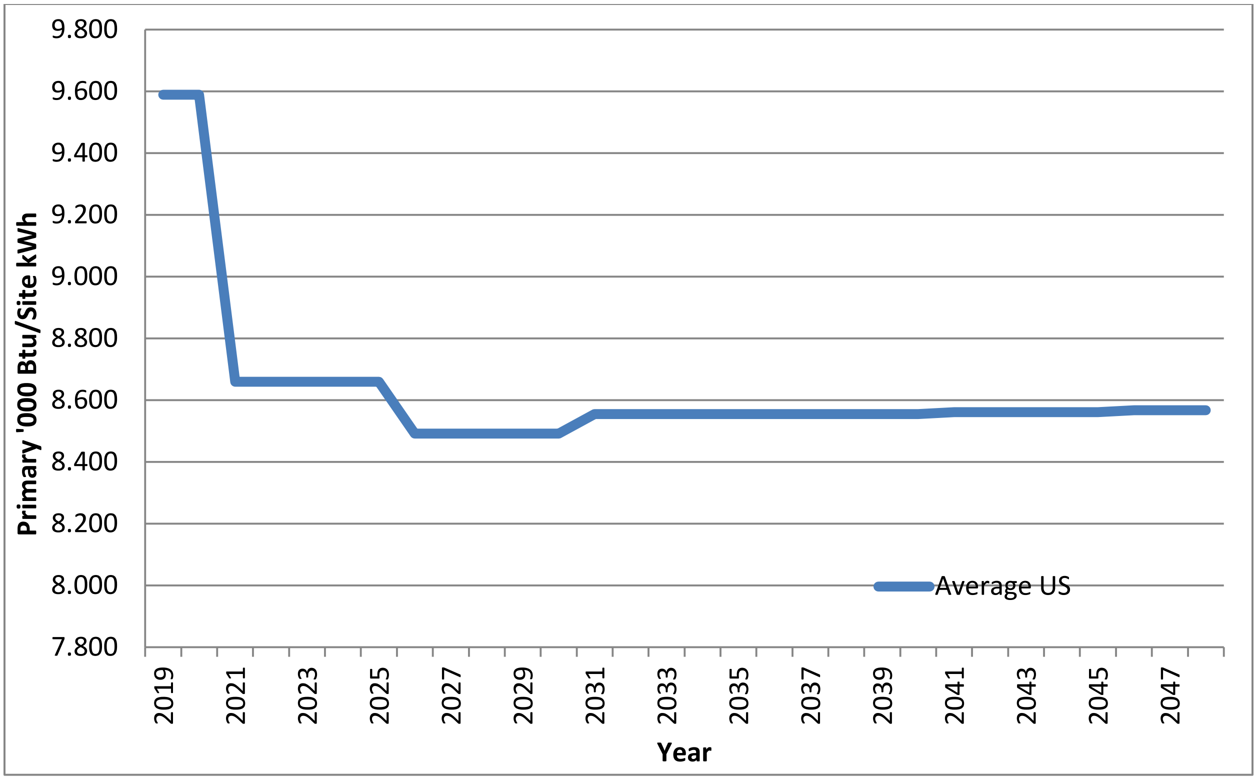

Figure 10.3.1 Site-to-Power Plant Energy Use Factor for Furnace Fans

10.3.2.1 Full-Fuel-Cycle Energy Factors

The full-fuel-cycle (FFC) measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. To complete the full-fuel-cycle by encompassing the energy consumed in extracting, processing, and transporting or distributing primary fuels, which we refer to as "upstream" activities, DOE developed FFC multipliers[c] using the data and projections generated by the National Energy Modeling System (NEMS) used for *AEO 2012*. The AEO provides extensive information about the energy system, including projections of future oil, natural gas and coal supply, energy use for oil and gas field and refinery operations, and fuel consumption and emissions related to electric power production. This information can be used to define a set of parameters representing the energy intensity of energy production.

Table 10.3.4 shows the FFC energy multipliers used for furnace fans for selected years. The method used to calculate FFC energy multipliers, which are based on site energy savings, is described in appendix 10-B. Note that the FFC factors for natural gas and petroleum fuels are applied to the additional furnace fuel use associated with higher-efficiency furnace fans.

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[c] FFC multipliers discussed in this chapter relate to the upstream part of the FFC process.

Table 10.3.4 Full-Fuel-Cycle (Upstream) Energy Multipliers (Based on AEO 2012)

	2015	**2020**	**2025**	**2030**	**2035**	**2040**
Electricity	1.042	1.041	1.040	1.040	1.041	1.041
Natural Gas	1.102	1.103	1.100	1.099	1.098	1.097
Petroleum Fuels	1.142	1.146	1.153	1.163	1.172	1.181

10.4 NET PRESENT VALUE OF CONSUMER BENEFITS

10.4.1 Definition

The NPV is the value in the present of a time-series of costs and savings. The NPV is described by the equation:

$$\boldsymbol{NPV = PVS - PVC}$$

Where:

PVS = present value of savings in operating cost (including costs for energy, repair, and maintenance); and
PVC = present value of increase in total installed cost (including costs for equipment and installation).

DOE determined the *PVS* and *PVC* according to the following expressions.

$$PVS = \sum OCS_y \times DF_y$$

$$PVC = \sum TIC_y \times DF_y$$

DOE calculated the total annual savings in operating cost by multiplying the number or stock of a given product (by vintage) by its per-unit operating cost savings (also by vintage). DOE calculated the total annual increase in installed cost by multiplying the number or stock of a given product (by vintage) by its per-unit total installed cost increase (also by vintage). Total annual savings in operating cost and increases in installed cost are calculated using the following equations.

$$OCS_y = \sum STOCK_V \times UOCS_V$$

$$TIC_y = \sum STOCK_V \times UTIC_V$$

Where:

OCS = total annual savings in operating cost each year summed over vintages of the product stock, $STOCK_V$;
TIC = total annual increase in installed cost each year summed over vintages of the product stock, $STOCK_V$;
DF = discount factor in each year;
$STOCK_V$ = stock of product (millions of units) of vintage V that survive in the year for which DOE calculated annual energy consumption;
$UOCS_V$ = annual per-unit savings in operating cost;
$UTIC_V$ = annual total per-unit increase in installed cost;
V = year in which the product was purchased as a new unit; and
y = year in the forecast.

DOE determined the PVC for each year from the compliance date of the standard until 2048. DOE determined the PVS for each year from the compliance date of the standard until the year when units purchased in 2048 retire. DOE calculated costs and savings as the difference between each standards case and the base case.

DOE calculated a discount factor from the discount rate and the number of years between the "present" (2013, the year to which the sum is being discounted) and the year in which the costs and savings occur. The NPV is the sum over time of the discounted net savings.

10.4.2 Inputs to Calculation

Listed below are the inputs to DOE's calculation of the NPV of costs and savings.

- Total installed cost per unit,
- annual per-unit savings in operation cost,
- shipments,
- equipment stock ($STOCK_V$),
- total annual increases in installed cost (TIC),
- total annual operating cost (OCS),
- discount factor (DF),
- present value of costs (PVC), and
- present value of savings (PVS).

The *total annual increase in installed cost* is equal to the annual change in the total per-unit installed cost (difference between base case and standards case) multiplied by the shipments forecasted for each standards case. As with calculating energy savings, DOE did not use base-case shipments to calculate total annual installed costs for all of the product classes. DOE used the projected shipments and stock for each standards case to calculate costs.

The annual operating cost includes energy, repair, and maintenance costs. The *total annual savings in operating cost* are equal to the change in the annual operating costs (difference between base case and standards case) per unit multiplied by the shipments forecasted for each candidate standard level. As with calculating total annual installed costs, DOE did not use base-case shipments to calculate savings in operating cost.

10.4.2.1 Total Installed Cost per Unit

DOE described the total per-unit installed cost for each product class as a function of product efficiency in chapter 8. Because the total per-unit annual installed cost depends directly on efficiency, DOE used the shipments-weighted efficiencies for the base and standards cases, combined with the total installed cost presented in chapter 8, to estimate the shipments-weighted total per-unit average annual installed cost under the base and standards cases. Table 10.4.1 shows the average installed cost of furnace fans in 2019 for the base and standards cases for the four product classes with the largest market shares.

For reasons discussed in chapter 8 of the TSD (section 8.2.1.4), DOE used a constant price assumption for the default projection in the NIA. To investigate the impact of different equipment price projections on the consumer net present value (NPV) for different efficiency levels, DOE also considered two alternative price trends. One assumes decreasing prices which used an exponential fit on the deflated price index for fractional horsepower motor manufacturing during the period of 1989 to 2004. The other assumes rising prices which is based on the same deflated price index between 2004 and 2012. Details on how these alternative price trends were developed are in appendix 10-C, which also presents the results of the sensitivity analysis.

Table 10.4.1 Average Installed Cost of Furnace Fans in 2019 for the Base and Standards Cases (2012$)

Product Class	Base Case	Standards Case					
		1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	$397	$401	$439	$447	$519	$672	$709
Non-weatherized, Condensing Gas Furnace Fan	$443	$446	$474	$480	$535	$656	$691
Weatherized Gas Furnace Fan	$438	$441	$462	$466	$520	$639	$674
Electric Furnace / Modular Blower Fan	$303	$307	$338	$336	$353	$464	$497

10.4.2.2 Annual Operating Cost per Unit

The per-unit annual operating cost includes costs for energy, repair, and maintenance. DOE determined the per-unit annual savings in energy costs by multiplying the per-unit annual savings in energy consumption developed for each product class by the appropriate energy price.

Estimates of the per-unit annual energy consumption for the base case and each standards case were presented in section 10.3.2.1. DOE forecasted the per-unit annual energy consumption for the base case for all product classes by applying a growth trend in efficiency.

Energy prices and trends in energy prices are described in chapter 8. DOE projected energy prices based on EIA's *AEO2012*[5] reference case scenario.[d]

DOE described the total per-unit repair and maintenance costs for each product class as a function of product efficiency in chapter 8. Because the per-unit repair and maintenance costs depend directly on efficiency, DOE used the efficiencies for the base and standards cases presented in section 10.2, combined with the repair and maintenance costs presented in chapter 8, to estimate the per-unit average repair and maintenance costs under the base and standards cases.

Table 10.4.2 shows the average operating cost of furnace fans in 2019 for the base and standards cases for the four product classes with the largest market shares. The operating costs change over time, depending on change in annual energy use and energy prices.

Table 10.4.2 Average Annual Operating Cost of Furnace Fans in 2019 for the Base and Standards Cases (2012$)

Product Class	Base Case	Standards Case					
		1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	$119.93	$115.12	$100.92	$86.26	$78.26	$80.67	$75.34
Non-weatherized, Condensing Gas Furnace Fan	$121.12	$117.58	$106.14	$94.15	$88.59	$90.75	$85.42
Weatherized Gas Furnace Fan	$93.16	$90.77	$84.83	$76.57	$71.25	$75.47	$71.21
Electric Furnace / Modular Blower Fan	$62.10	$60.67	$55.28	$51.46	$48.67	$51.94	$50.32

10.4.2.3 Equipment Stock

The stock of equipment in any given year depends on annual shipments and the lifetime of a given product class. The NIA model keeps track of the number of units shipped each year. The lifetime of a unit determines how many units shipped in previous years survive in the given year. DOE assumes that products have an increasing probability of retiring as they age. The

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[d] The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. DOE conducted sensitivity analyses using alternative economic growth scenario assumptions (see appendix 10-D).

probability of survival as a function of years since purchase is termed the survival function. Refer to the specific section for each product class in chapter 9 for further details on the survival functions that DOE used in its analysis.

10.4.2.4 Increases in Total Annual Installed Cost

The increase in total annual installed cost for a product under any given standards case is the product of the increase in total installed cost per unit attributable to the standard and the number of units of each vintage. This method accounts for differences in total installed cost from year to year. The equation for determining the total annual installed cost increase for a given candidate standards level is:

$$TIC = \sum STOCK_V \times UTIC_V$$

10.4.2.5 Savings in Total Annual Operating Cost

The savings in total annual operating cost for any given candidate standards level is the product of the annual per-unit savings in operating cost attributable to the standard and the number of units of each vintage. This method accounts for the year-to-year differences in annual operating cost savings. The equation for determining the total annual savings in operating cost for a given candidate standard level, which was presented in section 10.4.1, is repeated here.

$$OCS = \sum STOCK_V \times UOCS_V$$

As previously discussed, DOE applied a rebound effect to adjust its estimates of energy savings from standards cases that require BPM motor furnace fans. The take-back in energy consumption associated with the rebound effect provides consumers with increased value (e.g., enhanced comfort associated with use of constant circulation). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA.

10.4.2.6 Discount Factor

DOE multiplied monetary values in future years by a discount factor to determine the present value. The discount factor (DF) is described by the equation:

$$\boldsymbol{DF} = \frac{1}{(1+\boldsymbol{r})^{(y-yp)}}$$

Where:

r = discount rate,

y = year of the monetary value, and

y_P = year in which the present value is being determined.

Although DOE used consumer discount rates to determine the life-cycle cost of furnace fans (chapter 8), it used national discount rates to calculate national NPV. DOE estimated NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: Identifying and Measuring Benefits and Costs.[6] DOE defined the present year as 2013.

10.4.2.7 Present Value of Increased Installed Cost

The present value of increased installed cost is the difference between installation cost in each standards case and the base case discounted to the present and summed throughout the period over which DOE is considering the installation of units (from the compliance date of standards, 2019, through 2048). DOE calculated annual increases in installed cost as the difference in total installed cost for new equipment purchased each year, multiplied by the shipments in the standards case.

10.4.2.8 Present Value of Savings

The present value of annual savings in operating cost is the difference between the base case and each standards case discounted to the present and summed throughout the period from the compliance date, 2019, to the time when the last unit installed in 2048 is retired from service.

Savings represent decreases in operating cost (including electricity, repair, and maintenance) associated with the more energy efficient equipment purchased in each standards case compared to the base case. Total annual savings in operating cost are the savings per unit multiplied by the number of units of each vintage that survive in a particular year.

10.5 TRIAL STANDARD LEVELS

DOE developed TSLs that combine efficiency levels for each product class of furnace fans. Table 10.5.1 presents the efficiency levels for each product class in each TSL. TSL 6 consists of the max-tech efficiency levels. TSL 5 consists of those efficiency levels that provide the maximum NPV using a 7-percent discount rate (see section 10.6.2 for NPV results). TSL 4 consists of those efficiency levels that provide the maximum NPV using a 7-percent discount rate, and for which the percentage of consumers that receive an LCC benefit exceed the percentage that receive an LCC loss (see chapter 8 for LCC results). TSL 3 uses efficiency level 3 for all product classes. TSL 2 consists of efficiency levels that are the same as TSL 3 for non-weatherized gas furnace fans, weatherized gas furnace fans, and electric furnace fans, but are at efficiency level 1 for oil-fired furnace fans and manufactured home furnace fans. TSL 1 consists of the most common efficiency levels in the current market. The design options in each efficiency level are shown in Table 10.5.2.

Table 10.5.1 Trial Standard Levels for Furnace Fans

Product Class	Trial Standard Level (Efficiency Level) 1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	1	3	3	4	4	6
Non-weatherized, Condensing Gas Furnace Fan	1	3	3	4	4	6
Weatherized Gas Furnace Fan	1	3	3	4	4	6
Non-weatherized Oil Non-Condensing Furnace Fan	1	1	3	1	3	6
Non-weatherized Electric Furnace/Modular Blower Fan	1	3	3	4	4	6
Manufactured Home Non-Weatherized, Gas Non-Condensing Furnace Fan	1	1	3	1	3	6
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	1	1	3	1	3	6
Manufactured Home Electric Furnace/Modular Blower Fan	1	1	3	4	4	6

Table 10.5.2 Design Option for each Furnace Fan Efficiency Level

Efficiency Level	Design Option
0	Baseline PSC
1	Improved PSC
2	Inverter-driven PSC
3	Constant-torque BPM motor
4	Constant-torque BPM motor + multi-stage
5	Constant airflow BPM motor + multi-stage
6	Constant airflow BPM motor + multi-stage + backward-curved impeller

10.6 RESULTS

10.6.1 National Energy Savings

This section provides the national energy savings that DOE calculated for each of the TSLs analyzed for furnace fans. DOE based the inputs to the NIA model on weighted-average values, producing results that are discrete point values, rather than a distribution of values such as is generated by the life-cycle cost and payback period analysis. The energy savings in the tables below are net savings that reflect the subtraction of the additional furnace fuel use associated with higher-efficiency furnace fans. In addition, the energy savings reported for TSLs 2 and above reflect application of a rebound effect.

The difference between primary energy savings and FFC energy savings for all TSLs is small (less than 1%), because the upstream energy savings associated with the electricity savings are partially (or fully, for TSL 2 and 3) offset by the upstream energy use from the additional furnace fuel use due to higher-efficiency furnace fans (see Table 10.6.3).

Table 10.6.1 Primary National Energy Savings (quads)

Product Class	**Trial Standard Level**					
	1	**2**	**3**	**4**	**5**	**6**
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.25	1.02	1.02	1.86	1.86	2.40
Non-weatherized, Condensing Gas Furnace Fan	0.28	0.88	0.88	2.00	2.00	2.79
Weatherized Gas Furnace Fan	0.03	0.14	0.14	0.26	0.26	0.34
Non-weatherized Oil Non-Condensing Furnace Fan	0.01	0.01	0.03	0.01	0.03	0.05
Non-weatherized Electric Furnace/Modular Blower Fan	0.04	0.20	0.20	0.36	0.36	0.45
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.01	0.01	0.04	0.01	0.04	0.09
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.00	0.00	0.01	0.00	0.01	0.02
Manufactured Home Electric Furnace/Modular Blower Fan	0.01	0.01	0.03	0.06	0.06	0.07
Total – All Classes	0.63	2.27	2.34	4.56	4.62	6.22

Table 10.6.2 Full-Fuel-Cycle National Energy Savings (quads)

Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.26	1.02	1.02	1.87	1.87	2.42
Non-weatherized, Condensing Gas Furnace Fan	0.28	0.87	0.87	2.00	2.00	2.80
Weatherized Gas Furnace Fan	0.03	0.14	0.14	0.27	0.27	0.34
Non-weatherized Oil Non-Condensing Furnace Fan	0.00	0.00	0.02	0.00	0.02	0.05
Non-weatherized Electric Furnace/Modular Blower Fan	0.04	0.20	0.20	0.36	0.36	0.45
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.01	0.01	0.04	0.01	0.04	0.09
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.00	0.00	0.01	0.00	0.01	0.02
Manufactured Home Electric Furnace/Modular Blower Fan	0.01	0.01	0.03	0.06	0.06	0.07
Total – All Classes	0.63	2.25	2.33	4.58	4.63	6.25

Table 10.6.3 Upstream Energy Components (quads)

Source of Upstream Energy	Trial Standard Level					
	1	2	3	4	5	6
Electricity Savings	0.012	0.047	0.049	0.088	0.089	0.118
Additional Natural Gas	-0.009	-0.058	-0.060	-0.073	-0.075	-0.087
Additional Petroleum Fuels	0.000	0.000	-0.002	0.000	-0.002	-0.002
Net Savings	0.003	-0.011	-0.013	0.014	0.013	0.028

10.6.2 Net Present Value of Consumer Benefit

This section provides results of calculating the NPV for each candidate standard level considered for furnace fans. Results were calculated for the nation as a whole. Results, which are cumulative, are shown as the discounted dollar value of the net savings. DOE based the inputs to the NIA model on weighted-average values, yielding results that are discrete point values, rather than a distribution of values such as produced by the life-cycle cost and payback period analyses. A negative NPV indicates that the costs of a standard at a given efficiency level exceed the savings.

Table 10.6.4 Net Present Value of Consumer Benefit, Discounted at 3 Percent (billion 2012$)

Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	1.46	9.86	9.86	11.09	11.09	8.28
Non-weatherized, Condensing Gas Furnace Fan	1.49	11.16	11.16	12.23	12.23	9.20
Weatherized Gas Furnace Fan	0.17	1.12	1.12	1.30	1.30	0.49
Non-weatherized Oil Non-Condensing Furnace Fan	0.02	0.02	0.19	0.02	0.19	0.10
Non-weatherized Electric Furnace/Modular Blower Fan	0.15	1.05	1.05	1.29	1.29	0.12
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.04	0.04	0.25	0.04	0.25	-0.06
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.01	0.01	0.05	0.01	0.05	-0.02
Manufactured Home Electric Furnace/Modular Blower Fan	0.03	0.03	0.13	0.17	0.17	-0.17
Total – All Classes	3.37	23.30	23.81	26.16	26.57	17.95

Table 10.6.5 Net Present Value of Consumer Benefit, Discounted at 7 Percent (billion 2012$)

Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.53	3.52	3.52	3.71	3.71	1.98
Non-weatherized, Condensing Gas Furnace Fan	0.51	3.78	3.78	3.91	3.91	2.11
Weatherized Gas Furnace Fan	0.06	0.39	0.39	0.41	0.41	-0.01
Non-weatherized Oil Non-Condensing Furnace Fan	0.01	0.01	0.07	0.01	0.07	0.01
Non-weatherized Electric Furnace/Modular Blower Fan	0.05	0.33	0.33	0.40	0.40	-0.20
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.02	0.02	0.08	0.02	0.08	-0.09
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.00	0.00	0.02	0.00	0.02	-0.02
Manufactured Home Electric Furnace/Modular Blower Fan	0.01	0.01	0.04	0.05	0.05	-0.13
Total – All Classes	1.190	8.070	8.234	8.507	8.643	3.651

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APPENDIX 10-A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

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APPENDIX 10-A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

10-A.1 USER INSTRUCTIONS

The results obtained in this analysis can be examined and reproduced using the Microsoft Excel® spreadsheets accessible on the Internet from the Department of Energy's (DOE's) furnace fan rulemaking page: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/41. From that page, follow the links to the Preliminary Analysis phase of the rulemaking and then to the analytical tools.

10-A.2 STARTUP

The NIA spreadsheets enable the user to perform a National Impact Analysis (NIA) for the trial standard levels (TSLs) for residential furnaces fans. To execute the spreadsheet, the Department assumes that the user has access to a PC with a hardware configuration capable of running Windows 2003 or later. To use the NIA spreadsheets, the user requires Microsoft Excel® 2003 or later installed under the Windows operating system.

10-A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSIS WORKSHEETS

The NIA spreadsheets perform calculations to forecast the change in national energy use and net present value of financial impacts due to a revised energy efficiency standard. The energy use and associated costs for a given standard are determined by first calculating the shipments and then calculating the energy use and costs for all furnace fans shipped under that standard. The differences between the standards and base case can then be compared and the overall energy savings and net present values determined.

The NIA analysis is composed with two separate spreadsheets, the NIA and the NIAplus. The NIA spreadsheet calculates site energy savings from potential standards and net present values of the total consumer benefits. The outputs from the NIA spreadsheet are then used in the NIAplus spreadsheet to calculate primary energy savings and full fuel cycle (FFC) energy savings, as well as emission savings for each TSL.

The NIA spreadsheet consist of the following worksheets:

NIA Summary	Contains source energy savings results matrix, net present value results matrix, and a summary table for each product class.
NWGFnc	Contains non-weatherized non-condensing gas furnace NIA calculations.
NWGFc	Contains non-weatherized condensing gas furnace NIA calculations.
WGF	Contains weatherized gas furnace NIA calculations.
OF	Contains oil furnace NIA calculations.
EF	Contains electric furnace NIA calculations.

MHGFnc	Contains manufactured home non-condensing gas furnace NIA calculations.
MHGFc	Contains manufactured home condensing gas furnace NIA calculations.
MHEF	Contains manufactured home electric furnace NIA calculations.
WGF	Contains weatherized gas furnace NIA calculations.
OF	Contains oil furnace NIA calculations.
EF	Contains electric furnace NIA calculations.
MHGFnc	Contains manufactured home non-condensing gas furnace NIA calculations.
MHGFc	Contains manufactured home condensing gas furnace NIA calculations.
MHEF	Contains manufactured home electric furnace NIA calculations.
NIA Input	Contains energy use, electricity use, total installed price, annual repair and maintenance costs and base case distributions.
Learning Rate	Includes the learning multipliers to adjust the manufacturer's cost over the entire analysis period.
Fuel Prices	Contains energy prices for each product class by region, and energy price trends.
Historical Shipments	Includes historical data and the annual shipments forecasts for each product class.
AEO Housing Forecast	Includes Annual Energy Outlook (AEO) forecasts of housing stocks and housing starts by region.
New Saturation	Contains market saturation data for each product class in new homes.
Lifetime	Includes the lifetime and the retirement function for each product class.
Labels	Contains labels and definitions used throughout the spreadsheet – Also, worksheet where the TSLs used in the analysis are defined
Shipments	Shipment results for plotting.
Output Data	All output data that is produced during the analysis for all TSLs and product classes
for ImSet	Input for ImSet: employment analysis
Intermed. for NIAplus	Intermediate results for NIAplus – these cells are copied in the following worksheet ("for NIAplus") for each TSL
for NIAplus	Contains the input for NIAplus
for Ch.10	Contains the tables for Chapter 10 of the Technical Support Documents
for MIA	Contains the input for Manufacturer Impact Analysis
Distributions	Contains the distribution of the shipments for the assumed effective date of new standard (2019) for each product class, efficiency level and TSL
for NOPR	Contains
for NEMS	Contains the tables for NEMS

The NIAplus spreadsheet consists of the following worksheets: (There are other worksheets not listed below which contain data used to populate tables and graphs for the documentationand inputs for the MIA, Employment, NIAplus…])

Summary	Presents the results of the NIAplus analysis (national energy savings, net present values and emission analysis results) for a selected TSL, benefit scenario and discount rate. It also displays a button that allows to generate the same results for all TSLs, benefit scenarios and for both discount rates. The results are displayed in the *Summary Tables* worksheet.
Summary Tables	Present the results generated when running the macro which is run when clicking on the button in the worksheet *Summary*.
ROCIS	ROCIS results
Utility Impacts	Contains utility impact analysis
Emissions Reduction	Contains emission savings analysis
Factors	Contains energy use, emission, utility impact, monetization, and conversion factors.
Inputs	Contains the input from the NIA. When selecting this tab, the user is prompted to select whether or not to import the NIA results. More explanations are given in section 10-A.4.2.
NWGFnc	Contains non-weatherized non-condensing gas furnace NIAplus calculations.
NWGFc	Contains non-weatherized condensing gas furnace NIAplus calculations.
WGF	Contains weatherized gas furnace NIAplus calculations.
OF	Contains oil furnace NIAplus calculations.
EF	Contains electric furnace NIAplus calculations.
MHGFnc	Contains manufactured home non-condensing gas furnace NIAplus calculations.
MHGFc	Contains manufactured home condensing gas furnace NIAplus calculations.
MHEF	Contains manufactured home electric furnace NIAplus calculations.
WGF	Contains weatherized gas furnace NIAplus calculations.
OF	Contains oil furnace NIAplus calculations.
EF	Contains electric furnace NIAplus calculations.
MHGFnc	Contains manufactured home non-condensing gas furnace NIAplus calculations.
MHGFc	Contains manufactured home condensing gas furnace NIAplus calculations.
MHEF	Contains manufactured home electric furnace NIAplus calculations.
Charts for TSD	Contains chart used in Chapter 10

10-A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEETS

The NIA analysis is composed with two separate spreadsheets, the NIA and the NIAplus.

10-A.4.1 Instructions for NIA

Basic instructions for operating the NIA spreadsheets are as follows:

1. Once the NIA spreadsheet file has been downloaded from the Internet, open the file using Excel®. Click "Enable Macro" when prompted and then click on the tab for the worksheet User Inputs.
2. Use Excel's® View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.
3. The user can change the parameters in the sheet "NIA Summary". The default parameters are:

a. Discount Rate: Set to 7%. To change value, click on cell M11 and interchange value (7% or 3%).

b. Current Year: Set to 2013. To change value, click on cell M13 and change to desired year.

4. The user can change the TSL analyzed in the worksheet "Summary" by changing the value in cell K3d. The button "Generate Output" runs a macro that updates the input for the downstream analysis: shipment data, NIAplus input, and employment analysis input. The energy savings and net present value of consumer benefits for the selected TSL are contained in the table in cells J22 to M34.

   Note: Make sure that the spreadsheet is in automatic calculation mode. To change the calculation mode:

   1. In Excel 2007 and later, go to the tab "Formulas" in the Office ribbon.
   2. Click on the button "Calculation Options" and select "Automatic".

The results are automatically updated and are reported in the source energy savings matrix, net present value matrix, summary table for each product class, and charts of national impacts for each product class. [What spreadsheet are these in?]

10-A.4.2 Instructions for NIAplus

The NIAplus spreadsheet generates the national energy savings from potential standards, net present values of the total consumer benefits and emission analysis results for each TSLs.

In order to create the summary tables, click on the button "Generate Tables" located in the "Summary" tab in the NIAplus spreadsheet.

All the tables that are used in the TSDs will be created in a new file and the user will be prompted to save the new file. The results will also be transferred in the NIAplus spreadsheet and the tables in the "Summary" and "Summary Tables" tabs will update themselves. [Expand in more detail, what results…NPV, NES, monetized emissions, etc.]

10-A.4.3 Instructions to run the NIA for the 9-year analysis

The analysis usually covers a period of 30 years. In the NOPR document, 9-year analysis results are also reported. In order to change the analysis period to 9 years, the following steps should be followed:

1. In the NIA file, in the tab "NIA Summary" change the cell titled "Analysis Period" in the "User Input" section (cell M9) from 30 to 9 (this should change the analysis period from 2048 to 2027).

2. Click on the button "Generate Output".

3. After the NIA has run and generated the different tables that will be used in the NIAplus, open the NIAplus spreadsheet, and go to the tab "Input". When prompted with the message "Get NIA outputs?", click "Yes".

4. When the results from NIA have been imported into NIAplus, go to the tab "Summary" in the NIAplus, and click "Generate Tables". That will generate all results related to NIAplus and display them in the "Summary" and "Summary Tables" tabs.

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APPENDIX 10-B. FULL-FUEL-CYCLE MULTIPLIERS

10-B.1 INTRODUCTION

This appendix summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from potential standards. The FFC measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's traditional approach encompassed only site energy and the energy losses associated with generation, transmission, and distribution of electricity.[1] Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses. This appendix summarizes the methods used to incorporate the full-fuel-cycle impacts into the analysis.

This analysis uses several different terms to reference energy use. The physical sources of energy are the primary fuels such as coal, natural gas, liquid fuels, *etc*. Primary energy is equal to the heat content (Btu) of the primary fuels used to provide an end-use service. Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas and petroleum fuels are consumed at the site (for example in a furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed. For electricity, site energy is measured in kWh. In this case the primary energy is equal to the quads of primary energy required to generate and deliver the site electricity. This primary energy is calculated by multiplying the site kWh times the site-to-power plant energy use factor*,* given in chapter 10. For the FFC analysis, the upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in fuel cycle analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable fluxes (wind, solar and hydro). For the former, the upstream fuel cycle impacts are derived from the amount of fuel consumed at the power plant. For the latter, no fuel *per se* is used, so there is no upstream component.

10-B.2 METHODOLOGY

The mathematical approach is discussed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use,*[2] and details on the fuel production chain analysis are presented in the paper *Projections of Full Fuel Cycle Energy and Emissions Metrics*.[3] The text below provides a brief summary of the methods used to calculate FFC energy.

When all energy quantities are normalized to the same units, the FFC energy use can be represented as the product of the primary energy use and an *FFC multiplier*. The FFC multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, so the calculations do not require any assumptions about prices or other economic data. While in general these parameter values may vary by geographic region, for this analysis national averages are used.

In the notation below, the indices x and y are used to indicate fuel type, with x=c for coal, x=g for natural gas, x=p for petroleum fuels, x=u for uranium and x=r for renewable fluxes. The fuel cycle parameters are:

- a_x is the quantity of fuel x burned per unit of electricity output, on average, for grid electricity. The calculation of a_x includes a factor to account for transmission and distribution system losses.
- b_y is the amount of grid electricity used in production of fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBtu/physical unit)
- $z_x(s)$ is the emissions intensity for fuel x (mass of pollutant s per physical unit of x)

The parameters are calculated as a function of time with an annual time step; hence, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period. Fossil fuel quantities are converted to energy units using the heat content factors q_x. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-power plant energy use factor. The site-to-power plant energy use factor is defined as the ratio of the total primary energy consumption by the electric power sector (in quadrillion Btu's) divided by the total electricity generation in each year.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. A multiplier is also calculated for electricity reflecting the fuel mix used in its generation. The multipliers are dimensionless numbers that are applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

For DOE's appliance standards energy savings estimates, the fuel cycle analysis methodology is designed to make use of data and projections published in the Annual Energy Outlook (AEO). Table 10-B.2.1 provides a summary of the AEO data used as inputs to the different parameter calculations. The AEO does not provide all the information needed to estimate total energy use in the fuel production chain. Reference 3 describes the additional data sources used to complete the analysis. However, the time dependence in the FFC multipliers arises exclusively from variables taken from the AEO. The FFC analysis for furnace fans used data from *AEO-2012*.[4]

Table 10-B.2.1 Dependence of FFC Parameters on AEO Inputs

Parameter	Fuel	AEO Table	Variables
q_x	all	Conversion Factors	MMBtu per physical unit
a_x	all	Electricity Supply, Disposition, Prices, and Emissions	Generation by fuel type
		Energy Consumption by Sector and Source	Electric power sector energy consumption
b_c, c_{nc}, c_{pc}	coal	Coal Production by Region and Type	Production by coal type and sulfur content
b_p, c_{np}, c_{pp}	petroleum	Refining Industry Energy Consumption	Refining only energy use
		Liquid Fuels Supply and Disposition	Crude supply by source
		International Liquids Supply and Disposition	Crude oil imports
		Oil and Gas Supply	Crude oil domestic production
c_{nn}	natural gas	Oil and Gas Supply	US dry gas production
		Natural Gas Supply, Disposition and Prices	Pipeline, lease and plant fuel
z_x	all	Electricity Supply, Disposition, Prices and Emissions	Power sector emissions

10-B.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

FFC energy multipliers, which are based on site energy use, are presented in Table 10-B.3.1 for selected years. To extend the analysis period beyond 2035, the last year in the *AEO-2012* projection, the years 2020 to 2035 are used to define a linear trend to 2040, which is then extrapolated to the final year of the analysis period. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation over the forecast period.

Table 10-B.3.1 Full Fuel Cycle (Upstream) Energy Multipliers (Based on AEO 2012)

	2015	2020	2025	2030	2035	2040
Electricity	1.042	1.041	1.040	1.040	1.041	1.041
Natural Gas	1.102	1.103	1.100	1.099	1.098	1.097
Petroleum Fuels	1.142	1.146	1.153	1.163	1.172	1.181

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APPENDIX 10-C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

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APPENDIX 10-C. NATIONAL NET PRESENT VALUE OF CONSUMER BENEFITS USING ALTERNATIVE PRODUCT PRICE FORECASTS

10-C.1 INTRODUCTION

DOE used a constant price assumption for the default forecast in the NIA described in Chapter 10. In order to investigate the impact of different product price forecasts on the consumer net present value (NPV) for the considered TSLs for furnace fans, DOE also considered two alternative price trends for a sensitivity analysis. This appendix describes the alternative price trends and compares NPV results for these scenarios with the default forecast.

In recent rulemakings for several residential products, DOE has used the experience curve method to derive learning rates to forecast future prices. In the experience curve method, the real cost of production is related to the cumulative production, or experience, with a manufactured product. That experience usually is measured in terms of cumulative production. As experience (production) accumulates, the cost of producing the next unit decreases. The percentage reduction in cost that occurs with each doubling of cumulative production is known as the learning rate. A recent report from Lawrence Berkeley National Laboratory by Taylor and Fujita provides an overview of some of the major findings of the academic literature on learning curves, and describes the application of a component-based learning curve approach (by the Environmental Protection Agency and the National Highway Transportation Safety Administration) and a price-based learning curve approach (by DOE) in regulatory impact assessment.[1]

For some commercial and industrial products, there are insufficient data to apply a price-based learning curve approach, particularly with respect to cumulative production. In such cases, DOE used a constant price assumption for the default forecast in the NIA, but made use of price indexes that are relevant for the product in question to derive alternative price trends for sensitivity analysis.[a] Because DOE is using motor price trends as a proxy for furnace fan price trends, this approach was used for furnace fans.

10-C.2 ALTERNATIVE FURNACE FAN PRICE TREND SCENARIOS

DOE considered two alternative price trends for a sensitivity analysis. One that assumes decreasing prices used an exponential fit on the deflated price index for fractional horsepower motor manufacturing during the period of 1989 to 2004. The other assumes rising prices and is based on the same deflated price index between 2004 and 2012.

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[a] See appendix 10C of the final rule TSD for distribution transformers. http://www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0048-0760

10-C.2.1 Decreasing Price Scenario – Exponential Fit Approach

For the decreasing price scenario, DOE used an inflation-adjusted fractional horsepower motor manufacturing Producer Price Index (PPI) spanning the time period of 1989-2004 from the Bureau of Labor Statistics' (BLS) to fit an exponential model with *year* as the explanatory variable.[b] The PPI during this period of time showed a continuing downward trend, so the exponential fit based on this part of the historical PPI represents the decreasing price scenario of future price projection.

The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for fractional horsepower motors manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index. The deflated price index is presented in 2012 dollar values. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where Y is the motor price index, X is the time variable, *a* is the constant and *b* is the slope parameter of the time variable.

To estimate these exponential parameters, a least-square fit was performed on the inflation-adjusted motor price index versus *year* from 1989 to 2004. See Figure 10-C.2.1.

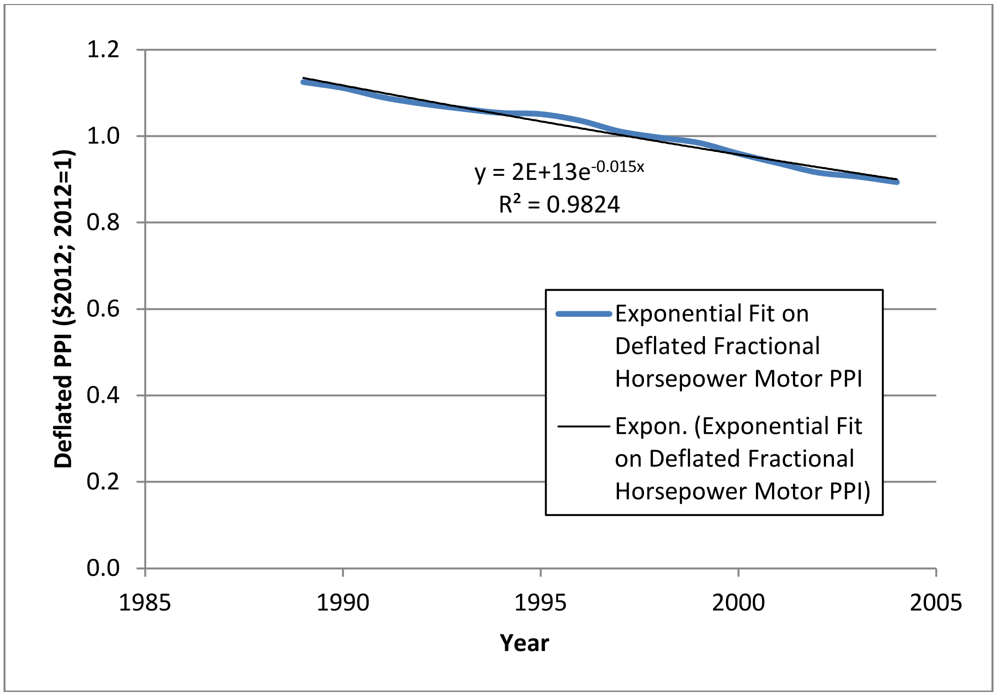

Figure 10-C.2.1 Deflated Fractional Horsepower Motors PPI versus Year, with Exponential Fit from 1989 to 2004

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[b] Series ID PCU 3353123353121; http://www.bls.gov/ppi/

The regression performed as an exponential trend line fit results in an R-square of 0.98, which indicates a very good fit to the data. The final estimated exponential function is:

$$Y = 2.50 \times 10^{13} \cdot e^{(-0.0154)X}$$

DOE then derived a price factor index for this scenario, renormalized with 2011 equal to 1, to project prices in each future year in the analysis period considered in the NIA. The index value in a given year is a function of the exponential parameter and *year*.

10-C.2.2 Increasing Price Scenario – Exponential Fit Approach

A similar approach was applied for the increasing price scenario. DOE used an inflation-adjusted fractional horsepower motor manufacturing Producer Price Index (PPI) spanning the time period of 2004-2012 from the Bureau of Labor Statistics' (BLS) to fit an exponential model with *year* as the explanatory variable. The PPI during this period of time shows a continuing upward trend, so the exponential fit based on this part of the historical PPI represents the increasing price scenario of future price projection. The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for fractional horsepower motors manufacturing was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index. The deflated price index is presented in 2012 dollar values. In this case, the exponential function takes the form of:

$$Y = a \cdot e^{bX}$$

where Y is the motor price index, X is the time variable, *a* is the constant and *b* is the slope parameter of the time variable.

To estimate these exponential parameters, a least-square fit was performed on the inflation-adjusted motor price index versus *year* from 2004 to 2012. See Figure 10-C.2.2.

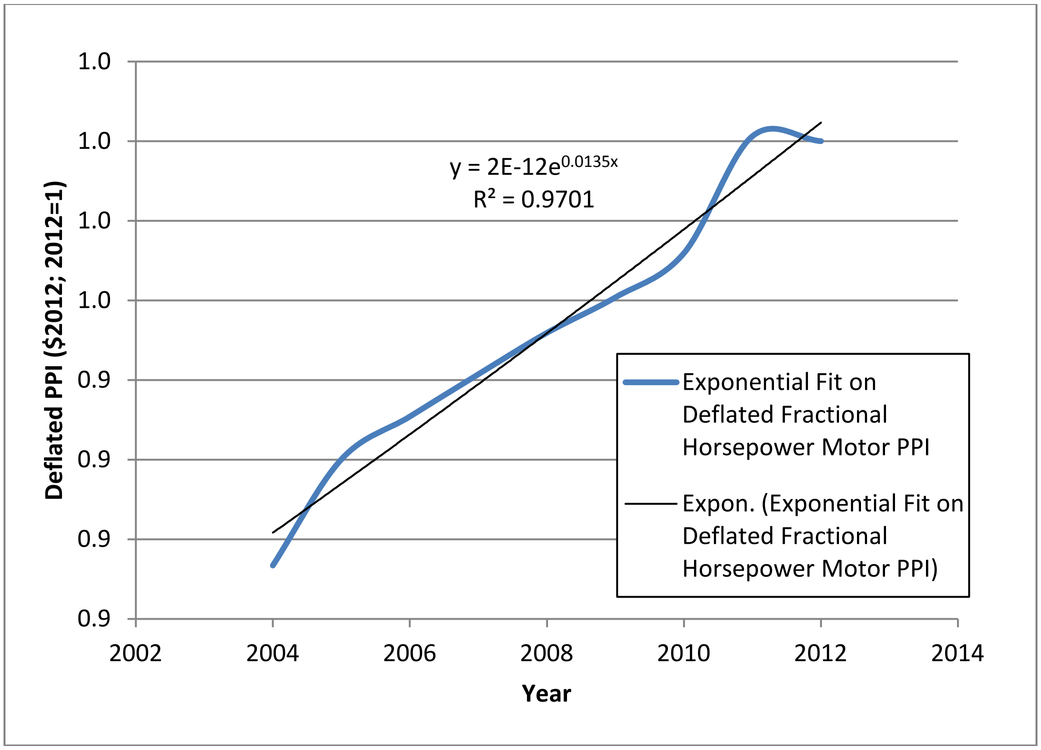

Figure 10-C.2.2 Deflated Fractional Horsepower Motors PPI versus Year, with Exponential Fit from 2004 to 2012

The regression performed as an exponential trend line fit results in an R-square of 0.97. The final estimated exponential function is:

$$Y = 1.53 \times 10^{(-12)} \cdot e^{0.0135X}$$

DOE then derived a price factor index for this scenario, renormalized with 2011 equal to 1, to project prices in each future year in the analysis period considered in the NIA. The index value in a given year is a function of the exponential parameter and *year*.

10-C.2.3 Summary

Table 10-C.2.1 shows the summary of the average annual rates of change for the product price index in each scenario. Figure 10-C.2.3 shows the resulting price trends.

Table 10-C.2.1 Price Trend Sensitivities

Sensitivity	Price Trend	Average Annual Rate of Change %
Medium (Default)	Constant Price Projection	0.0
Decreasing Price Scenario	Exponential Fit using data from 1989 to 2004	-1.53
Increasing Price Scenario	Exponential Fit using data from 2004 to 2012	1.36

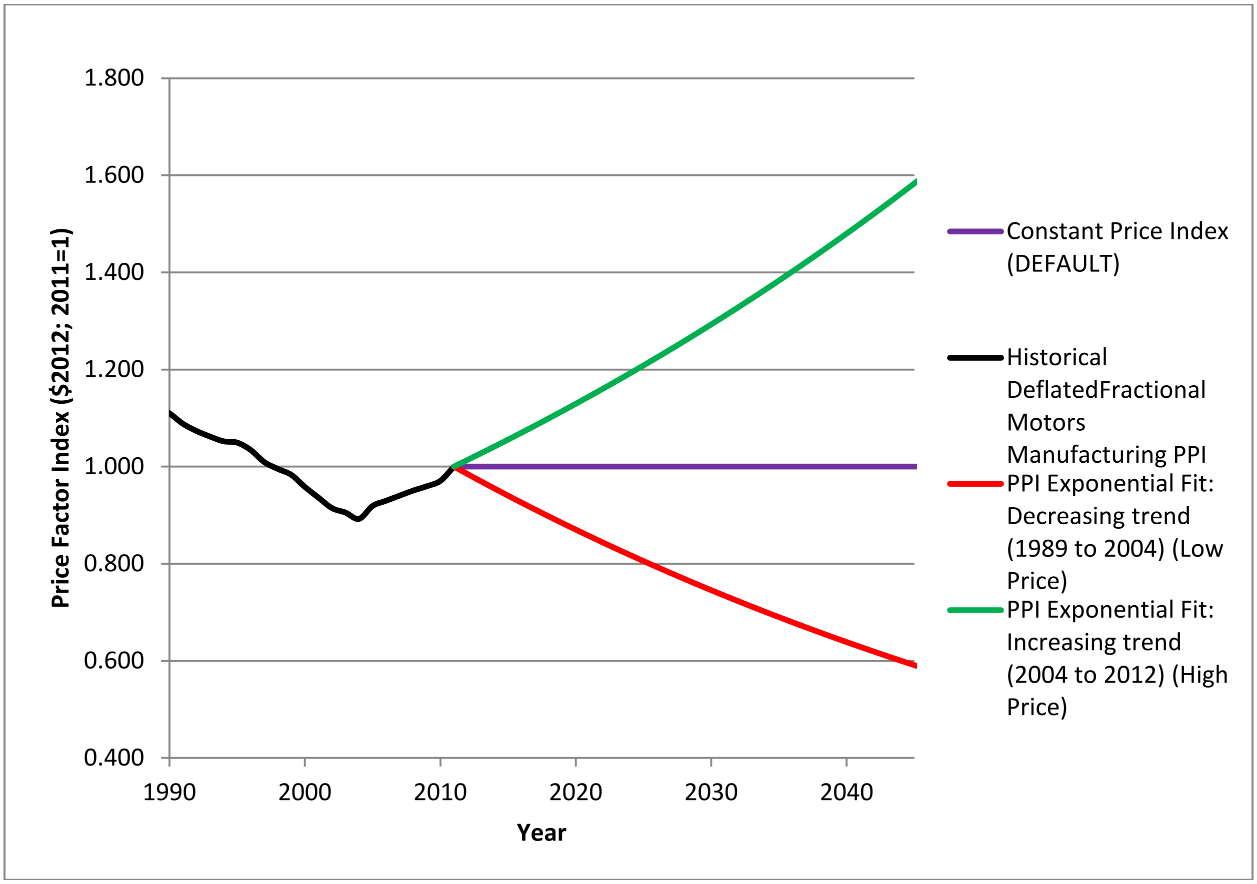

Figure 10-C.2.3 Furnace Fan Price Forecast Indexes

10-C.3 NET PRESENT VALUE RESULTS USING ALTERNATIVE PRODUCT PRICE TRENDS

This section presents the NPV results using the alternative product price forecast for each key product class. For non-weatherized gas furnace fans, it also compares the NPV using the default product price forecast with the NPV using the alternative product price forecasts. The results are only slightly sensitive to the alternative product price forecasts.

Table 10-C.3.1 NPV Using Reference Product Price Forecast, Discounted at 3 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	1.46	9.86	9.86	11.09	11.09	8.28
Non-weatherized, Condensing Gas Furnace Fan	1.49	11.16	11.16	12.23	12.23	9.20
Weatherized Gas Furnace Fan	0.17	1.12	1.12	1.30	1.30	0.49
Oil Furnace Fan	0.02	0.02	0.19	0.02	0.19	0.10
Electric Furnace / Modular Blower Fan	0.15	1.05	1.05	1.29	1.29	0.12
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.04	0.04	0.25	0.04	0.25	-0.06
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.01	0.01	0.05	0.01	0.05	-0.02
Manufactured Home Electric Furnace / Modular Blower Fan	0.03	0.03	0.13	0.17	0.17	-0.17
Total – All Classes	3.368	23.296	23.813	26.155	26.571	17.949

Table 10-C.3.2 NPV Using Reference Product Price Forecast, Discounted at 7 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	0.53	3.52	3.52	3.71	3.71	1.98
Non-weatherized, Condensing Gas Furnace Fan	0.51	3.78	3.78	3.91	3.91	2.11
Weatherized Gas Furnace Fan	0.06	0.39	0.39	0.41	0.41	-0.01
Oil Furnace Fan	0.01	0.01	0.07	0.01	0.07	0.01
Electric Furnace / Modular Blower Fan	0.05	0.33	0.33	0.40	0.40	-0.20
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.02	0.02	0.08	0.02	0.08	-0.09
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.00	0.00	0.02	0.00	0.02	-0.02
Manufactured Home Electric Furnace / Modular Blower Fan	0.01	0.01	0.04	0.05	0.05	-0.13
Total – All Classes	1.190	8.070	8.234	8.507	8.643	3.651

Table 10-C.3.3 NPV Using Alternative Product Price Forecast (Decreasing Trend), Discounted at 3 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	1.47	5.56	10.02	11.48	8.18	9.24
Non-weatherized, Condensing Gas Furnace Fan	1.50	6.29	11.34	12.69	8.72	10.51
Weatherized Gas Furnace Fan	0.17	0.54	1.14	1.36	0.47	0.69
Oil Furnace Fan	0.02	0.14	0.20	0.20	0.12	0.12
Electric Furnace / Modular Blower Fan	0.15	0.62	1.09	1.35	0.33	0.36
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.05	0.17	0.26	0.23	0.02	0.01
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.01	0.04	0.06	0.05	0.00	0.00
Manufactured Home Electric Furnace / Modular Blower Fan	0.03	0.05	0.14	0.19	-0.09	-0.11
Total – All Classes	3.402	13.415	24.241	27.547	17.745	20.825

Table 10-C.3.4 NPV Using Alternative Product Price Forecast (Decreasing Trend), Discounted at 7 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	0.53	1.93	3.59	3.88	2.14	2.40
Non-weatherized, Condensing Gas Furnace Fan	0.52	2.07	3.86	4.10	2.18	2.64
Weatherized Gas Furnace Fan	0.06	0.18	0.40	0.44	0.03	0.08
Oil Furnace Fan	0.01	0.05	0.07	0.06	0.02	0.02
Electric Furnace / Modular Blower Fan	0.05	0.18	0.35	0.42	-0.06	-0.10
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.02	0.05	0.09	0.06	-0.05	-0.06
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.00	0.01	0.02	0.01	-0.01	-0.02
Manufactured Home Electric Furnace / Modular Blower Fan	0.01	0.01	0.04	0.05	-0.08	-0.10
Total – All Classes	1.205	4.490	8.418	9.033	4.151	4.863

Table 10-C.3.5 NPV Using Alternative Product Price Forecast (Increasing Trend), Discounted at 3 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	1.44	5.30	9.69	10.67	6.40	7.21
Non-weatherized, Condensing Gas Furnace Fan	1.47	5.97	10.95	11.70	6.36	7.71
Weatherized Gas Furnace Fan	0.17	0.51	1.09	1.22	0.12	0.27
Oil Furnace Fan	0.02	0.13	0.19	0.18	0.07	0.07
Electric Furnace / Modular Blower Fan	0.14	0.53	1.00	1.22	-0.08	-0.15
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.04	0.15	0.23	0.17	-0.11	-0.13
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.01	0.03	0.05	0.04	-0.04	-0.04
Manufactured Home Electric Furnace / Modular Blower Fan	0.03	0.03	0.12	0.16	-0.18	-0.23
Total – All Classes	3.330	12.644	23.334	25.354	12.532	14.703

Table 10-C.3.6 NPV Using Alternative Product Price Forecast (Increasing Trend), Discounted at 7 Percent, for Furnace Fans (billion 2012$)

Key Product Class	Trial Standard Level					
	1	2	3	4	5	6
Non-weatherized, Non-condensing Gas Furnace Fan	0.52	1.82	3.45	3.53	1.37	1.53
Non-weatherized, Condensing Gas Furnace Fan	0.51	1.94	3.70	3.70	1.23	1.51
Weatherized Gas Furnace Fan	0.06	0.17	0.38	0.38	-0.12	-0.10
Oil Furnace Fan	0.01	0.04	0.06	0.06	0.00	0.00
Electric Furnace / Modular Blower Fan	0.05	0.14	0.32	0.37	-0.23	-0.30
Manufactured Home Non-weatherized, Non-condensing Gas Furnace Fan	0.02	0.04	0.07	0.03	-0.11	-0.12
Manufactured Home Non-weatherized, Condensing Gas Furnace Fan	0.00	0.01	0.02	0.01	-0.03	-0.03
Manufactured Home Electric Furnace / Modular Blower Fan	0.01	0.00	0.03	0.04	-0.12	-0.15
Total – All Classes	1.175	4.166	8.036	8.116	1.985	2.325

Table 10-C.3.7 Comparison of Total NPV across All Product Classes for Alternative Product Price Forecast

		Trial Standard Level					
		1	**2**	**3**	**4**	**5**	**6**
		billion 2012$					
Reference Case	NPV 3%	3.368	23.296	23.813	26.155	26.571	17.949
	NPV 7%	1.190	8.070	8.234	8.507	8.643	3.651
Decreasing Price Trend	NPV 3%	3.402	13.415	24.241	27.547	17.745	20.825
	NPV 7%	1.205	4.490	8.418	9.033	4.151	4.863
Increasing Price Trend	NPV 3%	3.330	12.644	23.334	25.354	12.532	14.703
	NPV 7%	1.175	4.166	8.036	8.116	1.985	2.325

APPENDIX 10-D. NATIONAL IMPACT ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR FURNACE FANS

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APPENDIX 10-D. NATIONAL IMPACT ANALYSIS USING ALTERNATIVE ECONOMIC GROWTH SCENARIOS FOR FURNACE FANS

10-D.1 INTRODUCTION

This appendix presents National Impact Analysis (NIA) results using energy price forecasts from alternative economic growth scenarios. The scenarios are based on the High Economic Growth case and the Low Economic Growth case from Energy Information Administration's (EIA's) *Annual Energy Outlook 2012* (*AEO2012*).[1] To estimate energy prices after 2035 in the high and low scenarios, DOE used the growth rate between 2020 and 2035. See appendix 8-C for details about alternative economic growth scenarios.

This appendix also describes the High and Low Economic Growth scenarios in further detail. See appendix 10-A for details about how to generate NIA results for High Economic Growth and Low Economic Growth scenarios using the NIA spreadsheet.

10-D.2 DESCRIPTION OF HIGH AND LOW ECONOMIC SCENARIOS

To generate NIA results reported in chapter 10, DOE uses the Reference case energy price and housing projections from *AEO2012*. The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. For *AEO2012*, EIA explored the impacts of alternative assumptions in other scenarios with different macroeconomic growth rates, world oil prices, rates of technology progress, and policy changes.

To reflect uncertainty in the projection of U.S. economic growth, EIA's *AEO2012* uses High and Low Economic Growth scenarios to project the possible impacts of alternative economic growth assumptions on energy markets.[2]

Energy prices are higher in the High Economic Growth scenario and lower in the Low Economic Growth scenario, except for electricity prices for the period between 2012 and 2027. See appendix 8-G for details about the effect of these alternative economic scenarios on energy prices.

Since *AEO 2012* provides the price trends by census division, each sampled household is then matched to the appropriate census division price trend. See chapter 10 for details about how energy price trends by census division are applied in the NIA analysis.

In addition, the High and Low Economic Growth scenarios provide different housing starts projections that affect the furnace shipments projections. Figure 10-D.2.1 shows the shipments projections based on the different *AEO 2012* scenarios.

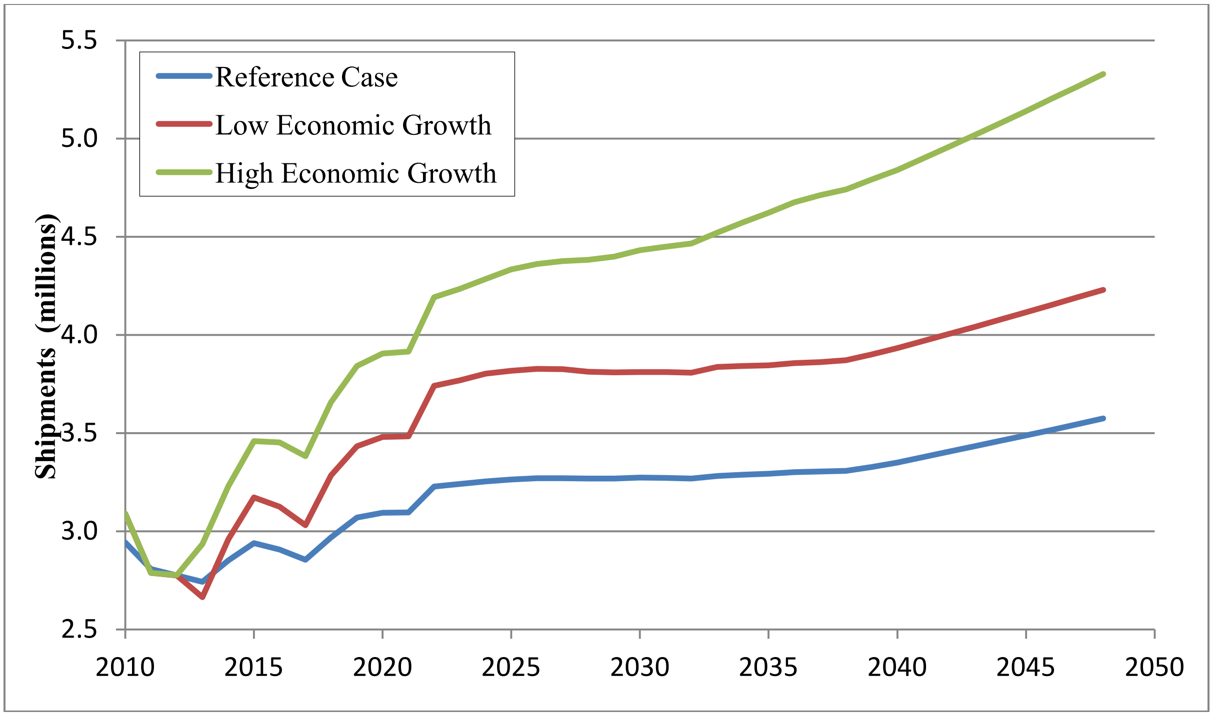

Figure 10-D.2.1 Shipment Projections for Reference Case and High and Low Economic Growth Scenarios (Base Case)

10-D.3 RESULTS

10-D.3.1 National Energy Savings

Table 10-D.2.1 and Table 10-D.2.2 show the national energy savings (NES) results for each of the Trial Standard Levels (TSLs) analyzed for furnace fans using the High Economic Growth and Low Economic Growth scenarios.

Table 10-D.3.1 Primary National Energy Savings (Quads) – Reference Case

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.254	1.021	1.021	1.861	1.861	2.404
Non-weatherized, Condensing Gas Furnace Fan	0.276	0.877	0.877	2.003	2.003	2.793
Weatherized Gas Furnace Fan	0.032	0.138	0.138	0.264	0.264	0.338
Non-weatherized Oil Non-Condensing Furnace Fan	0.005	0.005	0.025	0.005	0.025	0.051
Non-weatherized Electric Furnace/Modular Blower Fan	0.042	0.202	0.202	0.357	0.357	0.451
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.010	0.010	0.039	0.010	0.039	0.089
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.002	0.002	0.008	0.002	0.008	0.022
Manufactured Home Electric Furnace/Modular Blower Fan	0.009	0.009	0.034	0.060	0.060	0.073
Total – All Classes	0.631	2.265	2.344	4.562	4.617	6.221

Table 10-D.3.2 Primary National Energy Savings (Quads) – High Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.332	1.316	1.316	2.392	2.392	3.085
Non-weatherized, Condensing Gas Furnace Fan	0.332	1.037	1.037	2.349	2.349	3.246
Weatherized Gas Furnace Fan	0.042	0.178	0.178	0.334	0.334	0.421
Non-weatherized Oil Non-Condensing Furnace Fan	0.006	0.006	0.031	0.006	0.031	0.062
Non-weatherized Electric Furnace/Modular Blower Fan	0.053	0.246	0.246	0.436	0.436	0.549
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.015	0.015	0.056	0.015	0.056	0.125
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.003	0.003	0.010	0.003	0.010	0.028
Manufactured Home Electric Furnace/Modular Blower Fan	0.016	0.016	0.058	0.101	0.101	0.121
Total – All Classes	0.800	2.818	2.932	5.636	5.709	7.637

Table 10-D.3.3 Primary National Energy Savings (Quads) – Low Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.198	0.812	0.812	1.486	1.486	1.925
Non-weatherized, Condensing Gas Furnace Fan	0.234	0.756	0.756	1.739	1.739	2.446
Weatherized Gas Furnace Fan	0.024	0.107	0.107	0.212	0.212	0.277
Non-weatherized Oil Non-Condensing Furnace Fan	0.004	0.004	0.021	0.004	0.021	0.043
Non-weatherized Electric Furnace/Modular Blower Fan	0.034	0.169	0.169	0.297	0.297	0.377
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.009	0.009	0.034	0.009	0.034	0.076
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.002	0.002	0.007	0.002	0.007	0.020
Manufactured Home Electric Furnace/Modular Blower Fan	0.007	0.007	0.026	0.045	0.045	0.055
Total – All Classes	0.512	1.866	1.931	3.794	3.840	5.220

10-D.3.2 Net Present Value of Consumer Impacts

Table 10-D.2.3 through Table 10-D.2.6 show the national present value (NPV) results for each of the TSLs analyzed for furnace fans using the High Economic Growth and Low Economic Growth scenarios. A negative NPV indicates that the costs of a standard at a given efficiency level exceed the savings.

Table 10-D.3.4 Net Present Value, Discounted at 3 Percent (Billion 2012$) – Reference Case

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	1.457	9.864	9.864	11.093	11.093	8.278
Non-weatherized, Condensing Gas Furnace Fan	1.485	11.159	11.159	12.226	12.226	9.204
Weatherized Gas Furnace Fan	0.171	1.116	1.116	1.296	1.296	0.492
Non-weatherized Oil Non-Condensing Furnace Fan	0.024	0.024	0.191	0.024	0.191	0.098
Non-weatherized Electric Furnace/Modular Blower Fan	0.146	1.048	1.048	1.290	1.290	0.121
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.044	0.044	0.248	0.044	0.248	-0.056
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.009	0.009	0.054	0.009	0.054	-0.021
Manufactured Home Electric Furnace/Modular Blower Fan	0.032	0.032	0.133	0.173	0.173	-0.168
Total – All Classes	3.368	23.296	23.813	26.155	26.571	17.949

Table 10-D.3.5 Net Present Value, Discounted at 7 Percent (Billion 2012$) – Reference Case

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.529	3.520	3.520	3.713	3.713	1.982
Non-weatherized, Condensing Gas Furnace Fan	0.514	3.785	3.785	3.908	3.908	2.108
Weatherized Gas Furnace Fan	0.062	0.393	0.393	0.413	0.413	-0.009
Non-weatherized Oil Non-Condensing Furnace Fan	0.008	0.008	0.066	0.008	0.066	0.007
Non-weatherized Electric Furnace/Modular Blower Fan	0.048	0.334	0.334	0.398	0.398	-0.195
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.015	0.015	0.080	0.015	0.080	-0.091
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.003	0.003	0.017	0.003	0.017	-0.024
Manufactured Home Electric Furnace/Modular Blower Fan	0.011	0.011	0.038	0.047	0.047	-0.127
Total – All Classes	1.190	8.070	8.234	8.507	8.643	3.651

Table 10-D.3.6 Net Present Value, Discounted at 3 Percent (Billion 2012$) – High Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	1.999	13.543	13.543	15.890	15.890	14.110
Non-weatherized, Condensing Gas Furnace Fan	1.867	13.816	13.816	15.579	15.579	13.266
Weatherized Gas Furnace Fan	0.237	1.554	1.554	1.890	1.890	1.191
Non-weatherized Oil Non-Condensing Furnace Fan	0.031	0.031	0.244	0.031	0.244	0.180
Non-weatherized Electric Furnace/Modular Blower Fan	0.192	1.372	1.372	1.700	1.700	0.651
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.069	0.069	0.397	0.069	0.397	0.164
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.014	0.014	0.080	0.014	0.080	0.019
Manufactured Home Electric Furnace/Modular Blower Fan	0.062	0.062	0.288	0.386	0.386	0.062
Total – All Classes	4.471	30.461	31.295	35.558	36.166	29.643

Table 10-D.3.7 Net Present Value, Discounted at 7 Percent (Billion 2012$) – High Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.711	4.766	4.766	5.364	5.364	4.071
Non-weatherized, Condensing Gas Furnace Fan	0.639	4.654	4.654	5.022	5.022	3.504
Weatherized Gas Furnace Fan	0.084	0.542	0.542	0.616	0.616	0.243
Non-weatherized Oil Non-Condensing Furnace Fan	0.011	0.011	0.084	0.011	0.084	0.037
Non-weatherized Electric Furnace/Modular Blower Fan	0.063	0.441	0.441	0.535	0.535	0.005
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.024	0.024	0.131	0.024	0.131	-0.011
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.005	0.005	0.026	0.005	0.026	-0.009
Manufactured Home Electric Furnace/Modular Blower Fan	0.021	0.021	0.091	0.120	0.120	-0.040
Total – All Classes	1.557	10.464	10.736	11.696	11.898	7.799

Table 10-D.3.8 Net Present Value, Discounted at 3 Percent (Billion 2012$) – Low Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	1.071	7.197	7.197	7.478	7.478	3.502
Non-weatherized, Condensing Gas Furnace Fan	1.159	8.796	8.796	9.174	9.174	5.330
Weatherized Gas Furnace Fan	0.122	0.786	0.786	0.830	0.830	-0.110
Non-weatherized Oil Non-Condensing Furnace Fan	0.017	0.017	0.136	0.017	0.136	0.007
Non-weatherized Electric Furnace/Modular Blower Fan	0.109	0.779	0.779	0.944	0.944	-0.414
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.031	0.031	0.156	0.031	0.156	-0.275
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.007	0.007	0.038	0.007	0.038	-0.062
Manufactured Home Electric Furnace/Modular Blower Fan	0.017	0.017	0.042	0.047	0.047	-0.420
Total – All Classes	2.533	17.628	17.929	18.526	18.802	7.559

Table 10-D.3.9 Net Present Value, Discounted at 7 Percent (Billion 2012$) – Low Economic Growth

Product Classes	Trial Standard Levels					
	1	2	3	4	5	6
Non-Weatherized, Non-Condensing Gas Furnace Fan	0.393	2.570	2.570	2.388	2.388	0.130
Non-weatherized, Condensing Gas Furnace Fan	0.407	3.003	3.003	2.878	2.878	0.745
Weatherized Gas Furnace Fan	0.044	0.276	0.276	0.243	0.243	-0.243
Non-weatherized Oil Non-Condensing Furnace Fan	0.006	0.006	0.048	0.006	0.048	-0.027
Non-weatherized Electric Furnace/Modular Blower Fan	0.035	0.240	0.240	0.276	0.276	-0.412
Manufactured Home Non-Weatherized Gas, Non-Condensing Furnace Fan	0.011	0.011	0.046	0.011	0.046	-0.183
Manufactured Home Non-Weatherized Gas, Condensing Furnace Fan	0.002	0.002	0.012	0.002	0.012	-0.040
Manufactured Home Electric Furnace/Modular Blower Fan	0.005	0.005	0.002	-0.003	-0.003	-0.240
Total – All Classes	0.904	6.112	6.195	5.801	5.888	-0.270

10-D.3.3 Summary

Table 10-D.3.7 shows the NES and NPV results for each of the TSL for the Reference case and the High Economic Growth and Low Economic Growth scenarios. NES and NPV results are larger for High Economic Growth scenario and smaller for Low Economic Growth scenario compared to Reference case.

Table 10-D.3.10 Comparison of Energy Savings and Net Present Value Results for Reference Case and High and Low Economic Growth Scenarios

		Trial Standard Level					
		1	2	3	4	5	6
Reference	**Primary Energy Savings (quads)**	0.631	2.265	2.344	4.562	4.617	6.221
	NPV 3% (billion 2012$)	3.368	23.296	23.813	26.155	26.571	17.949
	NPV 7% (billion 2012$)	1.190	8.070	8.234	8.507	8.643	3.651
High Economic Growth	**Primary Energy Savings (quads)**	0.800	2.818	2.932	5.636	5.709	7.637
	NPV 3% (billion 2012$)	4.471	30.461	31.295	35.558	36.166	29.643
	NPV 7% (billion 2012$)	1.557	10.464	10.736	11.696	11.898	7.799
Low Economic Growth	**Primary Energy Savings (quads)**	0.512	1.866	1.931	3.794	3.840	5.220
	NPV 3% (billion 2012$)	2.533	17.628	17.929	18.526	18.802	7.559
	NPV 7% (billion 2012$)	0.904	6.112	6.195	5.801	5.888	-0.270

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 INTRODUCTION

The consumer subgroup analysis evaluates impacts on groups or customers who may be disproportionately affected by any national energy conservation standard. The U.S. Department of Energy (DOE) evaluates impacts on particular subgroups of consumers by analyzing the life-cycle cost (LCC) impacts and payback period (PBP) for those consumers from the considered energy efficiency levels. DOE determined the impact on consumer subgroups using the LCC spreadsheet models for furnace fans. Chapter 8 explains in detail the inputs to the models used in determining LCC impacts and PBPs.

DOE evaluated impacts on low-income households and households occupied solely by senior citizens (senior-only households). See appendix 8-A for details about how to generate LCC results for low-income and senior-only households using the LCC spreadsheet.

This chapter describes the subgroup identification in further detail and gives the results of the LCC and PBP analyses for the considered subgroups.

11.2 SUBGROUP DEFINITION

11.2.1 Senior-Only Households

Senior-only households have occupants who are all at least 65 years of age. Based on the Energy Information Administration's 2009 Residential Energy Consumption Survey (RECS 2009),[1] senior-only households comprise 17 percent of the country's households.

11.2.2 Low-Income Households

As defined in the RECS survey, low-income households are those at or below the "poverty line." The poverty line varies with household size, head of household age, and family income and in RECS encompasses a group of households with incomes below the poverty level in 2009 as defined by the U.S. Bureau of the Census.[2] The RECS survey classifies 15 percent of U.S. households as low-income.

11.2.3 Distribution of Subgroup Households with Furnace Fans

Table 11.2.1 shows the household sample sizes for each furnace fan product class, for the general population, for low-income, and for senior-only households.

Table 11.2.1 Subgroup Statistics for Furnace Fan Product Classes

Product Class	NWGFnc	NWGFc	WGF	OF	EF	MHGFnc	MHGFc	MHEF
National								
Projected Household. Weight in 2019	18.6	26.7	3.9	2.7	6.9	1.5	0.6	0.9
Number of RECS Household Records	4,839	4,839	3,690	293	1,849	156	156	149
Low Income								
Projected Household. Weight in 2019	1.8	2.4	0.3	0.2	1.2	0.3	0.2	0.2
Number of RECS Household Records	416	416	257	18	303	33	33	36
Fraction of National Household Weight	10%	9%	8%	7%	17%	23%	24%	26%
Senior Only								
Projected Household. Weight in 2019	3.0	4.6	0.6	0.5	0.8	0.3	0.1	0.1
Number of RECS Household Records	766	766	595	51	214	30	30	17
Fraction of National Household Weight	16%	17%	16%	20%	12%	21%	22%	10%

Note: In the LCC analysis in chapter 8, the national sample is broken up into replacement and new construction samples. For the subgroup analysis, since the number of households is rather small for some of the subgroups, DOE chose to only use a single sample for replacement and new construction markets.

11.3 RESULTS

Table 11.3.1 and Table 11.3.2 summarize the LCC and PBP results for low-income and senior-only households. Table 11.3.3 compares average LCC savings for the consumer subgroups with those for all households. The low-income and senior households show lower LCC savings for more efficient furnaces than the general population (except for senior households in electric furnaces and manufactured home gas furnaces, non-condensing).

Table 11.3.1 LCC and PBP Results for Low-Income Households

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
						% of Households with			
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	Net Cost	No Impact	Net Benefit	
NWGFnc	Baseline	$312	$1,423	$1,735	$0	0%	100%	0%	---
	1	$324	$1,302	$1,626	$35	4%	68%	28%	2.1
	2	$372	$1,135	$1,507	$123	35%	25%	40%	6.3
	3	$379	$984	$1,363	$232	25%	25%	50%	3.8
	4	$460	$935	$1,395	$206	43%	14%	43%	7.8
	5	$617	$1,004	$1,620	$7	64%	12%	24%	17.2
	6	$651	$962	$1,614	$14	71%	0%	29%	16.5
NWGFc	Baseline	$313	$1,853	$2,166	$0	0%	100%	0%	---
	1	$325	$1,711	$2,036	$32	2%	75%	23%	2.2
	2	$372	$1,490	$1,862	$129	30%	41%	29%	6.6
	3	$378	$1,288	$1,666	$245	16%	41%	43%	4.0
	4	$461	$1,257	$1,718	$212	35%	34%	31%	8.5
	5	$622	$1,341	$1,962	$35	55%	29%	17%	18.3
	6	$656	$1,289	$1,946	$52	71%	0%	29%	16.4
WGF	Baseline	$298	$1,263	$1,561	$0	0%	100%	0%	---
	1	$310	$1,151	$1,461	$19	1%	81%	18%	1.9
	2	$356	$1,038	$1,394	$45	19%	56%	25%	7.5
	3	$362	$882	$1,244	$113	9%	56%	35%	3.9
	4	$440	$840	$1,280	$90	34%	33%	33%	9.5
	5	$591	$940	$1,531	-$95	59%	27%	13%	22.9
	6	$625	$906	$1,530	-$94	77%	0%	23%	17.7
OF	Baseline	$382	$1,911	$2,293	$0	0%	100%	0%	---
	1	$399	$1,797	$2,197	$28	13%	71%	16%	8.3
	2	$464	$1,492	$1,957	$194	52%	28%	20%	20.2
	3	$476	$1,409	$1,886	$246	52%	28%	20%	15.3
	4	$563	$1,357	$1,920	$220	57%	28%	15%	24.5
	5	$790	$1,381	$2,171	$37	62%	28%	10%	60.1
	6	$825	$1,346	$2,170	$37	85%	0%	15%	34.1
EF	Baseline	$231	$856	$1,087	$0	0%	100%	0%	---
	1	$241	$782	$1,024	$17	6%	73%	21%	2.7
	2	$285	$670	$954	$56	32%	37%	31%	8.3
	3	$282	$584	$867	$111	25%	37%	38%	3.9
	4	$302	$537	$839	$132	31%	25%	44%	4.5
	5	$434	$603	$1,037	-$17	56%	25%	19%	17.8
	6	$465	$580	$1,045	-$25	76%	0%	24%	17.6

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
MHGFnc	Baseline	$247	$1,059	$1,306	$0	0%	100%	0%	---
	1	$258	$988	$1,246	$26	16%	56%	29%	2.7
	2	$303	$886	$1,188	$84	67%	0%	33%	11.3
	3	$307	$831	$1,138	$135	60%	0%	40%	6.0
	4	$383	$811	$1,194	$78	70%	0%	30%	11.4
	5	$527	$865	$1,391	-$119	85%	0%	15%	23.4
	6	$559	$848	$1,408	-$135	85%	0%	15%	24.3
MHGFc	Baseline	$250	$1,164	$1,414	$0	0%	100%	0%	---
	1	$261	$1,088	$1,349	$20	11%	68%	22%	3.6
	2	$305	$959	$1,264	$78	48%	29%	23%	11.5
	3	$310	$900	$1,210	$117	42%	29%	28%	6.5
	4	$386	$886	$1,272	$58	75%	4%	21%	15.9
	5	$533	$929	$1,462	-$124	85%	4%	11%	37.4
	6	$565	$908	$1,473	-$136	88%	0%	12%	37.9
MHEF	Baseline	$185	$440	$625	$0	0%	100%	0%	---
	1	$194	$412	$607	$5	16%	71%	13%	3.3
	2	$235	$384	$619	-$3	50%	38%	12%	13.4
	3	$232	$368	$600	$10	45%	38%	17%	5.6
	4	$251	$365	$616	-$2	53%	26%	21%	6.6
	5	$371	$422	$794	-$135	68%	26%	7%	25.5
	6	$401	$418	$820	-$161	92%	0%	8%	26.3

Table 11.3.2 LCC and PBP Results for Senior Only Households

	Efficiency Level	Life-Cycle Cost (2012$)			Life-Cycle Cost Savings				Median Payback Period *years*
		Average Installed Cost	Average Discounted Operating Cost	Average LCC	Average Savings (2012$)	% of Households with			
						Net Cost	No Impact	Net Benefit	
NWGFnc	Baseline	$344	$1,865	$2,208	$0	0%	100%	0%	---
	1	$356	$1,701	$2,057	$47	2%	68%	29%	1.8
	2	$404	$1,451	$1,856	$200	31%	25%	44%	5.4
	3	$415	$1,249	$1,664	$344	21%	25%	54%	3.7
	4	$498	$1,169	$1,667	$343	39%	14%	47%	7.2
	5	$665	$1,229	$1,895	$142	60%	12%	28%	15.6
	6	$701	$1,172	$1,873	$164	66%	0%	34%	15.3
NWGFc	Baseline	$335	$2,172	$2,507	$0	0%	100%	0%	---
	1	$347	$1,998	$2,345	$41	1%	75%	24%	1.6
	2	$394	$1,724	$2,119	$173	26%	41%	33%	5.1
	3	$403	$1,481	$1,884	$313	12%	41%	47%	3.2
	4	$486	$1,416	$1,902	$301	28%	34%	38%	6.6
	5	$654	$1,499	$2,152	$121	50%	29%	21%	14.5
	6	$688	$1,434	$2,122	$151	63%	0%	37%	12.2
WGF	Baseline	$331	$1,726	$2,057	$0	0%	100%	0%	---
	1	$342	$1,571	$1,913	$28	1%	81%	18%	1.7
	2	$390	$1,374	$1,764	$89	16%	56%	27%	6.3
	3	$399	$1,159	$1,558	$182	9%	56%	35%	3.5
	4	$479	$1,082	$1,561	$180	30%	33%	36%	8.0
	5	$641	$1,186	$1,826	-$16	55%	27%	17%	20.3
	6	$675	$1,135	$1,810	$1	70%	0%	30%	16.7
OF	Baseline	$381	$2,225	$2,607	$0	0%	100%	0%	---
	1	$399	$2,107	$2,506	$30	10%	71%	20%	4.5
	2	$464	$1,809	$2,273	$197	47%	28%	25%	14.3
	3	$476	$1,710	$2,186	$260	43%	28%	29%	9.1
	4	$562	$1,675	$2,237	$223	51%	28%	21%	14.0
	5	$789	$1,722	$2,511	$24	62%	28%	10%	31.5
	6	$824	$1,688	$2,512	$23	83%	0%	17%	26.9
EF	Baseline	$244	$1,127	$1,371	$0	0%	100%	0%	---
	1	$254	$1,020	$1,275	$26	4%	73%	23%	2.0
	2	$298	$860	$1,158	$100	24%	37%	39%	5.7
	3	$297	$728	$1,025	$184	18%	37%	45%	2.9
	4	$318	$652	$970	$226	23%	25%	52%	3.3
	5	$454	$724	$1,178	$71	49%	25%	26%	12.0
	6	$486	$688	$1,173	$75	65%	0%	35%	12.8

	Efficiency Level	**Life-Cycle Cost (2012$)**			**Life-Cycle Cost Savings**				**Median Payback Period** *years*
		Average Installed Cost	**Average Discounted Operating Cost**	**Average LCC**	**Average Savings (2012$)**	**% of Households with**			
						Net Cost	**No Impact**	**Net Benefit**	
MHGFnc	Baseline	$255	$1,105	$1,359	$0	0%	100%	0%	---
	1	$265	$1,028	$1,294	$28	12%	56%	32%	3.5
	2	$310	$904	$1,215	$107	68%	0%	32%	11.4
	3	$315	$848	$1,163	$159	60%	0%	40%	7.7
	4	$392	$819	$1,211	$111	72%	0%	28%	14.9
	5	$540	$866	$1,406	-$84	85%	0%	15%	31.2
	6	$572	$847	$1,419	-$97	85%	0%	15%	31.3
MHGFc	Baseline	$261	$1,211	$1,472	$0	0%	100%	0%	---
	1	$272	$1,128	$1,400	$22	8%	68%	24%	3.6
	2	$316	$984	$1,301	$91	47%	29%	23%	14.0
	3	$321	$920	$1,242	$133	41%	29%	30%	7.3
	4	$399	$897	$1,296	$81	72%	4%	24%	18.0
	5	$550	$937	$1,487	-$102	85%	4%	11%	41.9
	6	$583	$913	$1,496	-$110	88%	0%	12%	39.5
MHEF	Baseline	$192	$598	$790	$0	0%	100%	0%	---
	1	$201	$551	$753	$11	12%	71%	17%	2.5
	2	$242	$501	$743	$18	41%	38%	21%	9.9
	3	$239	$459	$698	$49	34%	38%	28%	3.9
	4	$259	$430	$689	$55	40%	26%	34%	4.4
	5	$383	$493	$876	-$84	62%	26%	12%	16.6
	6	$413	$482	$894	-$103	85%	0%	15%	15.8

Table 11.3.3 Comparison of Average LCC Savings and Median Payback Period Results for Consumer Subgroups and All Households

	Efficiency Level	Average LCC Savings 2012$			Median Payback Period Years		
		Low-Income	Senior	All	Low-Income	Senior	All
NWGFnc	1	$35	$47	$64	2.1	1.8	1.3
	2	$123	$200	$253	6.3	5.4	4.0
	3	$232	$344	$442	3.8	3.7	2.7
	4	$206	$343	$474	7.8	7.2	5.4
	5	$7	$142	$275	17.2	15.6	11.5
	6	$14	$164	$313	16.5	15.3	11.2
NWGFc	1	$32	$41	$49	2.2	1.6	1.4
	2	$129	$173	$203	6.6	5.1	4.1
	3	$245	$313	$361	4.0	3.2	2.7
	4	$212	$301	$371	8.5	6.6	5.4
	5	$35	$121	$199	18.3	14.5	11.7
	6	$52	$151	$238	16.4	12.2	11.0
WGF	1	$19	$28	$35	1.9	1.7	1.3
	2	$45	$89	$104	7.5	6.3	4.9
	3	$113	$182	$228	3.9	3.5	2.7
	4	$90	$180	$247	9.5	8.0	6.4
	5	-$95	-$16	$39	22.9	20.3	15.5
	6	-$94	$1	$67	17.7	16.7	13.3
OF	1	$28	$30	$40	8.3	4.5	5.5
	2	$194	$197	$245	20.2	14.3	12.3
	3	$246	$260	$344	15.3	9.1	7.0
	4	$220	$223	$326	24.5	14.0	12.1
	5	$37	$24	$120	60.1	31.5	27.5
	6	$37	$23	$132	34.1	26.9	25.4
EF	1	$17	$26	$21	2.7	2.0	2.4
	2	$56	$100	$84	8.3	5.7	6.2
	3	$111	$184	$160	3.9	2.9	3.2
	4	$132	$226	$185	4.5	3.3	3.5
	5	-$17	$71	$18	17.8	12.0	12.8
	6	-$25	$75	$17	17.6	12.8	13.4

	Efficiency Level	**Average LCC Savings** ***2012$***			**Median Payback Period** ***Years***		
		Low-Income	**Senior**	**All**	**Low-Income**	**Senior**	**All**
MHGFnc	1	$26	$28	$26	2.7	3.5	3.3
	2	$84	$107	$97	11.3	11.4	10.7
	3	$135	$159	$146	6.0	7.7	7.0
	4	$78	$111	$95	11.4	14.9	13.1
	5	-$119	-$84	-$102	23.4	31.2	26.2
	6	-$135	-$97	-$116	24.3	31.3	26.7
MHGFc	1	$20	$22	$27	3.6	3.6	2.7
	2	$78	$91	$96	11.5	14.0	10.5
	3	$117	$133	$152	6.5	7.3	6.5
	4	$58	$81	$111	15.9	18.0	14.8
	5	-$124	-$102	-$82	37.4	41.9	34.3
	6	-$136	-$110	-$86	37.9	39.5	32.2
MHEF	1	$5	$11	$14	3.3	2.5	2.5
	2	-$3	$18	$20	13.4	9.9	10.0
	3	$10	$49	$64	5.6	3.9	4.3
	4	-$2	$55	$78	6.6	4.4	4.6
	5	-$135	-$84	-$70	25.5	16.6	16.8
	6	-$161	-$103	-$86	26.3	15.8	17.1

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

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CHAPTER 12. MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE or the Department) is required to consider the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard. (42 U.S.C. 6313(a)(6)(B)(i)) The law also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id*. DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of new energy conservation standards on manufacturers of residential furnace fans, and assessed the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted for each product in this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM's key output is the industry net present value (INPV). The model estimates the financial impact of more-stringent energy conservation standards for each product by comparing changes in INPV between a base-case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, and market and product trends, as well as the impact of standards on subgroups of manufacturers.

12.2 METHODOLOGY

For this rulemaking, DOE considers the "furnace fan industry" to consist of manufacturers who assemble furnace fans as a component of their HVAC products.

DOE conducted the MIA in three phases. Phase I, "Industry Profile," consisted of preparing an industry characterization for the furnace fans industry, including data on sales volumes, pricing, employment, and financial structure. In Phase II, "Industry Cash Flow," DOE used the GRIM to assess the potential impacts of new energy conservation standards on manufacturers. DOE also developed interview guides to gather information on the potential impacts on these manufacturers. In Phase III, "Subgroup Impact Analysis," DOE interviewed manufacturers representing a broad cross-section of the residential furnace fans industry. Using information from Phase II, DOE refined its analysis in the GRIM, developed additional analyses for subgroups that required special consideration, and incorporated qualitative data from interviews into its analysis.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared a profile of the residential furnace fans industry that built on the market and technology assessment prepared for this rulemaking (refer to chapter 3 of the technical support document (TSD)). Before initiating the detailed impact studies, DOE collected information on the present and past structure and market characteristics of the residential furnace fans industry. This information included shipments, manufacturer markups, and the cost structures of various manufacturers. The industry profile includes: (1) further detail on the overall market and product characteristics; (2) estimated manufacturer market shares; (3) financial parameters such as net plant, property, and equipment (PPE); selling, general and administrative (SG&A) expenses; cost of goods sold, etc.; and (4) trends in the number of firms, market, and product characteristics. The industry profile included a top-down cost analysis of residential furnace fan manufacturers that DOE used to derive the preliminary financial inputs for the GRIM (*e.g.*, revenues, depreciation, SG&A, and research and development (R&D) expenses).

DOE also used public information to further calibrate its initial characterization of the industry, including Securities and Exchange Commission (SEC) 10-K reports,[1] Standard & Poor's (S&P) stock reports,[2] market research tools (*i.e.*, Hoovers[3]), corporate annual reports, and the U.S. Census Bureau's 2011 Annual Survey of Manufacturers.[4] DOE also characterized these industries using information from its engineering analysis and the life-cycle cost analysis.

12.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of potential new energy conservation standards on manufacturers of residential furnace fans. More-stringent energy conservation standards can affect manufacturer cash flows in three distinct ways: (1) create a need for increased investment; (2) raise production costs per unit; and (3) alter revenue due to higher per-unit prices and/or possible changes in sales volumes. To quantify these impacts, DOE used the GRIM to perform a cash-flow analysis for the residential furnace fans industry. In performing these analyses, DOE used the financial values derived during Phase I and the shipment scenarios used in the national impact analysis (NIA). In Phase II, DOE performed these preliminary industry cash-flow analyses and prepared written guides for manufacturer interviews.

12.2.2.1 Industry Cash-Flow Analysis

The GRIM uses several factors to determine a series of annual cash flows from the announcement year of new energy conservation standards until 30 years after the standards' compliance date. These factors include annual expected revenues, costs of goods sold, SG&A, taxes, and capital expenditures related to the new standards. Inputs to the GRIM include manufacturer production costs (MPCs), markup assumptions, and shipments forecasts developed in other analyses. DOE derived the manufacturing costs from the engineering analysis and information provided by the industry. It estimated typical manufacturer markups from public financial reports and interviews with manufacturers. DOE developed alternative markup scenarios for each GRIM based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 9 of the TSD, provided the basis for the shipment projections in the GRIM. The financial parameters were developed using publicly available manufacturer data and were revised with information submitted confidentially during manufacturer interviews. The GRIM results are compared to base case projections for the industry. The financial impact of new energy conservation standards is the difference between the discounted annual cash flows in the base case and standards case at each TSL.

12.2.2.2 Interview Guides

During Phase II of the MIA, DOE interviewed manufacturers to gather information on the effects of new energy conservation standards on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed an interview guide to interviewees. The interview guide provided a starting point for identifying relevant issues and impacts of new energy conservation standards on individual manufacturers or subgroups of manufacturers. Most of the information received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. The MIA interview topics included: (1) key issues to this rulemaking; (2) company overview and organizational characteristics; (3) engineering analysis follow-up; (4) manufacturer markups and profitability; (5) shipment projections and market shares; (6) distribution channels; (7) financial parameters; (8) conversion costs; (9) cumulative regulatory burden; (10) direct employment impact assessment; (11) exports, foreign competition, and outsourcing; (12) consolidation; and (13) impacts on small businesses.

12.2.3 Phase III: Subgroup Analysis

For its analysis, DOE presented the impacts on all classes of residential furnace fan products as a whole. While conducting the MIA, DOE interviewed a representative cross-section of residential furnace fan manufacturers. The MIA interviews broadened the discussion to include business-related topics. DOE sought feedback from industry on the approaches used in the GRIM and as well as key issues and concerns. During interviews, DOE defined one manufacturer subgroup, small manufacturers, that could be disproportionately impacted by new energy conservation standards.

12.2.3.1 Manufacturer Interviews

The information gathered in Phase I and the cash-flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for interested parties to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process.

DOE used these interviews to tailor the GRIM to reflect financial characteristics unique to the residential furnace fan industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire was acceptable, DOE sought interactive interviews, which help clarify responses and identify additional issues. The resulting information provides valuable inputs to the GRIM developed for the product classes.

12.2.3.2 Revised Industry Cash-Flow Analysis

In Phase II of the MIA, DOE provided manufacturers with preliminary GRIM input financial figures for review and evaluation. During the interviews, DOE requested comments on the values it selected for the parameters. DOE revised its industry cash-flow model based on this feedback. Section 12.4.3 provides more information on how DOE calculated the parameters.

12.2.3.3 Manufacturer Subgroup Analysis

Using average cost assumptions to develop an industry cash-flow estimate may not adequately assess differential impacts of new energy conservation standards among manufacturer subgroups. For example, small manufacturers, niche players, or manufacturers exhibiting a cost structure that largely differs from the industry average could be more negatively affected. To address this possible impact, DOE used the results of the industry characterization analysis in Phase I to group manufacturers that exhibit similar characteristics.

During the interviews, DOE discussed the potential subgroups and subgroup members it identified for the analysis. DOE asked manufacturers and other interested parties to suggest what subgroups or characteristics are the most appropriate to analyze. As described in section 12.2.3, DOE presents the industry impacts on residential furnace fan manufacturers as a whole because most of the product classes represent the same market served by the same manufacturers. However, as discussed below, DOE identified one manufacturer subgroup that warranted a separate impact analysis: small manufacturers.

Small-Business Manufacturer Subgroup

DOE investigated whether small business manufacturers should be analyzed as a manufacturer subgroup. DOE used the Small Business Administration (SBA) small business size standards effective on November 5, 2010, as amended, and the North American Industry Classification System (NAICS) code, presented in Table 12.2.1, to determine whether any small entities would be affected by the rulemaking.[5] For the product classes under review, the SBA bases its small business definition on the total number of employees for a business, its subsidiaries, and its parent companies. An aggregated business entity with fewer employees than the listed limit is considered a small business.

Table 12.2.1 SBA and NAICS Classification of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Air−conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing	N/A	750	333415

DOE used publicly available and proprietary information to identify potential small manufacturers. DOE's research involved industry trade association membership directories (including American Heating and Refrigeration Institute (AHRI) and North American Association of Food Equipment Manufacturers (NAFEM)), product databases (*e.g.*, AHRI Directory, NSF International listings, the SBA Database), individual company websites, and market research tools (*e.g.*, Hoovers.com) to create a list of companies that manufacture or sell products covered by this rulemaking. DOE also asked stakeholders and industry representatives if they were aware of any other small manufacturers during manufacturer interviews and at previous DOE public meetings. DOE screened out companies that did not offer products covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

Based on this analysis, DOE identified 14 residential furnace fan manufacturers that are small businesses. DOE made an effort to contact small businesses to solicit feedback on the potential impacts of energy conservation standards. The businesses replied with varying amounts of information in written responses and/or interviews. In addition to posing a subset of modified MIA interview questions, DOE solicited data on differential impacts these companies might experience from new energy conservation standards. Based on these interviews and industry research, DOE reports the potential impacts of this rulemaking on small manufacturers in section 12.6.

12.2.3.4 Manufacturing Capacity Impact

One significant outcome of new energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guides have a series of questions to help identify impacts of new standards on manufacturing capacity, specifically, capacity utilization and plant location decisions in the United States and North America, with and without new standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing PPE. DOE's estimates of the one-time capital changes and stranded assets affect the cash flow estimates in the GRIM. These estimates can be found in section 12.4.8. DOE's discussion of the capacity impact can be found in section 12.7.2.

12.2.3.5 Employment Impact

The impact of new energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic direct employment patterns might be affected, the interviews explored current employment trends in the residential furnace fan industry. The interviews also solicited manufacturer views on changes in employment patterns that may result from more-stringent standards. The employment impacts section of the interview guide focused on current employment levels associated with manufacturers at each production facility, expected future employment levels with and without new energy conservation standards, and differences in workforce skills and issues related to the retraining of employees. The employment impacts are reported in section 12.7.1.

12.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to new energy conservation standards and other regulatory actions affecting the same products. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified regulations relevant to residential furnace fans, such as State regulations and other Federal regulations that impact other products made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 12.7.3.

12.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

Each MIA interview starts by asking: "What are the key issues for your company regarding the energy conservation standard rulemaking?" This question prompts manufacturers to identify the issues they feel DOE should explore and discuss further during the interview. The following sections describe the most significant issues identified by manufacturers. These summaries are provided in aggregate to protect manufacturer confidentiality.

12.3.1 Testing and Certification Burdens

All interviewed manufacturers expressed concerns about testing and certification burdens. In particular, manufacturers were concerned about the additional time required to test products for compliance with the new standard. Because the test procedure proposed in the May 2012 furnace fan test procedure NOPR is different from testing methods that are currently being used, manufacturers argued that a significant amount of time would need to be invested. 77 FR 28674. Some manufacturers suggested that the testing burden could be reduced if the testing for FER could be coordinated with testing for AFUE. In general, manufacturers were more concerned about the additional time and labor required to conduct the testing rather than the cost of testing equipment and stations, which were expected to be minimal.

12.3.2 Market Size

During interviews, manufacturers raised concerns about the potential of new furnace fan energy conservations standards for residential furnace fans to cause the furnace fan market to contract. Manufacturers claimed that an increase in overall product costs, resulting from component changes or increased test burden, would lead to a reduced volume of furnace sales. They stated that higher costs could drive consumers to purchase refurbished or repaired units instead of new products. Higher costs might also push consumers towards using alternative heating technologies (e.g., space heaters or radiant heat) which may be less efficient. One manufacturer also noted that the market for residential furnace fan products has already shrunk 6-7 percent and is expected to have slow growth over the next few years. Given that manufacturers expect slow or no growth in the near future for most of the product classes even without new energy conservation standards, the addition of new standards could lead to further market contraction.

12.3.3 Cumulative Regulatory Burden

DOE identified a number of cumulative regulations that may affect residential furnace fan manufacturers. Interviewed manufacturers mentioned the following regulations as potentially having an impact and contributing to burden: (1) DOE Energy Conservation Standards for Furnaces and Central Air Conditioners and Heat Pumps; (2) DOE's Certification, Compliance, and Enforcement rulemaking; (3) DOE's Alternative Efficiency Determination Methods and Alternate Rating Methods rulemaking; (4) EPA's phaseout of Hydrochlorofluorocarbons (HCFCs); (5) EPA's Energy Star program; (6) State regulations such as California Title 24; (7) the South Coast Air Quality Management District Rule 1111; (8) Canadian energy efficiency regulations; and (9) ASHRAE Standard 90.1. Some manufacturers indicated that the largest portion of their research and development budget goes toward meeting the various DOE standards. One manufacturer also recommended that DOE standards should be spread apart by at least five year periods so that manufacturers can allocate appropriate time to meet to standards and develop new products.

DOE also asked manufacturers under what circumstances they would be able to coordinate expenditures related to other regulations. Manufacturers emphasized the benefits of having fewer metrics to evaluate and limiting the scope of coverage for residential furnace fans to strictly those units housed in furnaces. In addition, manufacturers requested that DOE consider harmonizing with international standards to lessen the cumulative burden. Manufacturers also requested that the compliance date for some standards be pushed out to allow enough time for product development and limit stranded assets.

12.3.4 Consumer Confusion

In addition to the regulatory burden imposed by multiple standards, manufacturers were concerned with issues arising from multiple metrics that all apply to a single product. Furnaces alone already have energy efficiency rating metrics for AFUE and standby power, so with an additional FER metric, furnaces would be labeled with three different metrics. Manufacturers stated during interviews that three metrics are too many for a single product, and that consumers who use these rating metrics to evaluate and compare product performance may get confused if multiple metrics are labeled on one furnace. Manufacturers recommended that DOE should focus on the thermal performance of the furnace and not the fan energy consumption, which is a small fraction of a furnace's overall energy use.

12.3.5 Motors

Manufacturers questioned the use of X13 and ECM motors as a design option to improve efficiency. As these motors employ more complex controls and have higher maintenance costs than PSC motors, it was suggested that long-term reliability may be an issue. Manufacturers expect that the number of warranty claims, as well as warranty-associated costs, would increase if use of X13s and ECMs increased. X13s and ECMs are also more-expensive components that would increase the initial cost of the products in which they are used. Since these motors would increase product price but reduce reliability, manufacturers anticipate more consumers seeking to repair or refurbish existing products rather than purchase new ones. Furthermore, manufacturers may face challenges in obtaining a sufficient supply of motors due to the potential supply limitations of ECMs.

12.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to new energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without new energy conservation standards.

12.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 12.4.1, is an annual cash flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses a number of inputs to arrive at a series of annual cash flows, beginning with the base year of the analysis, 2013, and continuing to 2048. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.[6]

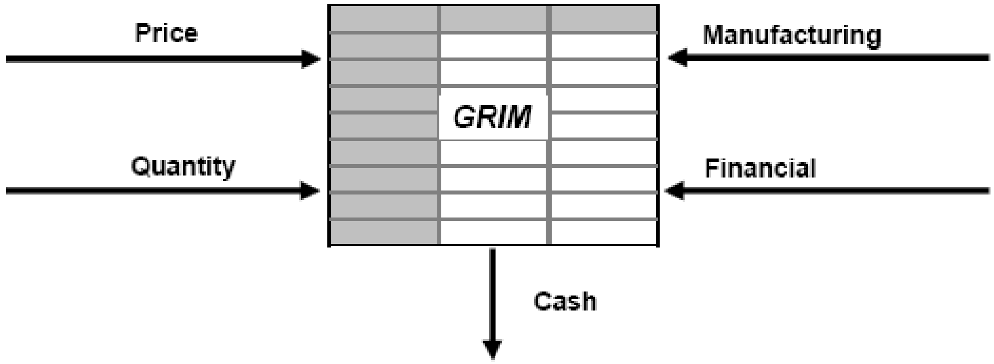

Figure 12.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base-case scenario and the standards-case scenario induced by new energy conservation standards. The difference in INPV between the base case and the standards case(s) represents the estimated financial impact of the new energy conservation standard on manufacturers. Appendix 12A provides more technical details and user information for the GRIM.

12.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, census data, credit ratings, the shipments model, the engineering analysis, and the manufacturer interviews.

12.4.2.1 Corporate Annual Reports

Corporate annual reports to the SEC (SEC 10-Ks) provided many of the initial financial inputs to the GRIM. These reports exist for publicly held companies and are freely available to the general public. DOE developed initial financial inputs to the GRIM by examining the annual SEC 10-K reports filed by publicly traded manufacturers of residential furnace fans. Since these companies do not provide detailed information about their individual product lines, DOE used the financial information for the entire companies as its initial estimates of the financial parameters in the GRIM analysis. These figures were later revised using feedback from interviews. DOE used corporate annual reports to derive the following initial inputs to the

GRIM:

- tax rate
- working capital
- SG&A
- R&D
- depreciation
- capital expenditures
- net PPE

12.4.2.2 Standard and Poor Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the cost of capital.

12.4.2.3 Shipment Model

The GRIM used shipment projections derived from DOE's shipments model in the NIA. Chapter 9 of the TSD describes the methodology and analytical model DOE used to forecast shipments.

12.4.2.4 Engineering Analysis

The engineering analysis establishes the relationship between manufacturer selling price (MSP) and energy efficiency for the products covered in this rulemaking. DOE adopted an efficiency-level approach in conjunction with a design option approach to identify incremental improvements in efficiency for each product class in its engineering analysis. The design option approach allowed DOE to model incremental improvements in efficiency for technologies that are currently not commercially available.

DOE also conducted a cost-assessment, which was based on reverse engineering data, to determine the manufacturing production costs (MPCs) at each efficiency level. DOE began this assessment by first conducting industry research to select product classes to directly analyze, developing baseline unit specifications, and selecting representative units with a range of efficiencies for analysis. To develop cost estimates, DOE conducted a price analysis, based upon physical teardowns of selected units, cost estimates from publicly available sources, and price quotes from manufacturers. DOE then developed a cost model to determine MPCs.

By applying derived manufacturer markups to the MPC, DOE calculated the MSP and constructed industry cost-efficiency curves. See chapter 5 of the TSD for a complete discussion of the engineering analysis.

12.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. DOE also interviewed manufacturers representing a significant portion of sales in every product class. During these discussions, DOE obtained information to determine and verify GRIM input assumptions in each industry. Key topics discussed during the interviews and reflected in the GRIM include:

- capital conversion costs (one-time investments in PPE);
- product conversion costs (one-time investments in research, product development, testing, and marketing);
- product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs;
- MPCs estimated in the engineering analysis; and
- profitability impacts.

12.4.3 Financial Parameters

Table 12.4.1 provides financial parameters for seven large companies engaged in manufacturing and selling furnace fan products. The values listed are averages over a 6-year period (2006 to 2011).

Table 12.4.1 GRIM Financial Parameters Based on 2006–2011 Weighted Company Financial Data

Parameter	Industry-Weighted Average	Manufacturers					
		A	B	C	D	E	F
Tax Rate (% of Taxable Income)	29.4%	28.0%	36.4%	33.8%	39.1%	17.8%	34.2%
Working Capital (% of Revenue)	11.6%	6.8%	21.6%	10.0%	13.7%	13.5%	19.1%
SG&A (% of Revenue)	15.1%	11.3%	18.5%	21.1%	20.2%	18.4%	12.0%
R&D (% of Revenues)	2.0%	3.2%	0.0%	1.4%	2.5%	1.6%	0.6%
Depreciation (% of Revenues)	2.1%	2.3%	2.3%	1.5%	3.5%	1.8%	1.5%
Capital Expenditures (% of Revenues)	1.6%	1.8%	1.5%	1.8%	1.3%	1.1%	1.3%

While most of these companies also manufacture products not covered by this rulemaking, DOE used these parameters as initial estimates. During interviews, manufacturers were asked to provide their own figures for the parameters listed in Table 12.4.1. Where applicable, DOE adjusted the parameters in the GRIM using manufacturer feedback and market share information.

12.4.4 Corporate Discount Rate

DOE used the weighted-average cost of capital (WACC) as the discount rate to calculate the INPV. A company's assets are financed by a combination of debt and equity. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the industry. DOE estimated the WACC for the residential furnace fans industry based on several representative companies, using the following formula:

WACC = After-Tax Cost of Debt x (Debt Ratio) + Cost of Equity x (Equity Ratio)

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The Capital Asset Pricing Model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

Cost of Equity = Riskless Rate of Return + β x Risk Premium

Where:

Riskless rate of return = the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield,
Risk premium = the difference between the expected return on stocks and the riskless rate, and
Beta (β) = the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index.

DOE calculated that the industry average cost of equity for the residential furnace fan industry is 12.0 percent (Table 12.4.2).

Table 12.4.2 Cost of Equity Calculation

Parameter	Industry Weighted Average	A	B	C	D	E	F
(1) Average Beta	1.14	1.10	0.37	1.06	0.85	1.64	1.00
(2) Yield on 10-Year (1928-2010)	5.2%						
(3) Market Risk Premium	6.0%						
Cost of Equity (2)+[(1)*(3)]	12.0%						
Equity/Total Capital	66.9%	70.6%	79.9%	50.4%	100.0%	70.9%	53.1%

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for six public manufacturers by using S&P ratings and adding the relevant spread to the risk-free rate.

In practice, investors use a variety of different maturity Treasury bonds to estimate the risk-free rate. DOE used the 10-year Treasury bond return because it captures long-term inflation expectations and is less volatile than short-term rates. The risk free rate is estimated to be approximately 5.2 percent, which is the average 10-year Treasury bond return between 1928 and 2011.

For the cost of debt, S&P's Credit Services provided the average spread of corporate bonds for the six manufacturers between 2006 and 2011. DOE added the industry-weighted average spread to the average T-Bill yield over the same period. Since proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry average tax rate to determine the net cost of debt for the industry. Table 12.4.3 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.*, the debt ratio (debt/total capital)).

Table 12.4.3 Cost of Debt Calculation

Parameter	Industry Weighted Average	A	B	C	D	E	F
S&P Bond Rating		A	A-	BBB	B	BBB	B+
(1) Yield on 10-Year (1928-2010)	5.2%						
(2) Gross Cost of Debt	8.1%	6.6%	6.8%	7.7%	11.2%	7.7%	10.7%
(3) Tax Rate	29.4%	28.0%	36.4%	33.8%	39.1%	17.8%	34.2%
Net Cost of Debt (2) x [1-(3)]	5.7%	4.8%	4.4%	5.1%	6.8%	6.3%	7.0%
Debt/Total Capital	33.1%	29.4%	20.1%	49.6%	0.0%	29.1%	46.9%

Using public information for these six companies, the initial estimate for the industry's WACC was approximately 10 percent. Subtracting an inflation rate of 3.09 percent over the analysis period used in the initial estimate, the inflation-adjusted WACC and the initial estimate of the discount rate used in the straw-man GRIM is 6.9 percent. DOE also asked for feedback on the discount rate during manufacturer interviews. Based on this feedback, DOE used a discount rate of 7.8 percent for the residential furnace fan industry.

12.4.5 Trial Standard Levels

DOE developed a number of efficiency levels for each product class. TSLs were then developed by selecting likely groupings of efficiency levels for all product classes. Table 12.4.4 presents the TSLs used for energy efficiency analysis in the GRIM.

Table 12.4.4 Trial Standard Levels for Energy Efficiency Analysis of Residential Furnace Fans

Product Class	Baseline	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6
NWG-NC	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
NWG-C	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
WG-NC	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
NWO-NC	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
EF/MB	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
MH-NWG-NC	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
MH-NWG-C	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
MH-EF/MB	Baseline	EL 1	EL 1	EL 3	EL 4	EL 4	EL 6

12.4.6 NIA Shipments

The GRIM estimates manufacturer revenues based on total-unit-shipment forecasts and the distribution of these values by efficiency level. Changes in the efficiency mix of the shipped units for a given standards case are a key driver of manufacturer finances. For this analysis, the GRIM applied the NIA shipments forecasts. As part of the shipments analysis, DOE estimated the base-case shipment distribution by efficiency level for each product class. In the standards case, DOE determined efficiency distributions for cases in which a potential standard applies for 2019 and beyond. DOE assumed that all shipments in the base case that did not meet the standard under consideration would meet the new standard in 2019 under a roll-up scenario. Consumers in the base case who purchase units above the standard level are not affected as they are assumed to continue to purchase the same base-case unit in the standards case.

See chapter 9 of the TSD for more information on the standards-case shipments for residential furnace fans.

12.4.7 Manufacturer Production Costs

Changes in production costs affect revenues and gross profits. Products that are more efficient typically cost more to produce than baseline products (as shown in chapter 5 of the TSD). For the MIA, DOE used the MPCs derived in the engineering analysis.

Manufacturing a higher efficiency product is typically more expensive than manufacturing a baseline product. MPCs increase at higher efficiency levels due to the use of more complex components, which are more costly than baseline components. These changes in MPCs can affect the revenues, gross margins, and cash flow of the industry, making these product cost data key GRIM inputs for DOE's analysis.

To calculate baseline MSP, DOE followed a three-step process. First, DOE derived MPCs from the engineering and teardown analyses. Second, DOE applied a manufacturer markup, which varies with the markup scenario (discussed in detail in section 12.4.9), to the MPCs. DOE did not include shipping costs in the MSP for its engineering analysis because DOE did not consider design options that would significantly impact the size and/or weight of the covered HVAC products in which furnace fans are used.

Table 12.4.5 through Table 12.4.12 show the production cost estimates used in the GRIM for each analyzed product class.

Table 12.4.5 Manufacturer Production Cost Breakdown (2011$) for NWG-NC

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.30	$105.44
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.30	$112.97
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.30	$144.44
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.30	$147.82
EL 4	$141.04	$1.76	$1.27	$3.63	$147.70	1.30	$192.01
EL 5	$200.95	$2.17	$1.27	$7.61	$212.00	1.30	$275.60
EL 6	$218.51	$2.17	$3.59	$5.29	$229.56	1.30	$298.43

Table 12.4.6 Manufacturer Production Cost Breakdown (2011$) for NWG-C

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.31	$106.25
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.31	$113.84
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.31	$145.55
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.31	$148.96
EL 4	$141.04	$1.76	$1.27	$3.63	$147.70	1.31	$193.49
EL 5	$200.95	$2.17	$1.27	$7.61	$212.00	1.31	$277.72
EL 6	$218.51	$2.17	$3.59	$5.29	$229.56	1.31	$300.72

Table 12.4.7 Manufacturer Production Cost Breakdown (2011$) for WG-NC

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.27	$103.01
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.27	$110.36
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.27	$141.11
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.27	$144.41
EL 4	$141.04	$1.76	$1.27	$3.63	$147.70	1.27	$187.58
EL 5	$200.95	$2.17	$1.27	$7.61	$212.00	1.27	$269.24
EL 6	$218.51	$2.17	$3.59	$5.29	$229.56	1.27	$291.54

Table 12.4.8 Manufacturer Production Cost Breakdown (2011$) for NWO-NC

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$93.68	$1.63	$2.98	$0.95	$99.24	1.35	$133.97
EL 1	$98.21	$2.20	$2.98	$4.65	$108.04	1.35	$145.85
EL 2	$135.97	$1.63	$2.98	$0.95	$141.53	1.35	$191.07
EL 3	$137.72	$1.76	$2.98	$3.71	$146.17	1.35	$197.33
EL 4	$173.48	$1.76	$2.98	$3.71	$181.93	1.35	$245.61
EL 5	$253.84	$2.33	$2.98	$10.03	$269.18	1.35	$363.39
EL 6	$271.71	$2.33	$8.61	$4.40	$287.05	1.35	$387.52

Table 12.4.9 Manufacturer Production Cost Breakdown (2011$) for EF/MB

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.19	$96.52
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.19	$103.41
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.19	$132.22
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.19	$135.31
EL 4	$111.95	$1.76	$1.27	$3.63	$118.61	1.19	$141.15
EL 5	$171.87	$2.17	$1.27	$7.61	$182.92	1.19	$217.67
EL 6	$189.42	$2.17	$3.59	$5.29	$200.47	1.19	$238.56

Table 12.4.10 Manufacturer Production Cost Breakdown (2011$) for MH-NWG-NC

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.25	$101.39
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.25	$108.63
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.25	$138.89
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.25	$142.14
EL 4	$141.04	$1.76	$1.27	$3.63	$147.70	1.25	$184.63
EL 5	$200.95	$2.17	$1.27	$7.61	$212.00	1.25	$265.00
EL 6	$218.51	$2.17	$3.59	$5.29	$229.56	1.25	$286.95

Table 12.4.11 Manufacturer Production Cost Breakdown (2011$) for MH-NWG-C

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.25	$101.39
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.25	$108.63
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.25	$138.89
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.25	$142.14
EL 4	$141.04	$1.76	$1.27	$3.63	$147.70	1.25	$184.63
EL 5	$200.95	$2.17	$1.27	$7.61	$212.00	1.25	$265.00
EL 6	$218.51	$2.17	$3.59	$5.29	$229.56	1.25	$286.95

Table 12.4.12 Manufacturer Production Cost Breakdown (2011$) for MH-EF/MB

Efficiency Level	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	$76.29	$1.63	$1.27	$1.92	$81.11	1.15	$93.28
EL 1	$79.84	$2.06	$1.27	$3.73	$86.90	1.15	$99.94
EL 2	$106.29	$1.63	$1.27	$1.92	$111.11	1.15	$127.78
EL 3	$107.05	$1.76	$1.27	$3.63	$113.71	1.15	$130.77
EL 4	$111.95	$1.76	$1.27	$3.63	$118.61	1.15	$136.40
EL 5	$171.87	$2.17	$1.27	$7.61	$182.92	1.15	$210.36
EL 6	$189.42	$2.17	$3.59	$5.29	$200.47	1.15	$230.54

12.4.8 Conversion Costs

New energy conservation standards typically cause manufacturers to incur one-time conversion costs to bring their production facilities and product designs into compliance with new regulations. For the MIA, DOE classified these one-time conversion costs into two major groups: capital conversion costs and product conversion costs. Capital conversion costs are one-time investments in PPE to adapt or change existing production facilities in order to fabricate and assemble new product designs that comply with new energy conservation standards. Product conversion costs are one-time investments in research, development, industry certification testing (*i.e.*, Underwriters Laboratories (UL) certifications and NSF International certifications), marketing, and other costs to make product designs comply with new energy conservation standards. DOE based its estimates of the conversion costs for each efficiency level on information obtained from manufacturer interviews and the design pathways analyzed in the engineering analysis.

12.4.8.1 Capital Conversion Costs

To evaluate the level of capital conversion expenditures manufacturers would likely incur to comply with energy conservation standards, DOE used the manufacturer interviews to gather data on the level of capital investment required at each efficiency level. DOE validated manufacturer comments through estimates of capital expenditure requirements derived from the product teardown analysis and engineering model described in chapter 5 of the TSD.

Most of the design options being considered require only a change in the type of motor used. Therefore, many of the design options do not incur capital expenditures for new tooling or equipment. However, the use of backward curved impellers could require significant changes in production processes and high capital expenditures since it would affect the fan housing. Expected capital conversion costs for each TSL are listed in Table 12.4.13.

Table 12.4.13 Industry Cumulative Capital Conversion Cost

TSL	**Capital Conversion Cost** ***$millions***
TSL 1	0.0
TSL 2	0.0
TSL 3	0.0
TSL 4	0.0
TSL 5	$155.0

At TSLs 1 through 5, DOE does not expect substantial capital conversion costs because manufacturers would be able to use a different motor type without making significant changes to their production processes.

At TSL 6, DOE anticipates very high capital conversion costs because manufacturers would need to make significant changes to their production processes in order to accommodate the use of backward inclined impellers. This design option would require modifying, or potentially eliminating, current fan housings.

12.4.8.2 Product Conversion Costs

DOE assessed the product conversion costs at each level by integrating data from quantitative and qualitative sources. For furnace fans, product conversion costs are the additional costs associated with redesigning products and updating product literature. DOE considered feedback from multiple manufacturers to determine product conversion costs at each efficiency level. Manufacturer numbers were aggregated to better reflect the industry as a whole and to protect confidential information.

DOE estimated product conversion costs based on manufacturer feedback, the engineering analysis, and efficiency distributions from the shipments analysis. The Department calculated product conversion costs using a percentage of annual R&D costs for the industry. Expected product conversion costs for each TSL are listed in Table 12.4.14.

Table 12.4.14 Industry Cumulative Product Conversion Cost

TSL	Product Conversion Cost *$millions*
TSL 1	1.1
TSL 2	2.8
TSL 3	2.9
TSL 4	3.1
TSL 5	3.2
TSL 6	9.3

At TSL 1, minimal product conversion costs are expected because a significant portion of the industry shipments already meet EL 1. Manufacturers estimated during interviews that approximately half a year of R&D would be needed to redesign products that do not currently meet this standard level.

At TSL 2, higher product conversion costs for the residential furnace fan industry arise from the selection of EL 3 for the higher volume product classes (which include the non-weatherized gas furnace, weatherized gas furnace, and electric furnace product classes). Product conversion costs are slightly higher at EL 3 because more product models in the furnace fan industry would need to be updated to meet this standard level. Furthermore, manufacturers expect that slightly more R&D time would need to be invested in redesigning each model.

At TSL 3, product conversion costs are higher because EL 3 has been selected for all product classes. Similar to TSL 2, more product models in the furnace fan industry would need to be updated to meet this standard level and slightly more R&D time would be needed to redesign each model. However, the increase in product conversion costs for the industry from TSL 2 to TSL 3 is minimal because the additional product classes that are now at EL 3 are low volume.

At TSL 4, several product classes, including the higher volume non-weatherized gas furnace, weatherized gas furnace, and electric furnace product classes and the lower volume manufactured housing electric furnace product class, must meet EL 4. Although product conversion costs at EL 4 are similar to those at EL 3, slightly more models need to be redesigned. Therefore, product conversion costs at TSL 4 are slightly higher than they are at TSL 3.

At TSL 5, the non-weatherized gas furnace, weatherized gas furnace, electric furnace, and manufactured housing electric furnace product classes are still at EL 4, similar to TSL 4. However, unlike at TSL 4, the oil furnace and manufactured housing non-weatherized gas furnace product classes must now meet EL 3. As a result, more product models in the furnace fan industry would need to be updated to meet this standard level, but because these are low volume product classes, the increase in product conversion costs from TSL 4 to TSL 5 is minimal.

At TSL 6, all product classes must meet EL 6. Since manufacturers do not have experience using backward curved impellers in their residential furnace fans, and 100% of products would need to be redesigned, manufacturers expect a significant increase in product conversion costs at this standard level.

12.4.9 Markup Scenarios

DOE used multiple standards-case markup scenarios to represent the uncertainty about the impacts of energy conservation standards on prices and profitability. In the base case, DOE used the same markups applied in the engineering analysis. In the standards case, DOE modeled two markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of new energy conservation standards: (1) a preservation of gross margin percentage scenario and (2) a preservation of earnings before interest and tax (EBIT) scenario. These scenarios lead to different markups values that, when applied to the inputted MPCs, result in varying revenue and cash flow impacts.

12.4.9.1 Preservation of Gross Margin Percentage Scenario

Under the preservation-of-gross-margin-percentage scenario, DOE applied a single uniform “gross margin percentage” markup across all efficiency levels. As production costs increase with efficiency, this scenario implies that the absolute dollar markup will increase as well. DOE assumed the non-production cost markup—which includes SG&A expenses, R&D expenses, interest, and profit— to be the following for furnace fans:

Product Class	NWG-NC	NWG-C	WG-NC	NWO-NC	EF/MB	MH-NWG-NC	MH-NWG-C	MH-EF/MB
Markup	1.3	1.31	1.27	1.35	1.19	1.25	1.25	1.15

This markup is equal to the one DOE assumed in the engineering analysis. Manufacturers indicated that it is optimistic to assume that, as their MPCs increase in response to an energy conservation standard, they would be able to maintain the same gross margin percentage markup. Therefore, DOE assumes that this scenario represents an upper bound to industry profitability under an energy conservation standard.

12.4.9.2 Preservation of Operating Profit Scenario

In the preservation of operating profit scenario, manufacturer markups are set so that operating profit one year after the compliance date of the new energy conservation standards is the same as in the base case. Under this scenario, as the cost of production and the cost of sales increase, manufacturers are generally required to reduce their markups to a level that maintains base-case operating profit. The implicit assumption behind this markup scenario is that the industry can only maintain its operating profit in absolute dollars after the standard. Operating margin in percentage terms is squeezed (reduced) between the base case and standards case. During interviews, multiple manufacturers expressed concern that the higher production costs could harm profitability. Incorporating this feedback, DOE modeled the preservation of operating profit scenario.

12.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIM estimated indicators of financial impacts on the residential furnace fan industry. The following sections detail additional inputs and assumptions for residential furnace fans. The main results of the MIA are also reported in this section. The MIA consists of two key financial metrics: INPV and annual cash flows.

12.5.1 Introduction

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE’s net present value, which is applied to the U.S. economy. The INPV is the sum of all net cash flows discounted at the industry’s cost of capital or discount rate. The GRIM for this rulemaking estimates cash flows from 2013 to 2048, the same analysis period used in the NIA (chapter 10 of the TSD). This timeframe models both the short-term impacts on the industry from the base year of the analysis until the compliance date (2013 to 2019) and a long-term assessment over the 30-year analysis period used in the NIA (2019 – 2048).

In the MIA, DOE compares the INPV of the base case (no new energy conservation standards) to that of each TSL. The difference between the base case and a standards case INPV is an estimate of the economic impacts the TSL would have on the industry. The markup scenarios are described in greater detail in section 12.4.9.

While INPV is useful for evaluating the long-term effects of new energy conservation standards, short-term changes in cash flow are also important indicators of the industry’s financial situation. For example, a large investment over 1 or 2 years could strain the industry’s access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even though recovery may be possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To provide an idea of the behavior of short-term annual net cash flows, Figure 12.5.1 and Figure 12.5.2 present the annual net cash flows through 2028.

Annual cash flows are discounted to the base year, 2013. After the standards announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the new energy conservation standard. Cash flows between the announcement date and the compliance date are driven by the level of conversion costs and the proportion of these investments spent every year. The more stringent the new energy conservation standard, the greater the impact on industry cash flows in the years leading up to the compliance date, as product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the new energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, new energy conservation standards could create stranded assets, *i.e.*, tooling and equipment that could have been used longer if the energy conservation standard had not made them obsolete. In this year, manufacturers write down the remaining book value of existing tooling and equipment whose value is affected by the new energy conservation standard. This one-time write-down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, higher inventory carrying to sell more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can be either positively or negatively affected in the year the standard takes effect.

12.5.2 Residential Furnace Fans Financial Impacts

Table 12.5.1 and Table 12.5.2 provide the INPV estimates for residential furnace fans for the two markup scenarios. Figure 12.5.1 and Figure 12.5.2 present the net annual cash flows for the two scenarios.

Table 12.5.1 Preservation of Gross Margin Percentage Scenario Changes in INPV for Residential Furnace Fans

	Units	Base Case	Trial Standard Level					
			1	2	3	4	5	6
INPV	2012$ M	252.2	252.9	265.7	265.1	286.0	286.5	310.4
Change in INPV	2012$ M	-	0.7	13.5	12.9	33.8	34.2	58.2
	(%)	-	0.3	5.3	5.1	13.4	13.6	23.1

Table 12.5.2 Preservation of Operating Profit Scenario Changes in INPV for Residential Furnace Fans*

	Units	Base Case	Trial Standard Level					
			1	2	3	4	5	6
INPV	2012$ M	252.2	249.2	225.5	223.6	197.8	196.7	82.1
Change in INPV	2012$ M	-	(3.0)	(26.7)	(28.6)	(54.4)	(55.5)	(170.1)
	(%)	-	(1.2)	(10.6)	(11.3)	(21.6)	(22.0)	(67.5)

* Numbers in parentheses indicate negative numbers.

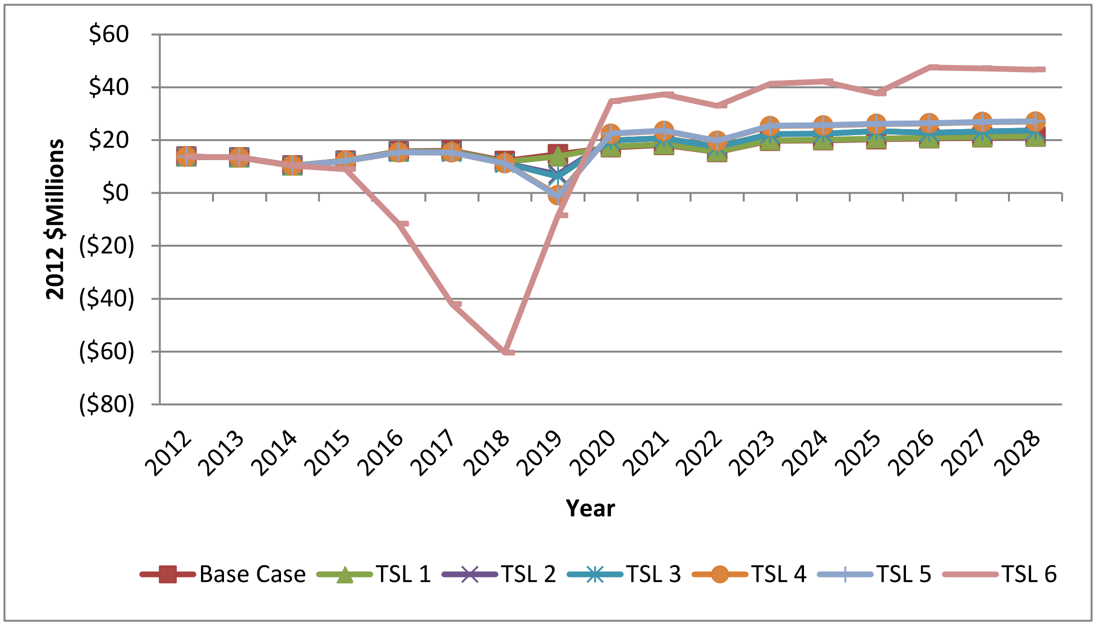

Figure 12.5.1 Annual Industry Net Cash Flows for Residential Furnace Fans (Preservation of Gross Margin Percentage Markup Scenario)

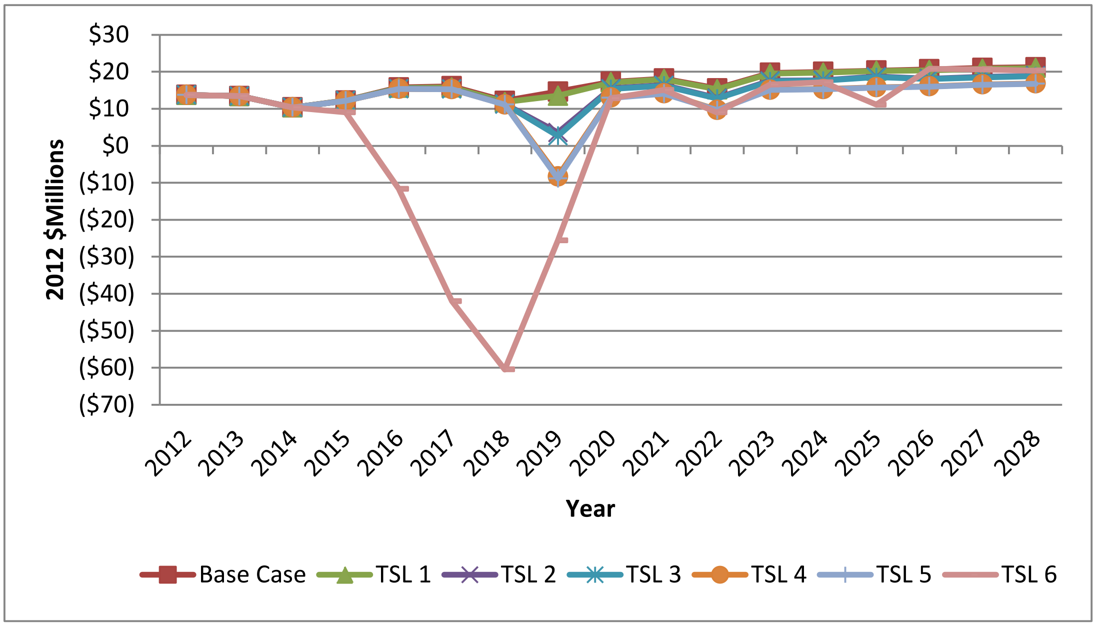

Figure 12.5.2 Annual Industry Net Cash Flows for Residential Furnace Fans (Preservation of Operating Profit Markup Scenario)

12.6 IMPACTS ON SMALL BUSINESS MANUFACTURERS

DOE conducted a more focused inquiry of the companies that could be small business manufacturers of products covered by this rulemaking. For the category "Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing," the SBA has set a size threshold of 750 employees or less for an entity to be considered as a small business. During its market survey, DOE used all available public information to identify potential small manufacturers. DOE's research involved industry trade association membership directories (including AHRI, NAFEM, and NSF International), product databases (*e.g.*, Federal Trade Commission (FTC), The Thomas Register, California Energy Commission (CEC), and ENERGY STAR® databases), individual company websites, and market research tools (*e.g.*, Hoovers reports) to create a comprehensive list of companies that manufacture or sell products covered by this rulemaking. DOE also asked stakeholders and industry representatives if they were aware of any other small manufacturers during manufacturer interviews and at previous DOE public meetings. DOE reviewed publicly available data and contacted select companies on its list, as necessary, to determine whether they met the SBA's definition of a small business manufacturer of covered residential furnace fans. DOE screened out companies that did not offer products covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

DOE identified at least 40 manufacturers in the residential furnace fans industry, and 14 of the manufacturers identified are believed to be small businesses. As part of the MIA, the Department interviewed seven residential furnace fan manufacturers, including one small manufacturer. Based on the large number of small residential furnace fan manufacturers and the potential scope of the impact, DOE could not certify that the proposed standards would not have a significant impact on a significant number of small businesses with respect to the residential furnace fans industry.

DOE recognizes that new energy conservation standards can potentially have disproportionate impacts on small businesses. Larger manufacturers could have a competitive advantage due to their size and ability to access capital that may not be available to small businesses. Larger businesses also have larger production volumes over which to spread costs. DOE provides additional analysis in section VI.B, "Review under the Regulatory Flexibility Act," in the notice of proposed rulemaking.

12.7 OTHER IMPACTS

12.7.1 Employment

To quantitatively assess the impacts of energy conservation standards on direct employment in the residential furnace fan industry, DOE used the GRIM to estimate the domestic labor expenditures and number of employees in the base case and at each TSL from 2013 through 2048. DOE used statistical data from the U.S. Census Bureau's 2011 Annual Survey of Manufacturers (ASM), the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures related to manufacturing of the product are a function of the labor intensity of the product, the sales volume, and an assumption that wages remain fixed in real terms over time. The total labor expenditures in each year are calculated by multiplying the MPCs by the labor percentage of MPCs.

Labor costs at each efficiency level vary depending on the design options selected. At all efficiency levels, labor costs are primarily based on the labor needed to create the fan housing. However, at certain efficiency levels, more labor is also needed for additional components. DOE took into account additional labor to install an inverter at EL 2; multi-staging elements at EL 4; multi-staging elements and improved PCB at EL 5; and multi-staging elements, improved PCB, and a backward curved impeller at EL 6.

The total labor expenditures in the GRIM were then converted to domestic production employment levels by dividing production labor expenditures by the annual payment per production worker (production worker hours times the labor rate found in the U.S. Census Bureau's 2011 ASM). The estimates of production workers in this section cover workers, including line-supervisors who are directly involved in fabricating and assembling a product within the manufacturing facility. Workers performing services that are closely associated with production operations, such as materials handling tasks using forklifts, are also included as production labor. DOE's estimates only account for production workers who manufacture the specific products covered by this rulemaking.

The total direct employment impacts calculated in the GRIM are the changes in the number of production workers in the furnace fan industry resulting from the new energy conservation standards, as compared to the base case. Using the GRIM, DOE estimates that there would be approximately 300 domestic production workers in 2019 in the absence of new energy conservation standards.

Table 12.7.1 shows the range of impacts of potential new energy conservation standards on U.S. production workers in the furnace fan industry.

Table 12.7.1 Potential Changes in the Total Number of Domestic Production Workers in 2018

TSL	1	2	3	4	5	6
Total Number of Domestic Production Workers 2019	301	301	301	301	301	351
Potential Changes in Domestic Production Workers 2019*	(301) to 0	(301) to 0	(301) to 0	(301) to 0	(301) to 0	(301) to 50

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

The employment impacts shown in Table 12.7.1 represent the potential changes in production employment that could result from new energy conservation standards. The upper end of the results in the table estimates the change in the number of production workers based on the change in labor costs associated with each efficiency level. It assumes that manufacturers would continue to produce the same scope of covered products within the United States and that domestic production would not shift to countries with lower labor costs. For residential furnace fans, DOE does not expect significant changes in domestic employment levels from baseline to EL 5 because these efficiency levels can be achieved by substituting a higher-efficiency component for an existing component. DOE found during manufacturer interviews that the assembly processes for integrating the higher-efficiency components do not differ significantly from those used for existing components. For instance, manufacturers design their housings and motor mounts to be compatible with all motor types. Consequently, no additional labor is required to integrate higher efficiency motors and controls to reach EL 1 through EL 3, and labor costs will be equivalent to the baseline at those levels. The same is true for integration of components that enable multi-stage heating capabilities to reach EL 4 and EL 5. The only standard level at which significant changes in employment are expected to occur is at EL6, the max tech level. At EL 6, DOE estimates increases in labor costs because backwards-inclined impeller assemblies are heavier and require more robust mounting approaches than are currently used for forward-curved impeller assemblies. The alternate mounting approaches needed to integrate backward-inclined impeller assemblies could require manufacturers to modify their current assembly processes, resulting in increased labor. However, DOE received limited feedback from manufacturers regarding the labor required to produce furnace fans with backward curved impellers because they generally do not have any experience in working with this design option.

The lower end of the range indicates the total number of U.S. production workers in the industry who could lose their jobs if all existing production were moved outside of the United States. One manufacturer mentioned during interviews that employment could potentially be affected if their profit margins decreased due to a new standard. In this case, they may consider moving their production facilities to another country.

DOE notes that the employment impacts discussed here are independent of the employment impacts to the broader U.S. economy, which are documented in chapter 15 of the NOPR TSD.

12.7.2 Production Capacity

According to the residential furnace fan manufacturers interviewed, the new energy conservation standards proposed in today's NOPR would not significantly affect manufacturers' production capacities. Some manufacturers mentioned that capacity could potentially be impacted by additional testing requirements and bottlenecks with sourcing if motor suppliers cannot keep up with demand, but manufacturing capacity was generally not a concern until max tech levels. Thus, at the proposed TSL, DOE believes manufacturers would be able to maintain manufacturing capacity levels and continue to meet market demand under new energy conservation standards.

12.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an entire industry. Assessing the impact of a single regulation may overlook this cumulative regulatory burden. In addition to the new energy conservation regulations on residential furnace fans, several other regulations apply to these and other products produced by the same manufacturers.

Companies that produce a wide range of regulated products may be faced with more capital and product development expenditures than competitors with a narrower scope of products. Regulatory burdens can prompt companies to exit the market or reduce their product offerings, potentially reducing competition. Smaller companies in particular can be disproportionately affected by regulatory costs since these companies have lower sales volumes over which they can amortize the costs of meeting new regulations. A proposed standard is not economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

12.7.3.1 DOE Certification, Compliance, and Enforcement (CC&E) Rule and Alternative Energy Determination Methods (AEDM) Rule

The test procedure SNOPR for residential furnace fans included proposed sampling specifications for CC&E testing that required, unless otherwise specified, a minimum of two units to be tested for each basic model. 78 FR at 19625 (April 2, 2013).

Manufacturers indicated during interviews that the regulatory burden from certification and compliance testing is one of the biggest problems they face. One manufacturer stated that it could potentially shut down the industry due to the large number of basic models that need to be tested. DOE recognizes that the CC&E requirements contribute to cumulative regulatory burden, but DOE does not find that testing furnace fans according to its proposed test procedure would be unduly burdensome.

12.7.3.2 DOE Energy Conservation Standards for Furnaces and Central Air Conditioners and Heat Pumps

On June 27, 2011, DOE published a direct final rule in the Federal Register to amend the energy conservation standards for residential furnaces, central air conditioners, and heat pumps. 76 FR 37408. (DOE subsequently confirmed adoption of these standards through publication of a notice of effective date and compliance dates for this rulemaking in the Federal Register on October 31, 2011. 76 FR 67037.) Compliance with these standards is required on May 1, 2013 for non-weatherized furnaces and on January 1, 2015 for weatherized furnaces, central air conditioners, and heat pumps. However, a proposed settlement in the regional energy-efficiency standards lawsuit, if approved by the Court, would vacate the standards for non-weatherized gas furnaces with a compliance date of May 1, 2013, and remand for further rulemaking. If so, DOE would create a new rulemaking in which all interested parties would be able to participate in developing a new standard for non-weatherized furnaces. The agreement is awaiting approval by the D.C. Circuit Court of Appeals. Since furnace fan manufacturers are also manufacturers of the HVAC product in which the furnace fan is used, furnace fan manufacturers must comply with the amended energy conservation standards for residential furnaces, central air conditioners, and heat pumps. At the minimum energy efficiency levels selected for the direct final rule, DOE estimated that the total industry investment required to meet the amended energy conservation standards would be $28 million (in 2009$). At the minimum energy efficiency levels selected for the furnace fan notice of proposed rulemaking, DOE estimates that the total industry investment would be $3.1 million. Manufacturers of furnace fans face product conversion costs related to standards for furnace fans, as well as product and capital conversion costs related to standards for residential furnaces, central air conditioners, and heat pumps.

The direct final rule for energy conservation standards for residential furnaces, central air conditioners, and heat pumps includes standards for energy efficiency as well as standards for standby mode and off mode energy consumption. DOE has completed a test procedure final rule for standby mode and off mode energy consumption in residential furnaces. 77 FR 76831 (Dec. 31, 2012). DOE is also preparing a test procedure for standby mode and off mode energy consumption in residential central air conditioners and heat pumps.

In addition to setting a base national standard, the June 27, 2011 final rule also implemented regional standard levels, where the minimum efficiency level for a product is determined by the geographic region in which it is sold. For non-weatherized gas furnaces, a minimum 90% AFUE standard would be effective in northern regions by May 1, 2013. However, the American Public Gas Association (APGA) challenged the stricter regional standards. On January 11, 2013, the Department of Justice (on behalf of DOE) and APGA filed a joint motion that requested the court to enter an agreement to settle the challenge. On April 5, 2013, DOE issued a statement that, "in an exercise of its enforcement discretion, DOE will, during the pendency of the litigation, act in a manner consistent with the terms of the settlement agreement with regard to the enforcement of the standards." Therefore, DOE will not enforce regional standards starting May 1, 2013.

12.7.3.3 EPA Phaseout of Hydrochlorofluorocarbons (HCFCs)

The U.S. is obligated under the Montreal Protocol to limit production and consumption of HCFCs through incremental reductions, culminating in a complete phaseout of HCFCs by 2030. On December 15, 2009, EPA published the "2010 HCFC Allocation Rule," which allocates production and consumption allowances for HCFC-22 for each year between 2010 and 2014. 74 FR 66412. On January 4. 2012, EPA published the "2012 HCFC Allocation Proposed Rule," which proposes to lift the regulatory ban on the production and consumption of HCFC-22 (following a court decision in August 2010 to vacate a portion of the "2010 HCFC Allocation Rule") by establishing company-by-company HCFC-22 baselines and allocating allowances for 2012-2014. 77 FR 237.

HCFC-22, which is also known as R-22, is a popular refrigerant that is commonly used in air-conditioning products. Manufacturers of residential furnace fans who also manufacture residential central air conditioners must comply with the allowances established by the allocation rule, thereby facing a cumulative regulatory burden.

12.7.3.4 EPA ENERGY STAR

During interviews, some manufacturers stated that ENERGY STAR specifications for residential furnaces, central air conditioners, and heat pumps would be a source of cumulative regulatory burden. ENERGY STAR specifications are as follows:

Gas Furnaces	Rating of 90% AFUE or greater for U.S. South gas furnaces Rating of 95% AFUE or greater for U.S. North gas furnaces Less than or equal to 2.0% furnace fan efficiency
Oil Furnaces	Rating of 85% AFUE or greater Less than or equal to 2.0% furnace fan efficiency
Air-Source Heat Pumps	>= 8.2 HSPF/ >=14.5 SEER/ >=12 EER* for split systems >= 8.0 HSPF/ >=14 SEER/ >=11 EER* for single package equipment
Central Air Conditioners	>=14.5 SEER/ >=12 EER* for split systems >=14 SEER/ >=11 EER* for single package equipment

DOE realizes that the cumulative effect of several regulations on an industry may significantly increase the burden faced by manufacturers that need to comply with multiple regulations and certification programs from different organizations and levels of government. However, DOE notes that certain standards, such as ENERGY STAR, are optional for manufacturers. Furthermore, for certain products listed in the table above, ENERGY STAR standards are equivalent to the standards set in DOE's June 2011 direct final rule for energy conservation standards for residential furnaces, central air conditioners, and heat pumps.

12.7.3.5 Canadian Energy Efficiency Regulations

In June 2010, the Office of Energy Efficiency of National Resources Canada (NRCan) published a bulletin to announce the proposal of new electricity reporting requirements for air handlers used in residential central heating and cooling systems that are imported into Canada for sale or lease. In November 2011, NRCan published a regulatory update which stated that NRCan intends to apply reporting requirements to only air handlers used in residential gas furnaces, and that requirements for air handlers used in other heating and cooling systems would be expanded in a future regulatory amendment. In this update, NRCan proposed to use Canadian Standards Association (CSA) C823-11 (Performance of air handlers in residential space conditioning systems) as the test method for determining efficiency. Consequently, manufacturers of furnace fans used in residential gas furnaces may face additional reporting requirements if they sell their products in Canada.

12.7.3.6 California Title 24

Title 24, Part 6, of the California Code of Regulations includes building energy efficiency standards for residential and nonresidential buildings. The California Energy Commission (CEC) published new standards in 2008, which became effective January 1, 2010, that include watts per cubic foot per minute (W/CFM) limits for fans used in central, residential HVAC systems.

12.7.3.7 ASHRAE Standard 90.1

ASHRAE Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings," sets minimum efficiency standards for buildings, except low-rise residential buildings. On May 16, 2012, DOE published the final rule in the Federal Register for Energy Conservation Standards and Test Procedures for Commercial Heating, Air-Conditioning, and Water-Heating Equipment, through which DOE adopted the efficiency levels specified in ASHRAE Standard 90.1–2010. 77 FR 28928

Included in the ASHRAE standards are minimum efficiency levels for commercial heating, air conditioning, and water heating equipment. Some manufacturers of residential furnace fans also manufacture this equipment.

12.7.3.8 Low NO_X requirements

Rule 1111 of the South Coast Air Quality Management District (AQMD) currently requires residential furnaces installed in the District to meet a NO_X emission limit of 40 nanograms per joule (ng/J) of heat output. The development of this rule is an ongoing process to evaluate low No_X technologies for combustion equipment. In 1983, the rule was amended to limit applicability to furnaces with a heat input of less than 175,000 Btu per hour, or for combination heating and cooling units, a cooling rate of less than 65,000 Btu per hour. The rule was again amended in 2009 to establish a new limit of 14 ng/J for non-condensing, condensing, weatherized, and mobile home furnaces, with the following compliance schedule:[a]

Compliance Date	Furnace Type
Oct 1, 2014	Condensing Furnace
Oct 1, 2015	Non-condensing Furnace
Oct 1, 2016	Weatherized Furnace
Oct 1, 2018	Mobile Home Furnace

The Proposed Amended Rule (PAR) 1111 affects manufacturers, distributors, wholesalers, builders, and installers of residential furnaces. AHRI indicates that, although there are currently no manufacturers of fan-type gas-fired residential furnaces within the AQMD jurisdiction, some of these manufacturers do sell and distribute products installed in this district.

PAR 1111 also provides manufacturers with an alternative compliance option. For any furnace type, a manufacturer may request a delayed compliance date of up to three years if they submit a plan and pay an emission mitigation fee.

12.8 CONCLUSION

The following section summarizes the impacts for the scenarios DOE believes are most likely to capture the range of impacts on residential furnace fan manufacturers as a result of new energy conservation standards. DOE also notes that while these scenarios bound the range of most plausible impacts on manufacturers, there potentially could be circumstances that cause manufacturers to experience impacts outside of this range.

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[a] http://www.arb.ca.gov/DRDB/SC/CURHTML/R1111.pdf

For this rulemaking, TSLs are defined as shown in Table 12.8.1.

Table 12.8.1 TSLs for the Residential Furnace Fans Rulemaking

Product Class	Baseline	TSL1	TSL2	TSL3	TSL4	TSL5	TSL6
NWG-NC	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
NWG-C	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
WG-NC	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
NWO-NC	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
EF/MB	Baseline	EL 1	EL 3	EL 3	EL 4	EL 4	EL 6
MH-NWG-NC	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
MH-NWG-C	Baseline	EL 1	EL 1	EL 3	EL 1	EL 3	EL 6
MH-EF/MB	Baseline	EL 1	EL 1	EL 3	EL 4	EL 4	EL 6

At TSL 1, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$3.0 million to $0.7 million, or a change in INPV of -1.2 percent to 0.3 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 2.8 percent to $11.78 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates no capital conversion costs at TSL 1, because manufacturers would be able to use a different motor type without making significant changes to their manufacturing equipment or production processes. DOE anticipates minor product conversion costs associated with redesigning products that are currently below the proposed efficiency level and updating product literature.

At TSL 2, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$26.7 million to $13.5 million, or a change in INPV of -10.6 percent to 5.3 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 6.9 percent to $11.28 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates no capital conversion costs at TSL 2, because manufacturers would be able to use a different motor type without making significant changes to their manufacturing equipment or production processes. DOE anticipates product conversion costs at TSL 2 to be higher than those at TSL 1 because more products in the market, with the exception of oil furnaces and manufactured housing products, would need to be redesigned in order to meet the higher proposed efficiency levels. Additional product literature would also need to be updated for the redesigned products.

At TSL 3, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$28.6 million to $12.9 million, or a change in INPV of -11.3 percent to 5.1 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 7.2 percent to $11.25 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates no capital conversion costs at TSL 3, because manufacturers would be able to use a different motor type without making significant changes to their manufacturing equipment or production processes. DOE anticipates product conversion costs at TSL 3 to be slightly higher than those at TSL 2 because more manufactured housing products in the market would need to be redesigned in order to meet the higher proposed efficiency levels. Additional product literature would also need to be updated for the redesigned products.

At TSL 4, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$54.4 million to $33.8 million, or a change in INPV of -21.6 percent to 13.4 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 7.9 percent to $11.17 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates no capital conversion costs at TSL 4, because manufacturers would be able to use a different motor type without making significant changes to their manufacturing equipment or production processes. DOE anticipates product conversion costs at TSL 4 to be higher than those at TSL 3 because more products in the market, with the exception of oil furnaces, would need to be redesigned in order to meet the higher proposed efficiency levels. Additional product literature would also need to be updated for the redesigned products.

At TSL 5, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$55.5 million to $34.2 million, or a change in INPV of -22.0 percent to 13.6 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 8.0 percent to $11.15 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates no capital conversion costs at TSL 5, because manufacturers would be able to use a different motor type without making significant changes to their manufacturing equipment or production processes. DOE anticipates product conversion costs at TSL 5 to be slightly higher than those at TSL 4 because more oil furnaces and manufactured housing electric furnaces in the market would need to be redesigned in order to meet the higher proposed efficiency levels. Additional product literature would also need to be updated for the redesigned products.

At TSL 6, DOE estimates impacts on INPV for residential furnace fan manufacturers to range from -$170.1 million to $58.2 million, or a change in INPV of -67.5 percent to 23.1 percent. At this potential standard level, industry free cash flow is estimated to decrease by approximately 598.7 percent to -$60.44 million, compared to the base-case value of $12.12 million in the year before the compliance date (2018).

DOE anticipates very high capital conversion costs at TSL 6 because manufacturers would need to make significant changes to their manufacturing equipment and production processes in order to accommodate the use of backward-inclined impellers. This design option would require modifying, or potentially eliminating, current fan housings. DOE also anticipates high product conversion costs to develop new designs with backward-inclined impellers for all their products. Some manufacturers may also have stranded assets from specialized machines for building fan housing that can no longer be used.

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

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CHAPTER 13. EMISSIONS IMPACT ANALYSIS

13.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH_4) and nitrous oxide (N_2O), as well as the reductions to emissions of all species due to "upstream" activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE's FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of power sector emissions uses marginal emissions intensity factors derived from runs of DOE's NEMS-BT model, described in Chapter 15. DOE used the version of NEMS based on the *Annual Energy Outlook 2012 (AEO 2012).*[1] Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2012* generally represents current Federal and State legislation and final implementation regulations in place as of the end of December 2011. Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[2]

Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA, GHG Emissions Factors Hub.[a] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[3] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated using the energy savings calculated in the national impact analysis (chapter 10).

13.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C.

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[a] http://www.epa.gov/climateleadership/guidance/ghg-emissions.html

Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). The *AEO 2012* NEMS used for this analysis assumes the implementation of CSAPR.[b]

The attainment of emissions caps is typically flexible among affected Electric Generating Units (EGUs) and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2015, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2012* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, NEMS shows a reduction in SO_2 emissions when electricity demand decreases (e.g., as a result of energy efficiency standards). Emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2015 and beyond.

CSAPR established a cap on NO_x emissions in 28 eastern States and the District of Columbia. Energy conservation standards are expected to have little effect on NO_x emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by CSAPR, so DOE estimated NOx emissions reductions from potential standards for those States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg

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[b] On December 30, 2011, the D.C. Circuit stayed the new rules while a panel of judges reviews them, and told EPA to continue enforcing CAIR. See *EME Homer City Generation, LP v. EPA*, Order, No. 11-1302, Slip Op. at *2 (D.C. Cir. Dec. 30, 2011). On August 21, 2012, the D.C. Circuit vacated CSAPR. See *EME Homer City Generation, LP v. EPA*, No. 11-1302, 2012 WL 3570721 at *24 (D.C. Cir. Aug. 21, 2012). The court required EPA to continue administering CAIR. AEO 2012 had been finalized prior to both these decisions, however. DOE understands that CAIR and CSAPR are similar with respect to their effect on emissions impacts of energy efficiency standards.

emissions. DOE estimated mercury emissions reductions using the NEMS-BT based on *AEO 2012*, which incorporates the MATS.

13.3 POWER SECTOR AND SITE EMISSIONS FACTORS

The analysis of power sector emissions uses marginal emissions intensity factors derived from runs of DOE's NEMS-BT model, using the version updated to the *Annual Energy Outlook 2012 (AEO 2012).* To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity, fuel use and power sector emissions. A marginal emissions intensity factor is defined by dividing the reduction in the total emissions of a given pollutant by the reduction in total generation (in billion kWh). DOE uses the site energy savings multiplied by a T&D loss factor to estimate the reduction in generation for each TSL. Details on the approach used may be found in Coughlin (2013).[3]

Table 13.3.1 presents the average power plant emissions factors for selected years. These power plant emissions factors are derived from the emissions factors of the plant types used to supply electricity to homes. DOE did not have data on the load shape of furnace fans, so it used a load shape that has constant energy use and is used when the building is occupied. The average factors for each year take into account the projected shares of each of the sources in total electricity generation.

The power plant emissions factor for NOx is an average for the entire U.S. The marginal calculation based on the NEMS-BT model accounts for the fact that NOx emissions are capped in some States.

Table 13.3.2 presents the natural gas site combustion emissions factors for selected years.

Table 13.3.1 Power Plant Emissions Factors

	Unit*	**2016**	**2020**	**2025**	**2030**	**2035**	**2040**
CO_2	kg/MWh	708	708	575	680	746	746
SO_2	g/MWh	853	853	689	193	326	326
NOx	g/MWh	1336	1336	85	245	378	378
Hg	g/MWh	0.0011	0.0011	0.0011	0.0012	0.0027	0.0027
N_2O	g/MWh	7.2	7.3	7.5	7.4	7.4	7.3
CH_4	g/MWh	50	51	52	52	51	51

* Refers to site electricity savings.

Table 13.3.2 Natural Gas Site Combustion Emissions Factors

	Unit*	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
CO_2	kg/mcf	54.2	54.2	54.2	54.2	54.2	54.2
NOx	g/ mcf	29.0	29.2	28.3	27.7	27.2	26.6
N_2O	g/ mcf	0.102	0.102	0.102	0.102	0.102	0.102
CH_4	g/ mcf	1.022	1.022	1.022	1.022	1.022	1.022

* Refers to site gas savings.

13.4 UPSTREAM FACTORS

The upstream emissions accounting uses the same approach as the upstream energy accounting described in appendix 10-B. See also Coughlin (2013).[3] When demand for a particular fuel is reduced, there is a corresponding reduction in the emissions from combustion of that fuel at either the building site or the power plant. The associated reduction in energy use for upstream activities leads to further reductions in emissions. These upstream emissions are defined to include the combustion emissions from the fuel used upstream, the fugitive emissions associated with the fuel used upstream, and the fugitive emissions associated with the fuel used on site.

Fugitive emissions of CO_2 occur during oil and gas production, but are small relative to combustion emissions. They comprise about 2.5% of total CO_2 emissions for natural gas and 1.7% for petroleum fuels. Fugitive emissions of methane occur during oil, gas and coal production. Combustion emissions of CH_4 are very small, while fugitive emissions (particularly for gas production) may be relatively large. Hence, fugitive emissions make up over 99% of total methane emissions for natural gas, about 95% for coal, and 93% for petroleum fuels.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 13.4.1 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_x emissions do not apply to upstream combustion sources.

Table 13.4.1 Electricity Upstream Emissions Factors

	Unit*	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
CO_2	kg/MWh	30.1	29.4	28.7	28.8	28.9	29.0
SO_2	g/MWh	5.4	5.5	5.8	5.8	5.7	5.6
NOx	g/MWh	178	174	170	170	171	172
Hg	g/MWh	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
N_2O	g/MWh	0.26	0.26	0.27	0.26	0.26	0.26
CH_4	g/MWh	2034	1950	1890	1916	1930	1951

* Refers to site electricity savings.

Table 13.4.2 illustrates the natural gas upstream emissions factors for selected years. These were used to estimate the emissions associated with the increased gas use at some of the considered efficiency levels.

Table 13.4.2 Natural Gas Upstream Emissions Factors

	Unit*	2015	2020	2025	2030	2035	2040
CO_2	kg/ mcf	6.8	6.8	6.7	6.6	6.5	6.5
SO_2	g/ mcf	0.028	0.029	0.028	0.027	0.027	0.027
NOx	g/ mcf	42	42	41	40	40	40
N_2O	g/ mcf	0.010	0.011	0.010	0.010	0.010	0.010
CH_4	g/ mcf	623	617	607	601	596	590

* Refers to site gas use.

13.5 EMISSIONS IMPACT RESULTS

Table 13.5.1 presents the estimated cumulative emissions reductions for the lifetime of products sold in 2019-2048 for each TSL.

Table 13.5.1 Cumulative Emissions Reduction for Potential Standards for Furnace Fans

	TSL					
	1	2	3	4	5	6
Power Sector and Site Emissions*						
CO_2 (million metric tons)	57.1	214.2	221.8	416.4	421.7	563.8
SO_2 (thousand tons)	30.7	122.4	126.3	227.2	229.9	303.7
NO_X (thousand tons)	31.2	117.0	121.3	227.2	230.2	307.8
Hg (tons)	0.2	0.9	1.0	1.8	1.8	2.4
N_2O (thousand tons)	0.7	2.7	2.7	5.0	5.0	6.7
CH_4 (thousand tons)	4.7	18.2	18.9	34.2	34.7	46.0
Upstream Emissions						
CO_2 (million metric tons)	1.9	6.0	6.1	13.4	13.4	18.5
SO_2 (thousand tons)	0.5	2.0	2.0	3.7	3.7	5.0
NO_X (thousand tons)	12.2	38.3	39.2	86.2	86.6	119.6
Hg (tons)	0.0	0.0	0.0	0.0	0.0	0.0
N_2O (thousand tons)	0.0	0.1	0.1	0.2	0.2	0.2
CH_4 (thousand tons)	127.9	352.8	365.7	879.4	887.6	1249.3
Total Emissions						
CO_2 (million metric tons)	59.0	220.2	227.9	429.8	435.2	582.3
SO_2 (thousand tons)	31.2	124.4	128.4	230.9	233.6	308.7
NO_X (thousand tons)	43.4	155.3	160.4	313.5	316.9	427.4
Hg (tons)	0.2	1.0	1.0	1.8	1.8	2.4
N_2O (thousand tons)	0.7	2.7	2.8	5.1	5.2	6.9
CH_4 (thousand tons)	132.6	371.0	384.6	913.7	922.3	1295.3

* Includes emissions from additional gas use of more-efficient furnace fans.

Figure 13.5.1 through Figure 13.5.6 show the annual reductions for total emissions for each type of emission from each TSL. The reductions reflect the lifetime impacts of products sold in 2019-2048.

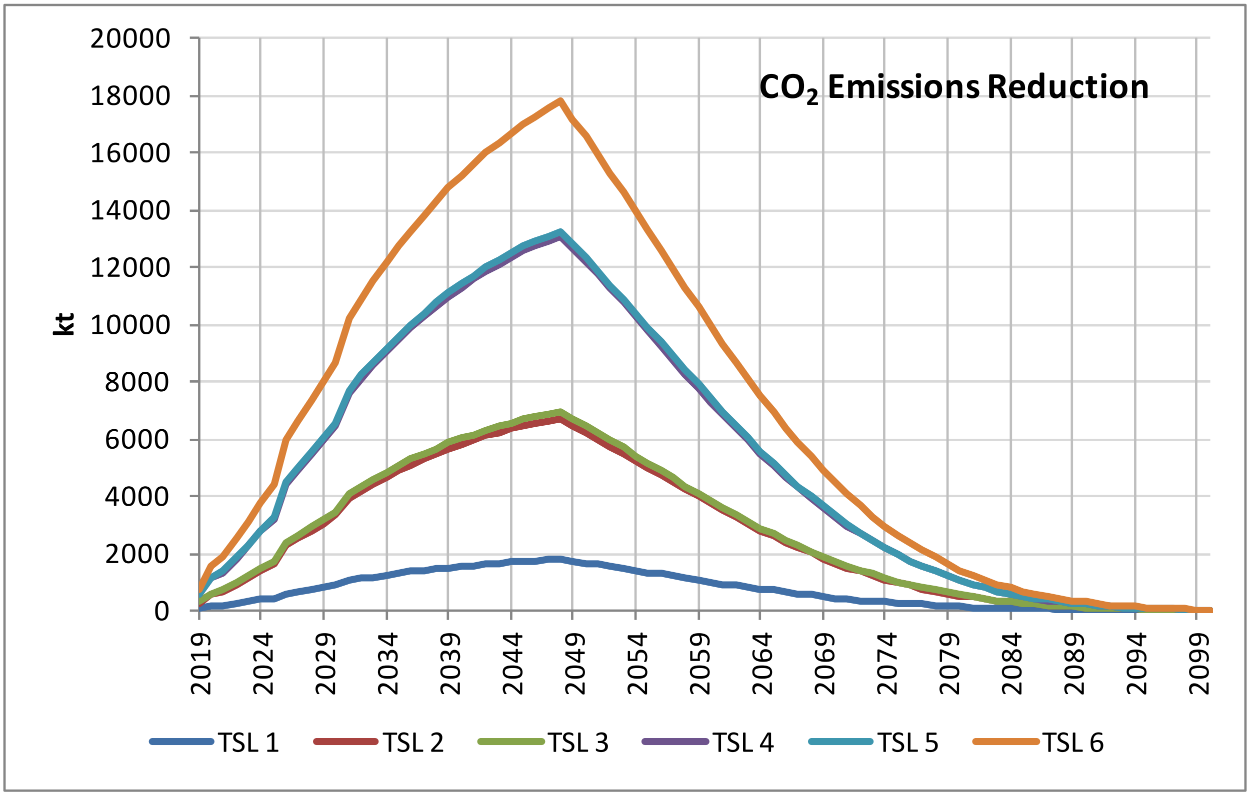

Figure 13.5.1 Furnace Fans: CO_2 Total Emissions Reduction

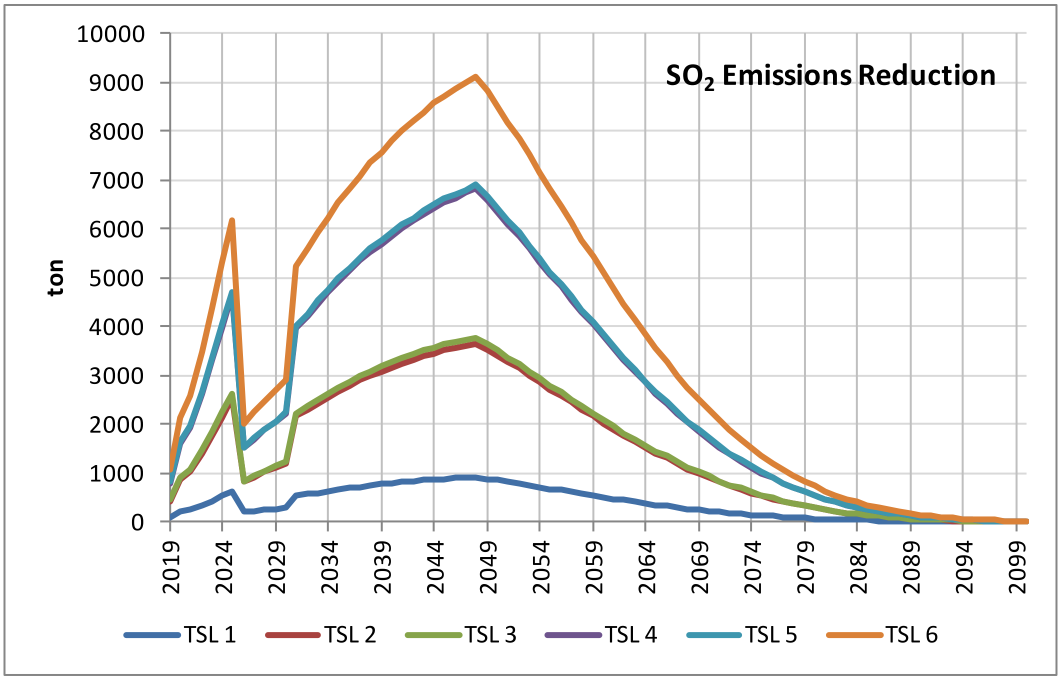

Figure 13.5.2 Furnace Fans: SO_2 Total Emissions Reduction

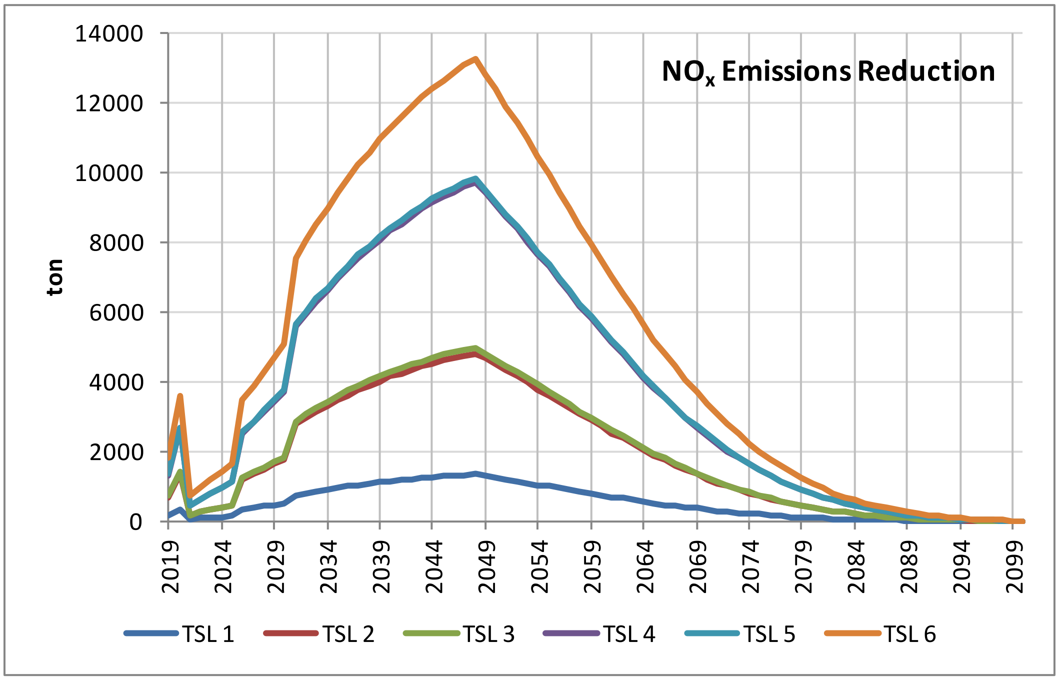

Figure 13.5.3 Furnace Fans: NO_x Total Emissions Reduction

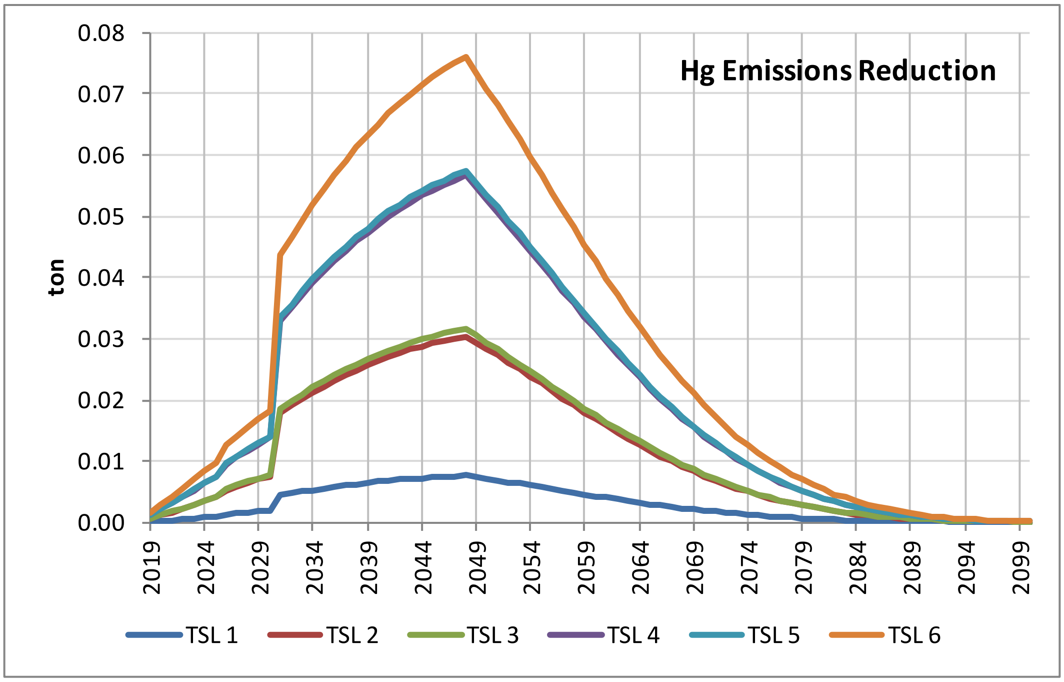

Figure 13.5.4 **Furnace Fans: Hg Total Emissions Reduction**

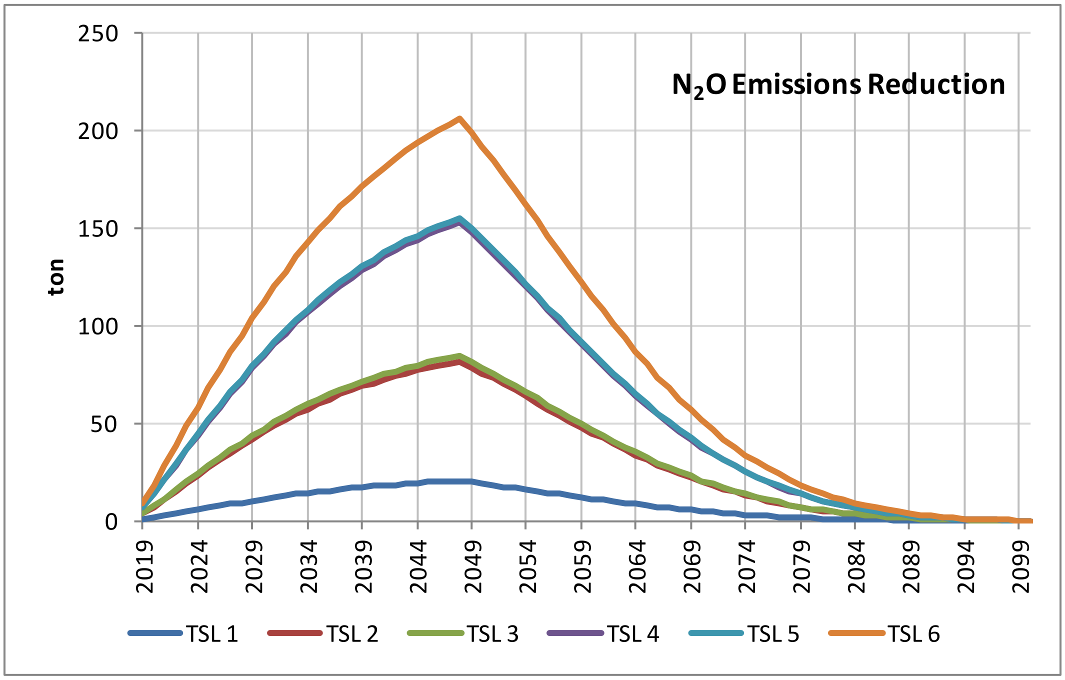

Figure 13.5.5 **Furnace Fans: N_2O Total Emissions Reduction**

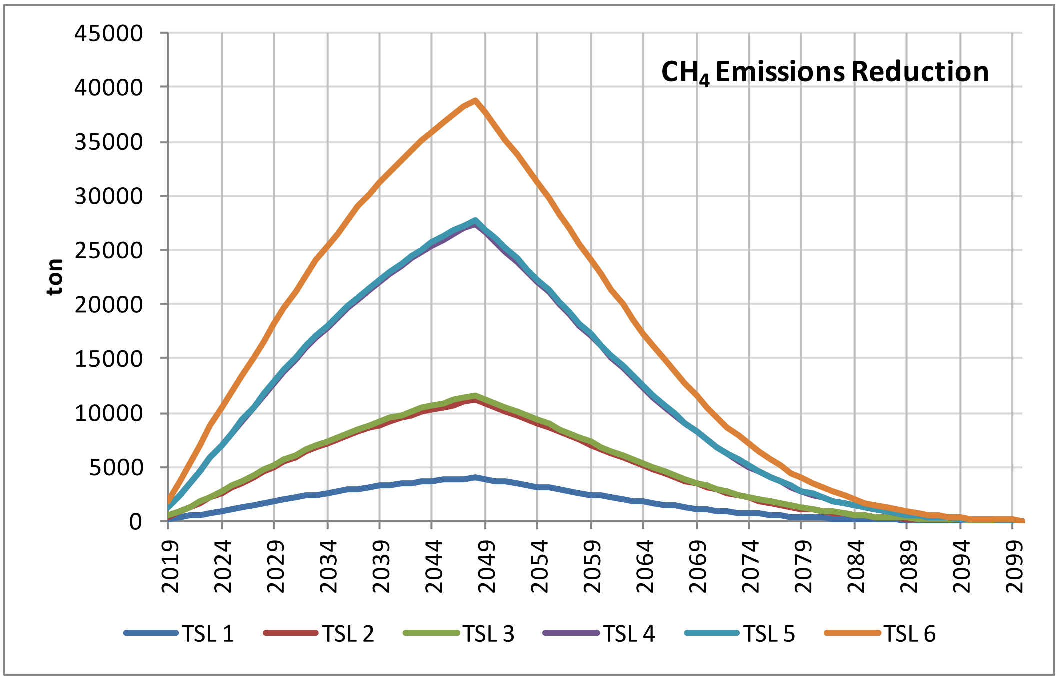

Figure 13.5.6 Furnace Fans: CH$_4$ Total Emissions Reduction

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14.1 INTRODUCTION

As part of its assessment of energy conservation standards for furnace fans, DOE estimated the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X) that are expected to result from each of the TSLs considered. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the benefits estimates considered.

14.2 MONETIZING CARBON DIOXIDE EMISSIONS

14.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b) of Executive Order 12866, agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to allow agencies to incorporate the monetized social benefits of reducing CO_2 emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

14.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council[1] points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2.[2] These interim values represented the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules.

14.2.3 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates, which were considered for this proposed rule. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[a] These models are frequently cited in the peer-reviewed literature and were used in the last assessment of the

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[a] The models are described in appendix 14-A of the TSD.

Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses.[b] (The 2010 report is reproduced in appendix 14-A.) Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time, as depicted in Table 14.2.1. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects,[c] although preference is given to consideration of the global benefits of reducing CO_2 emissions.

The SCC values used for the NOPR were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature.[d] Table 14.2-2 shows the updated sets of SCC estimates in five year increments from 2010 to 2050. Appendix 14-B provides the full set of SCC estimates, as well as the 2013 report from the interagency group. The central value that emerges is the average SCC across models at the 3 percent discount rate. However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance of including all four sets of SCC values.

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[b] *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, February 2010. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf

[c] It is recognized that this calculation for domestic values is approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time.

[d] *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, April 2013.

Table 14.2-1 Annual SCC Values from 2010 Interagency Report, 2010 – 2050 (in 2007 dollars per metric ton)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Table 14.2-2 Annual SCC Values from 2013 Interagency Update, 2010–2050 (in 2007 dollars per metric ton CO_2)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95th Percentile
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced CO_2 emissions, DOE used the values from the 2013 interagency report, which is reprinted in appendix 14-B of this TSD, escalated to 2012$ using the GDP price deflator. For each of the four cases specified, the values used for emissions in 2015 were $12.9, $40.8, $62.2, and $117.0 per metric ton avoided. DOE derived values after 2050 using the relevant growth rates for the 2040-2050 period in the interagency update.

DOE multiplied the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

14.3 VALUATION OF OTHER EMISSIONS REDUCTIONS

DOE considered the potential monetary benefit of reduced NO_X emissions from the TSLs it considered. As noted in chapter 13, new or amended energy conservation standards would reduce NO_X emissions in those 22 States that are not affected by caps. DOE estimated the monetized value of NO_X emissions reductions resulting from each of the TSLs considered based on environmental damage estimates found in the relevant scientific literature. Available estimates suggest a very wide range of monetary values, ranging from $468 to $4,809 per ton in 2012$).[4] In accordance with OMB guidance, DOE calculated a range of monetary benefits using each of the economic values for NO_X and real discount rates of 3 percent and 7 percent.[5]

DOE is still evaluating appropriate values to use to monetize avoided SO_2 and Hg emissions. It did not monetize these emissions for the furnace fan NOPR.

14.4 RESULTS

Table 14.4.1 presents the global values of CO_2 emissions reductions for each considered TSL. DOE calculated domestic values as a range from 7 percent to 23 percent of the global values, and these results are presented in Table 14.4.2.

Table 14.4.1 Estimates of Global Present Value of CO_2 Emissions Reduction for Potential Standards for Furnace Fans

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2012$			
Power Sector and Site Emissions**				
1	298	1531	2499	4725
2	1121	5747	9378	17733
3	1161	5951	9711	18363
4	2177	11165	18221	34452
5	2205	11309	18455	34894
6	2944	15103	24652	46603
Upstream Emissions				
1	10	51	82	156
2	31	160	262	495
3	32	164	268	506
4	70	359	585	1106
5	70	360	588	1111
6	97	497	810	1531
Total Emissions				
1	308	1582	2581	4880
2	1152	5907	9639	18228
3	1193	6115	9978	18869
4	2247	11524	18807	35558
5	2275	11669	19043	36005
6	3041	15600	25462	48134

* For each of the four cases, the corresponding SCC value for emissions in 2015 are $12.9, $40.8, $62.2, and $117.0 per metric ton (2012$).

** Includes site emissions associated with additional use of natural gas by more-efficient furnace fans.

Table 14.4.2 Estimates of Domestic Present Value of CO_2 Emissions Reduction for Potential Standards for Furnace Fans

TSL	SCC Case*			
	5% discount rate, average	3% discount rate, average	2.5% discount rate, average	3% discount rate, 95th percentile
	million 2012$			
Power Sector and Site Emissions**				
1	20.9 to 68.6	107.2 to 352.2	174.9 to 574.7	330.7 to 1086.7
2	78.5 to 257.8	402.3 to 1321.8	656.4 to 2156.8	1241.3 to 4078.5
3	81.3 to 267.0	416.6 to 1368.8	679.8 to 2233.5	1285.4 to 4223.6
4	152.4 to 500.7	781.6 to 2568.0	1275.5 to 4190.9	2411.6 to 7923.9
5	154.4 to 507.2	791.6 to 2601.0	1291.9 to 4244.7	2442.6 to 8025.6
6	206.1 to 677.0	1057.2 to 3473.8	1725.6 to 5669.9	3262.2 to 10718.7
Upstream Emissions				
1	0.7 to 2.3	3.5 to 11.6	5.8 to 19.0	10.9 to 35.8
2	2.2 to 7.2	11.2 to 36.9	18.3 to 60.2	34.7 to 113.9
3	2.2 to 7.4	11.5 to 37.7	18.7 to 61.5	35.4 to 116.3
4	4.9 to 16.1	25.1 to 82.5	41.0 to 134.6	77.4 to 254.4
5	4.9 to 16.2	25.2 to 82.8	41.1 to 135.1	77.8 to 255.5
6	6.8 to 22.3	34.8 to 114.2	56.7 to 186.3	107.2 to 352.2
Total Emissions				
1	21.6 to 70.9	110.7 to 363.8	180.7 to 593.7	341.6 to 1122.5
2	80.7 to 265.0	413.5 to 1358.7	674.8 to 2217.1	1275.9 to 4192.4
3	83.5 to 274.4	428.1 to 1406.5	698.5 to 2295.0	1320.8 to 4339.9
4	157.3 to 516.8	806.7 to 2650.5	1316.5 to 4325.5	2489.1 to 8178.4
5	159.3 to 523.4	816.8 to 2683.8	1333.0 to 4379.8	2520.3 to 8281.0
6	212.8 to 699.3	1092.0 to 3588.0	1782.3 to 5856.2	3369.4 to 11070.9

* For each of the four cases, the corresponding SCC value for emissions in 2015 are$12.9, $40.8, $62.2, and $117.0 per metric ton (2012$).

** Includes site emissions associated with additional use of natural gas by more-efficient furnace fans.

Table 14.4.3 presents the present value of cumulative NO_X emissions reductions for each TSL, calculated using the average dollar-per-ton values and seven-percent and three-percent discount rates.

Table 14.4.3 Estimates of Present Value of NO_X Emissions Reduction for Potential Standards for Furnace Fans

TSL	3% Discount Rate	7% Discount Rate
	million 2012$	
Power Sector and Site Emissions*		
1	31.0	10.7
2	116.4	40.0
3	120.7	41.4
4	226.2	77.8
5	229.2	78.8
6	306.1	105.3
Upstream Emissions		
1	12.4	4.4
2	39.0	13.9
3	39.9	14.3
4	88.0	31.6
5	88.4	31.7
6	122.3	44.0
Total Emissions		
1	43.4	15.1
2	155.4	53.9
3	160.5	55.7
4	314.2	109.4
5	317.6	110.6
6	428.3	149.3

* Includes site emissions associated with additional use of natural gas by more-efficient furnace fans.

REFERENCES

1. National Research Council, *Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use*, 2009. National Academies Press. Washington, DC. <http://www.nap.edu/catalog.php?record_id=12794>

2. Interagency Working Group on Social Cost of Carbon, *Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866,* February, 2010. United States Government. <http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>

3. Interagency Working Group on Social Cost of Carbon, *Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, Technical Model Update for the Social Cost of Carbon (SCC): Internal EPA Draft,* February 13, 2013. United States Government.

4. U.S. Office of Management and Budget (OMB), *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, 2006. Washington, DC. <http://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/2006_cb/2006_cb_final_report.pdf>

5. U.S. Office of Management and Budget (OMB), *Circular A-4: Regulatory Analysis,* 2003. (Posted September 17, 2003) (Last accessed April, 2013.) <http://www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf>

APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866[a]

14A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

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[a] Prepared by Interagency Working Group on Social Cost of Carbon, United States Government.
With participation by:
Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Energy and Climate Change
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 14A.1.1 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

	Discount Rate			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

14A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. We report estimates of the SCC in dollars per metric ton of carbon dioxide throughout this document.[b]

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

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[b] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67 (the molecular weight of CO_2 divided by the molecular weight of carbon = 44/12 = 3.67).

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, "to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020. See section 16-A.5 for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues raised in this document and consider public comments as part of the ongoing interagency process.

14A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a "domestic" SCC value of \$2 per ton of CO_2 and a "global" SCC value of \$33 per ton of CO_2 for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO_2. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO_2 (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO_2 for 2007 emission reductions (in 2007 dollars). In addition, EPA's 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as "very preliminary" SCC estimates subject to revision. EPA's global mean values were \$68 and \$40 per ton CO_2 for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO_2 emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO_2. The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The \$55 and \$10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The \$19 value was chosen as a central value between the \$5 and \$33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in connection with proposed rules, including the joint EPA-DOT fuel economy and CO_2 tailpipe emission proposed rules.

14A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, the interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable, since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

14A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.[c] These models are frequently cited in the peer-

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[c] The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy. is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socioeconomic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in "natural capital." By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), "other vulnerable market sectors" (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact "catastrophic" climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea's (2009) review concludes that "in general, DICE assumes very effective adaptation, and largely ignores adaptation costs."

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.[d]

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a "discontinuity" (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on

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[d] Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we re-calibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

the absolute temperature change but also on the rate of temperature change and level of regional income.[e] In the forestry and agricultural sectors, economic damages also depend on CO_2 concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he characterizes several omitted impacts as "big unknowns": for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, "Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues."

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO_2 fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO_2 fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers' current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figures 16A.4.1 and 16A.4.2, using the modeler's default scenarios and mean input assumptions. There are significant differences between the three models both at lower (figure 16A.4.2) and higher (figure 16A.4.1) increases in global-average temperature.

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[e] In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

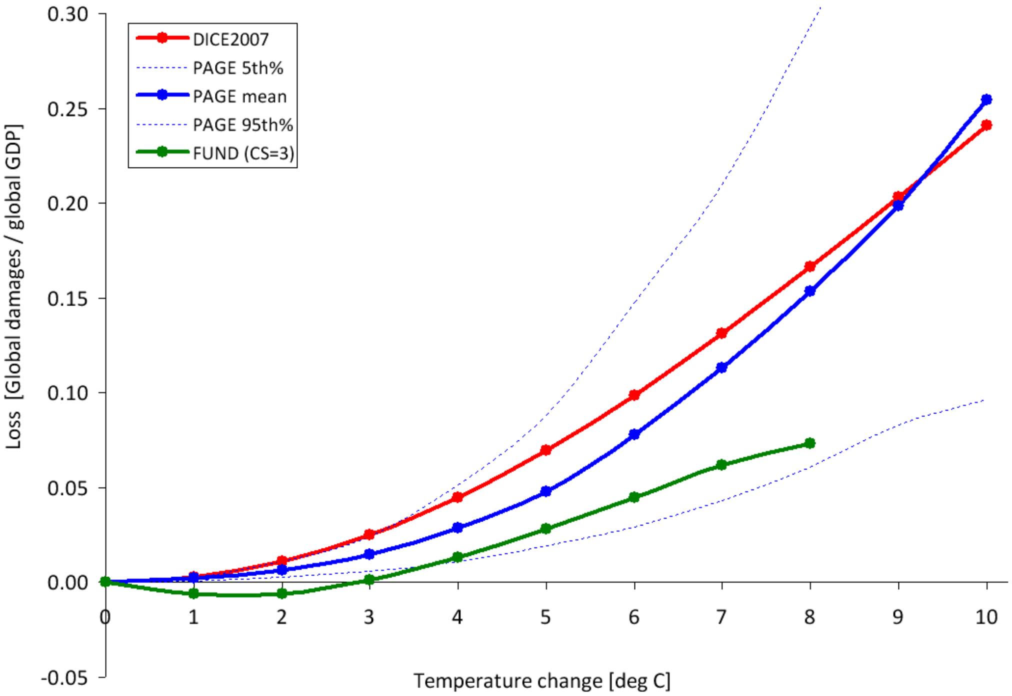

Figure 14A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models[f]

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is

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[f] The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socioeconomic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

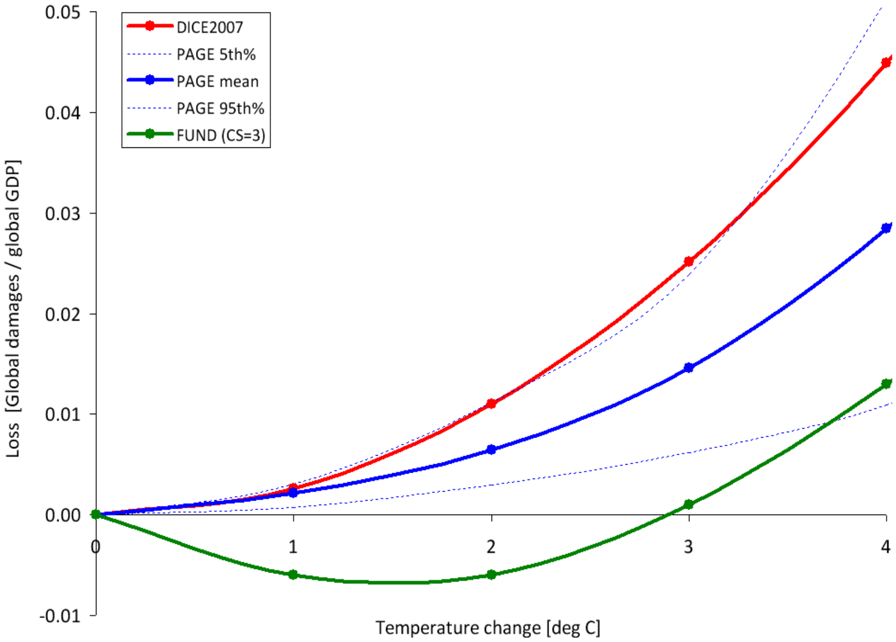

Figure 14A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

14A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.[g]

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the

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[g] It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ "equity weighting" to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of $500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of $2,000 than in one with a per-capita GDP of $40,000. The main argument for this approach is that a loss of $500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.[h] For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.[i]

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are

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[h] It is plausible that a loss of $X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate "equity weight" is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

[i] Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic SCC become available, the Federal government will examine these to determine whether to update its approach.

14A.4.3 Valuing Non-CO_2 Emissions

While CO_2 is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO_2. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO_2 emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO_2 fertilization. Thus, transforming gases into CO_2-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO_2 gases.

In light of these limitations, and the significant contributions of non-CO_2 emissions to climate change, further research is required to link non-CO_2 emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO_2 greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

14A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.[j] It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

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[j] The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

> *Basing our assessment on a combination of several independent lines of evidence…including observed climate change and the strength of known feedbacks simulated in [global climate models], we conclude that the global mean equilibrium warming for doubling CO_2, or 'equilibrium climate sensitivity', is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C.* [k]
>
> *For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range.* (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 16A.4.1 included below gives summary statistics for the four calibrated distributions.

Table 14A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

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[k] This is in accord with the judgment that it "is likely to lie in the range 2 °C to 4.5 °C" and the IPCC definition of "likely" as greater than 66 percent probability (Le Treut et al.2007). "Very likely" indicates a greater than 90 percent probability.

(1) a median equal to 3°C, to reflect the judgment of "a most likely value of about 3 °C";[1]
(2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
(3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that "values substantially higher than 4.5°C still cannot be excluded." Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity "is very likely larger than 1.5°C." Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of "very likely" as "greater than 90 percent probability," it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

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[1] Strictly speaking, "most likely" refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or "most likely" value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

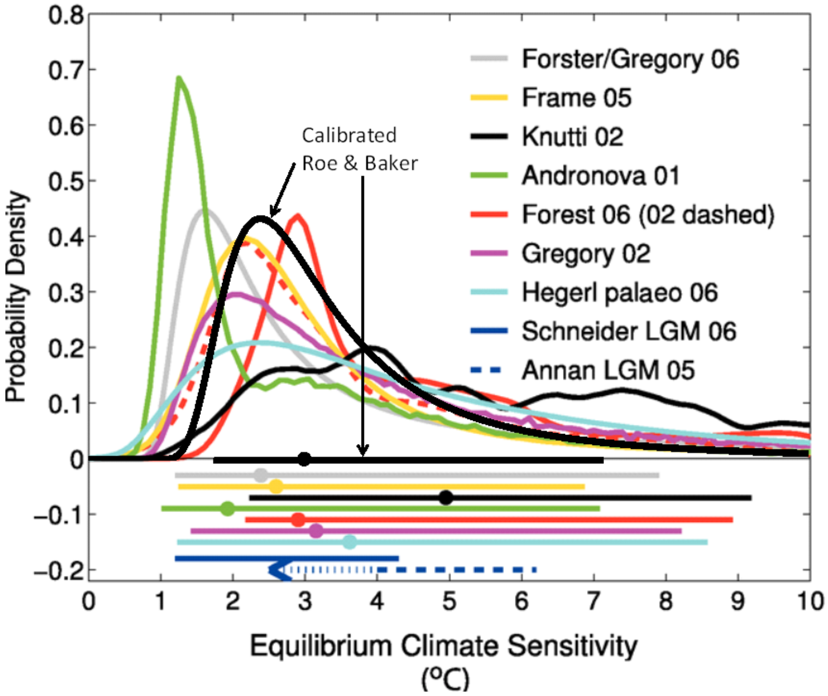

Figure 14A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 16A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.[m]

14A.4.5 Socioeconomic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socioeconomic and emissions parameters for use in PAGE, DICE, and FUND. Socioeconomic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO_2 emissions, and non-CO_2 radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

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[m] The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socioeconomic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 16A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO_2 (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO_2e (i.e., CO_2-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m^2) in 2100, a lower-than-BAU trajectory.[n] Out of the 10 models included in the EMF-22 exercise, we selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO_2e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

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[n] Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

Table 14A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO_2 Emissions ($GtCO_2$/yr)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005$)[o]

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)

EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways.

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[o] While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtsmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).[p] Second, the socioeconomic trajectories associated with a 550 ppm CO_2e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.[q] We chose not to include socioeconomic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be $51.8, $71.0 and $93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO_2 emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Annex for greater detail.

14A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated

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[p] For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

[q] For example, MiniCAM projects if all non-US OECD countries reduce CO_2 emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO_2 concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.” For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return “because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use” (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word “potentially” is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).[r] This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.[s] A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity

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[r] The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

[s] The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes, which yields a real rate of roughly 5 percent.[t]

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).[u] These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.[v] In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the "Ramsey discount rate," $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η. Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.[w] Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

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[t] Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

[u] The parameter ρ □measures the *pure rate of time preference*: people's behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

[v] In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

[w] Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth (CRRA < 2) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

- ρ. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an inter-generational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).

- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. ☐The choice

the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.[x]

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate of greater than 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η, we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the

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[x] Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and the variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.[y] A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).[z]

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously

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[y] For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

[z] Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.[aa] Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

14A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year *t*.

For each of the IAMs, the basic computational steps for calculating the SCC in a particular year *t* are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.

2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.

[aa] Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

    a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
    b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.
    c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.

3. Add an additional unit of carbon emissions in year *t.* (The exact unit varies by model.)

4. Recalculate the temperature effects and damages expected in all years beyond *t* resulting from this adjusted path of emissions, as in step 2.

5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)

6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.

7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.

8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO_2 (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO_2 in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no IAM or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 16A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 14A.5.1 Disaggregated Social Cost of CO_2 Values by Model, Socioeconomic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

	Discount rate:	**5%**	**3%**	**2.5%**	**3%**
Model	*Scenario*	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around $9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around $9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to $8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.[bb]

[bb] Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ, and 0.5, 1, and 2 for η, respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of ρ = 0, 1, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g, varies over time but is treated deterministically in two of the three models. In DICE, g is

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 16A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

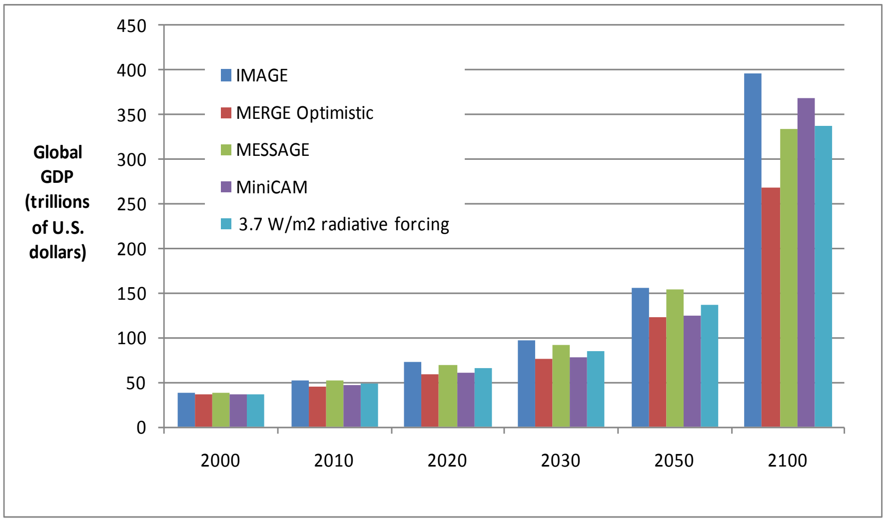

Figure 14A.5.1 Level of Global GDP across EMF Scenarios

Table 16A.5.2 shows the four selected SCC values in five-year increments from 2010 to 2050. Values for 2010, 2020, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

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endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

Table 14A.5.2 Social Cost of CO_2, 2010 – 2050 (in 2007 dollars)

Discount Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 16A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	**5%** Avg	**3%** Avg	**2.5%** Avg	**3.0%** 95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.[cc]

14A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO_2 emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold “are limited and do not apply to a wide range of potential uncertain scenarios."

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-

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[cc] However, it is possible that other benefits or costs of proposed regulations unrelated to CO_2 emissions will be discounted at rates that differ from those used to develop the SCC estimates.

impact, low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.[dd] For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs understate or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, but lower-impact, damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

[dd] However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that "the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon." Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

14A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models' functional forms may not adequately capture: (1) potentially discontinuous "tipping point" behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic "tipping points" at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 16A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 16A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socioeconomic and emission trajectories of $113 per ton of CO_2 is almost double the value estimated by DICE, $58 per ton in 2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 14A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shifts into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Sterner and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

14A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO_2 in 2015 and \$26 per ton of CO_2 in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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14A.9 ANNEX

Table 14A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex provides additional technical information about the non-CO_2 emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300 and shows the full distribution of 2010 SCC estimates by model and scenario combination.

14A.9.1 Other (non-CO2) gases

In addition to fossil and industrial CO_2 emissions, each EMF scenario provides projections of methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and net land use CO_2 emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO_2 EMF emissions only, we calculated the RF associated with the EMF atmospheric CO_2 concentrations and subtracted them from the EMF total RF.[ee] This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO_2 gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH_4, N_20, SF_6, and the CO_2 emissions from land were replaced with the EMF values.

PAGE: PAGE models CO_2, CH_4, sulfur hexafluoride (SF_6), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH_4 and SF_6 factors[ff], decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH_4, N_20, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO_2 emissions were added to the fossil and industrial CO_2 emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO_2 emissions is embedded in an exogenous non-CO_2 RF vector. To decompose this exogenous forcing path into EMF non-CO_2 gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO_2 sources is -0.06 W/m^2 in 2005, as reported in AR4, and increases linearly to 0.3 W/m^2 in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH_4, N_20, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was $0.48 + 0.16 + 0.34 = 0.98$ W/m^2 and RF from total aerosols was -1.2 W/m^2. Thus, the -.06 W/m^2 non-CO_2 forcing in DICE can be

---

[ee] Note EMF did not provide CO_2 concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial, and land CO_2 emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO_2 concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

[ff] Both the model default CH_4 emissions and the initial atmospheric CH_4 is set to zero to avoid double counting the effect of past CH_4 emissions.

decomposed into: 0.98 W/m^2 due to the EMF non-CO_2 gases, -1.2 W/m^2 due to aerosols, and the remainder, 0.16 W/m^2, due to other residual forcing.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO_2 gases based on the following two assumptions:

> (1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter; and
> (2) With respect to RF from non-CO_2 gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

> *Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulfur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.*[gg]

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, the figure below shows that the sulfur dioxide emissions peak over the short term of some SRES scenarios above the upper bound estimates of the more recent scenarios.[hh] Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.[ii] The lower-bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

[gg] AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

[hh] See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

[ii] See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. Environmental Science and Technology, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. Science, 294(5548): 1835-1837.

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m^2; forcing due to other non-CO_2 gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m^2.

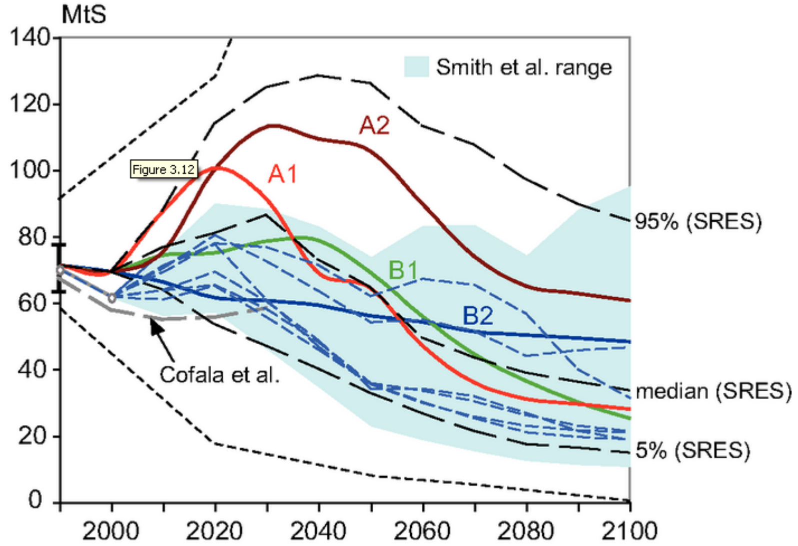

Figure 14A.9.2 Sulfur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th, and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO_2 emissions scenarios developed pre-SRES.
Source: IPCC (2007), AR4 WGIII 3.2, http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than $2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or $0.50-$3)–depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO_2 emissions are added to the fossil and industrial CO_2 emissions pathway.

14A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in the year 2300.
3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non-CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).[jj] The resulting range of EMF population trajectories (figure below) also encompass the UN medium scenario forecasts through 2300—global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non-CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

[jj] United Nations. 2004. *World Population to 2300*. http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf

Figures below show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non-CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

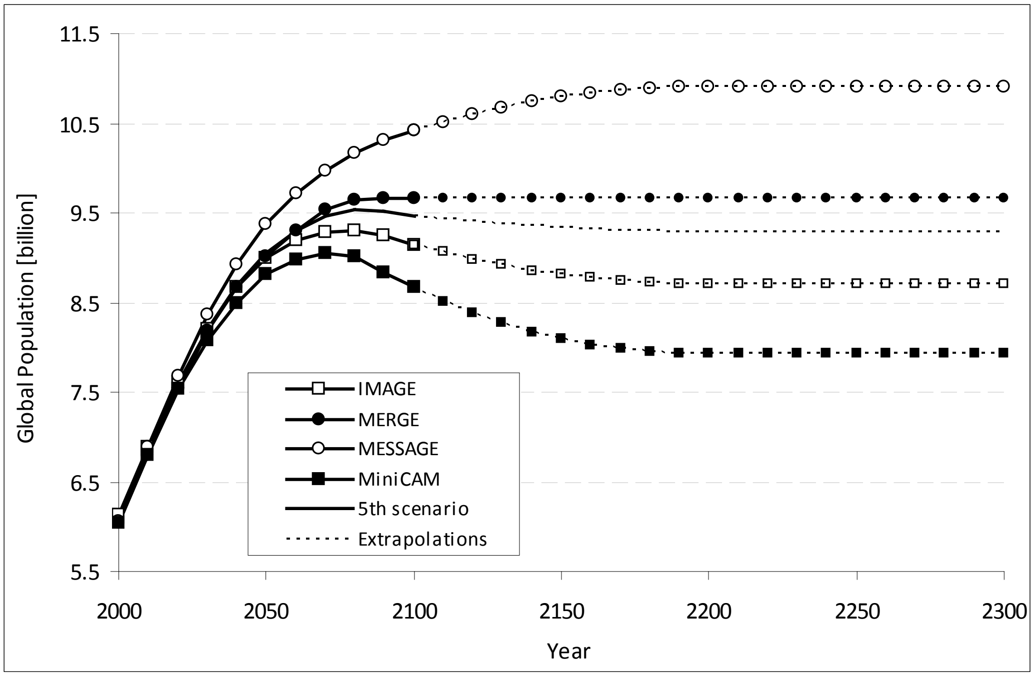

Figure 14A.9.3 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

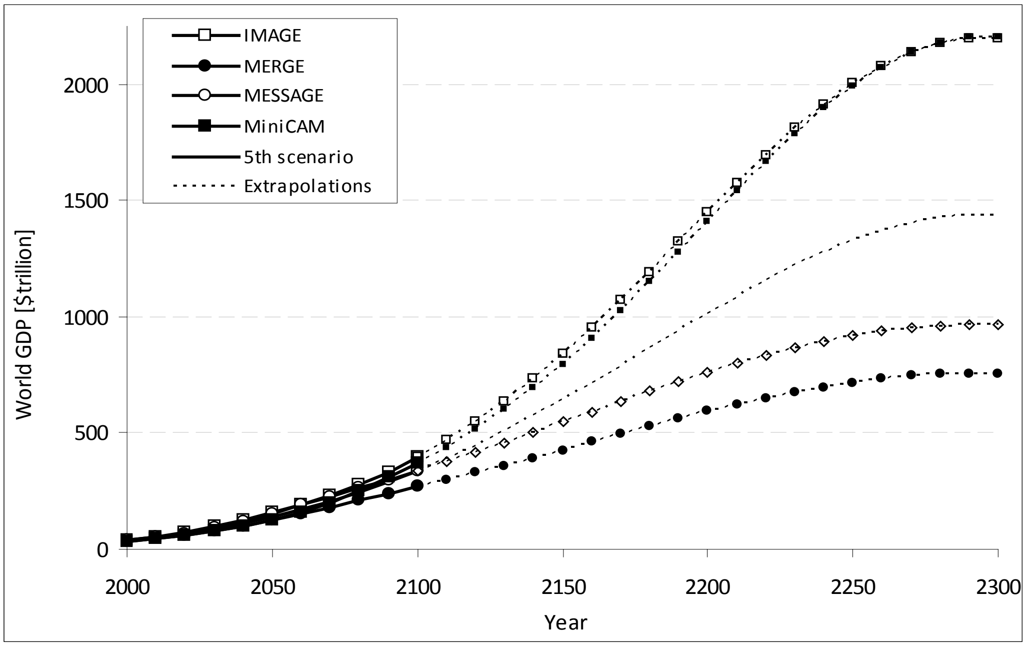

Figure 14A.9.4 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

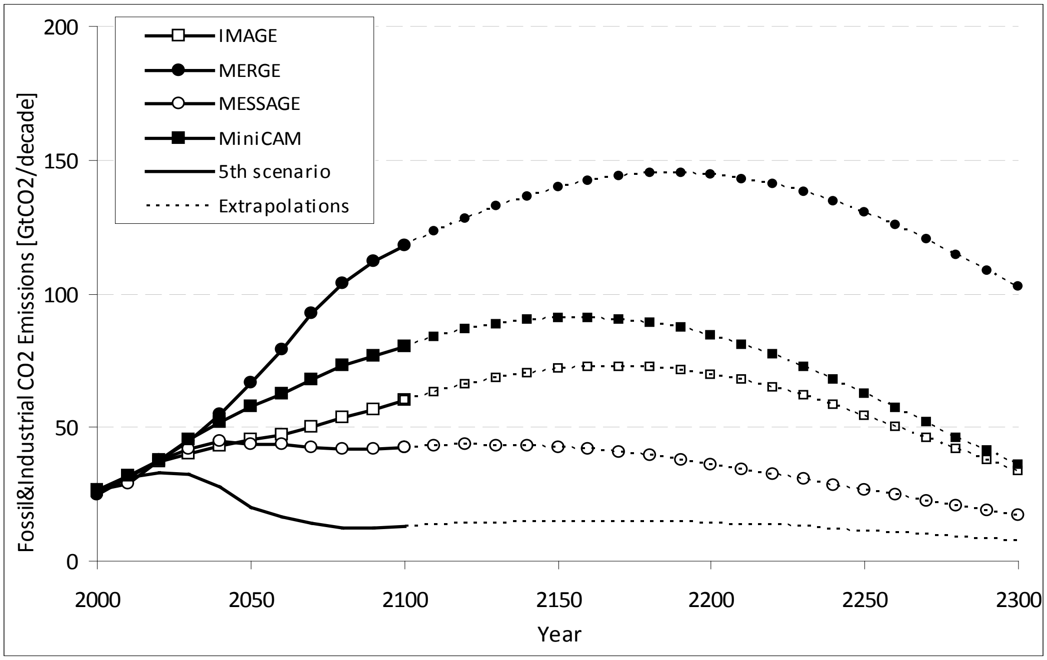

Figure 14A.9.5 Global Fossil and Industrial CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO_2 intensity (CO_2/GDP) over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

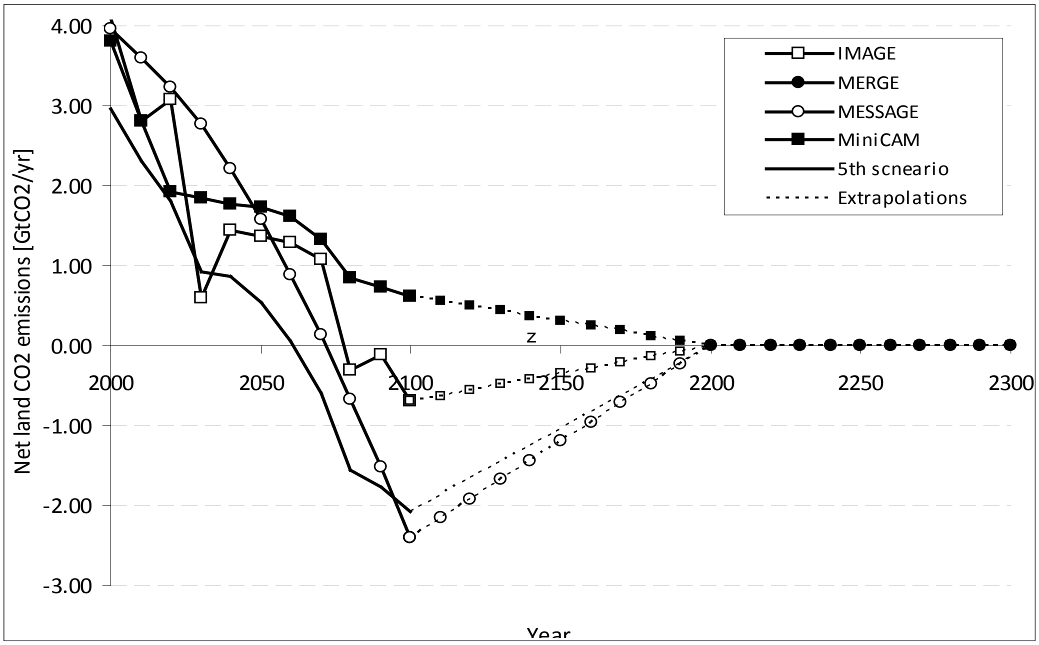

Figure 14A.9.6 Global Net Land Use CO_2 Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)[kk]

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

[kk] MERGE assumes a neutral biosphere so net land CO_2 emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

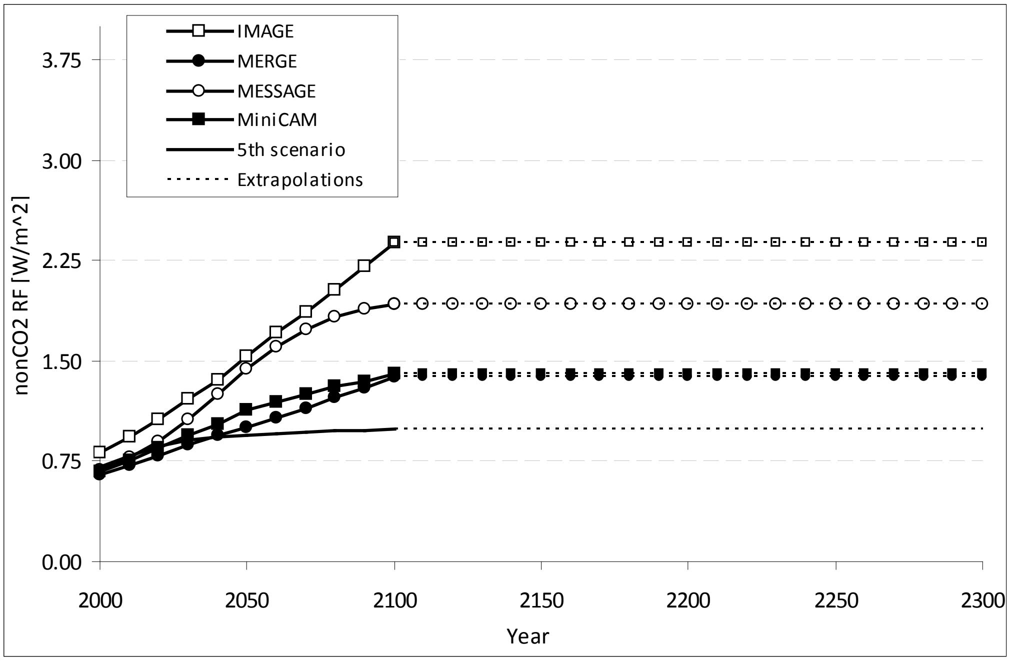

Figure 14A.9.7 Global Non-CO_2 Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO_2 radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

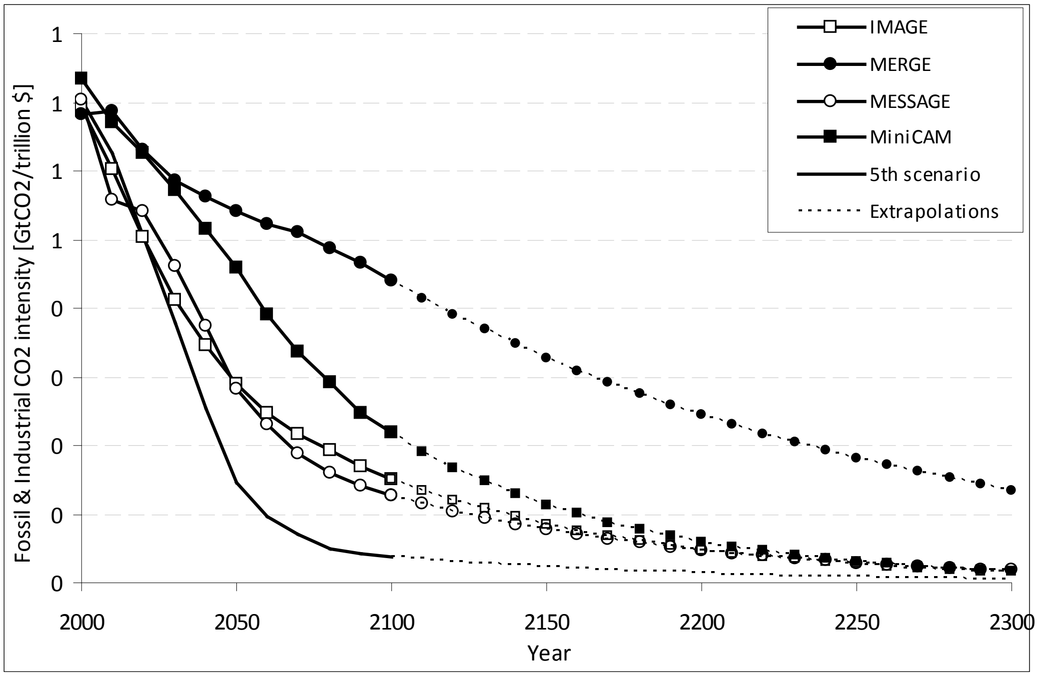

Figure 14A.9.8 Global CO_2 Intensity (fossil & industrial CO_2 emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO_2/GDP growth rate over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO_2e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 14A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9
Scenario	**DICE**									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8
Scenario	**FUND**									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 14A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

Scenario	**DICE**									
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

Scenario	**FUND**									
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 14A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007\$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	**PAGE**									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7
Scenario	**DICE**									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0
Scenario	**FUND**									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

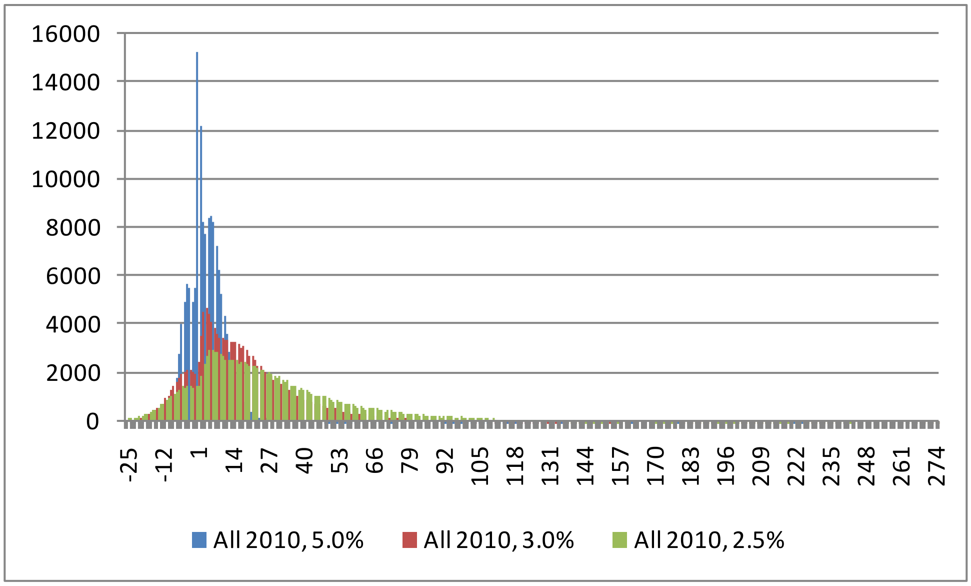

Figure 14A.9.9 Histogram of Global SCC Estimates in 2010 (2007\$/ton CO_2), by discount rate

* The distribution of SCC values ranges from -\$5,192 to \$66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 14A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#######
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 14-B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

14-B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report of the Interagency Working Group on the Social Cost of Carbon of the United States Government. Minor changes were made to the working group's report to make it more consistent with the rest of this technical support document.

14-B.2 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC) [a] estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).[1] E.O. 13563 commits the Administration to regulatory decision making "based on the best available science."[b] Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.[c] New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO_2 emissions are quantified.

Section 14-B.3 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 14-B.4 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models.

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[a] In this document, we present all values of the SCC as the cost per metric ton of CO_2 emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO_2 and the mass of carbon is 3.67.

[b] http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

[c] See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).[1]

14-B.3 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

14-B.3.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)[2] and on DICE2010 in Nordhaus (2010)[3] and the associated on-line appendix containing supplemental information.

14-B.3.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are "calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)" (Nordhaus 2008 p 44).[2d] Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).[3] For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each

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[d] MAGICC is a simple climate model initially developed within the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from much more sophisticated state of the art earth system simulation models (Randall et al. 2007).[4]

decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

14-B.3.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.[e] The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.[4] [f] The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

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[e] Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.

[f] For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)[5] and NAS (2011).[6]

14-B.3.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),[3] who notes that "…damages in the uncontrolled (baseline) [i.e., reference] case … in 2095 are $12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

14-B.3.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.[g] Notable changes, due to their impact on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.[h] We discuss each of these in turn.

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[g] http://www.fund-model.org/. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013).[7] For the purpose of computing the SCC, the relevant changes are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH4 and N2O and incorporating the indirect forcing effects of CH4, along with making minor stability improvements in the sea wall construction algorithm.

[h] The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not the subject of significant updates.

14-B.3.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

14-B.3.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

14-B.3.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0,\infty)$ and $(-\infty,0]$, respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the "lost" value approached (+/-) infinity). The net effect of this change on the SCC estimates is difficult to predict.

14-B.3.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year's increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year's level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

14-B.3.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).[8] FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH4 emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increase by 40% to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

14-B.3.3 PAGE

PAGE09 (Hope 2012)[9] includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).[10, 11, 12] A description of PAGE2002 can be found in Hope (2006).[13]

14-B.3.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

14-B.3.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

14-B.3.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region’s coastline relative to the EU (Hope 2011b).[11] Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC’s third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

14-B.3.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a “discontinuity” were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of "discontinuity" is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

14-B.3.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)[12] estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

14-B.3.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO_2 absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO_2 emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

14-B.4 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.[1] The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

Table 14-B.4.1 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 14-B.4.1 Revised Social Cost of CO_2, 2010 – 2050 (in 2007 dollars per ton of CO_2)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	95th
2010	11	33	52	90
2015	12	38	58	109
2020	12	43	65	129
2025	14	48	70	144
2030	16	52	76	159
2035	19	57	81	176
2040	21	62	87	192
2045	24	66	92	206
2050	27	71	98	221

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 14-B.4.2 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

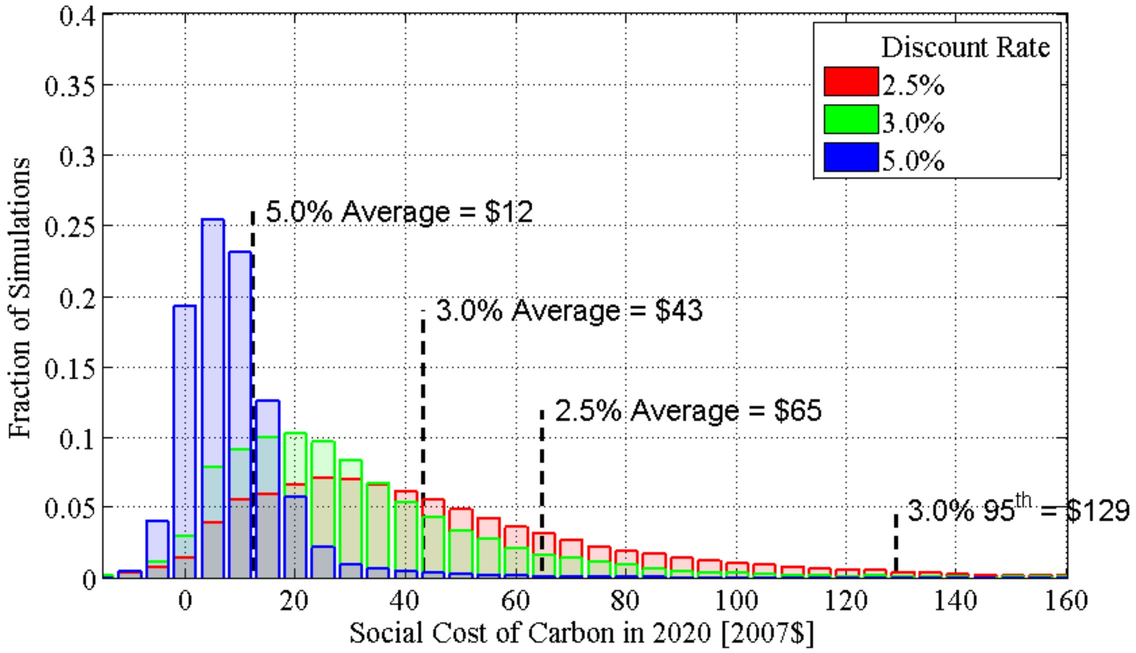

Figure 14-B.4.2 Distribution of SCC Estimates for 2020 (in 2007$ per ton CO_2)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models through running them for a set of perturbation years out to 2050. Table 14-B.4.2 illustrates how the growth rate for these four SCC estimates varies over time.

Table 14-B.4.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.2%	2.4%	4.3%
2020-2030	3.4%	2.1%	1.7%	2.4%
2030-2040	3.0%	1.8%	1.5%	2.0%
2040-2050	2.6%	1.6%	1.3%	1.5%

The future monetized value of emission reductions in each year (the SCC in year t multiplied by the change in emissions in year t) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

14-B.5 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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ANNEX

Table 14-B.5.1 Annual SCC Values: 2010-2050 (2007$/ton CO_2)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	95th
2010	11	33	52	90
2011	11	34	54	94
2012	11	35	55	98
2013	11	36	56	102
2014	11	37	57	106
2015	12	38	58	109
2016	12	39	60	113
2017	12	40	61	117
2018	12	41	62	121
2019	12	42	63	125
2020	12	43	65	129
2021	13	44	66	132
2022	13	45	67	135
2023	13	46	68	138
2024	14	47	69	141
2025	14	48	70	144
2026	15	49	71	147
2027	15	49	72	150
2028	15	50	73	153
2029	16	51	74	156
2030	16	52	76	159
2031	17	53	77	163
2032	17	54	78	166
2033	18	55	79	169
2034	18	56	80	172
2035	19	57	81	176
2036	19	58	82	179
2037	20	59	84	182
2038	20	60	85	185
2039	21	61	86	188
2040	21	62	87	192
2041	22	63	88	195
2042	22	64	89	198
2043	23	65	90	200
2044	23	65	91	203
2045	24	66	92	206
2046	24	67	94	209
2047	25	68	95	212
2048	25	69	96	215
2049	26	70	97	218
2050	27	71	98	221

Table 14-B.5.2 202 Global SCC Estimates at 2.5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955

Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126

Scenario	FUND									
IMAGE	-17	-1	5	17	34	44	59	90	113	176
MERGE	-7	2	7	16	30	35	49	72	91	146
MESSAGE	-19	-4	2	12	27	32	46	70	87	135
MiniCAM Base	-9	1	8	18	35	45	59	87	108	172
5th Scenario	-30	-12	-5	6	19	24	35	57	72	108

Table 14-B.5.3 SCC Estimates at 3 Percent Discount Rate (2007$/ton CO2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660

Scenario	DICE									
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79

Scenario	FUND									
IMAGE	-14	-3	1	9	20	25	35	54	69	111
MERGE	-8	-1	3	9	18	22	31	47	60	97
MESSAGE	-16	-5	-1	6	16	18	28	43	55	88
MiniCAM Base	-9	-1	3	10	21	27	35	53	67	107
5th Scenario	-22	-10	-5	2	10	13	20	33	42	63

Table 14-B.5.4 2020 Global SCC Estimates at 5 Percent Discount Rate (2007$/ton CO_2)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario					PAGE					
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208

Scenario					DICE					
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21

Scenario					FUND					
IMAGE	-9	-5	-3	-1	2	3	6	11	15	25
MERGE	-6	-3	-2	0	3	4	7	12	16	27
MESSAGE	-10	-6	-4	-1	2	2	5	9	13	23
MiniCAM Base	-7	-3	-2	0	3	4	7	11	15	26
5th Scenario	-11	-7	-5	-2	0	0	3	6	8	14

CHAPTER 15. UTILITY IMPACT ANALYSIS

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CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, DOE analyzes the changes in electric installed capacity and generation that result for each trial standard level (TSL).

The utility impact analysis uses a variant of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). DOE uses a variant of this model, referred to as NEMS-BT,[b] to account for selected utility impacts of energy conservation standards. DOE's analysis consists of a comparison between model results for the most recent AEO Reference Case and for cases in which energy use is decremented to reflect the impact of standards. For the analysis of standards on furnace fans, DOE used the version of NEMS based on *AEO 2012*.[2]

NEMS-BT has a number of advantages that have led to its use in the analysis of energy conservation standards:

- NEMS-BT uses a set of assumptions that are well known and fairly transparent, due to the exposure and scrutiny each *AEO* receives.
- NEMS-BT is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS-BT permits the modeling of interactions among the various energy supply and demand sectors.

15.2 METHODOLOGY

DOE uses NEMS-BT to estimate the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. In practice, the numerical differences between marginal and average values may turn out to be smaller than the intrinsic uncertainties in the AEO.

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview*.[1]

[b] DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on DOE/EIA assumptions, DOE refers to it by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed).

NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation (TWh) from the stock of electric generating capacity changes, the total generation capacity itself (GW) may change, and the mix of capacity by fuel type may change. Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use.

To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity and total generation. Regional effects of a standard can be accounted for by defining the energy demand decrement as a function of census division.

The output of the NEMS-BT analysis includes the effective marginal heat rate (ratio of the change in energy consumption in quads to the change in generation in TWh), and the capacity reduction by plant type for a given reduction in total generation. DOE uses the site energy savings multiplied by a T&D loss factor to estimate the reduction in generation for each TSL. The relationship between a reduction[c] in electricity generation (TWh) and the reduction in capacity (GW) is estimated based on the output of NEMS-BT model runs using the end-use specific energy demand decrement. Details on the approach used may be found in Coughlin (2013).[3]

NEMS-BT provides output for the following capacity types: coal, nuclear, combined cycle (natural gas), renewable sources, oil and natural gas steam, combustion turbine/diesel, pumped storage, fuel cells, and distributed generation (natural gas). DOE grouped oil and natural gas steam and combustion turbine/diesel into a “peaking” category, and grouped pumped storage, fuel cells, and distributed generation (natural gas) into an “other” category.

In general, energy conservation standards impact primarily fossil combustion (coal, natural gas and diesel) and renewables. Pumped storage and nuclear power are very insensitive to small changes in demand, while fuel cells and distributed generation make up a very small fraction (less than 1%) of the generation capacity base.

15.3 UTILITY IMPACT RESULTS

This section presents results of the analysis for all of the capacity types except “Other”, for which the impacts are very small.

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[c] These reductions are defined relative to the AEO Reference case.

15.3.1 Installed Capacity

The figures in this section show the changes in U.S. electricity installed capacity that result for each TSL by major plant type for selected years. The changes have been calculated based on factors (MW of capacity reduction per GWh of generation reduction) estimated from a NEMS-BT model run that simulated a decrement in energy demand for a load shape that approximates furnace fans. Note that a negative number means an increase in capacity under a TSL.

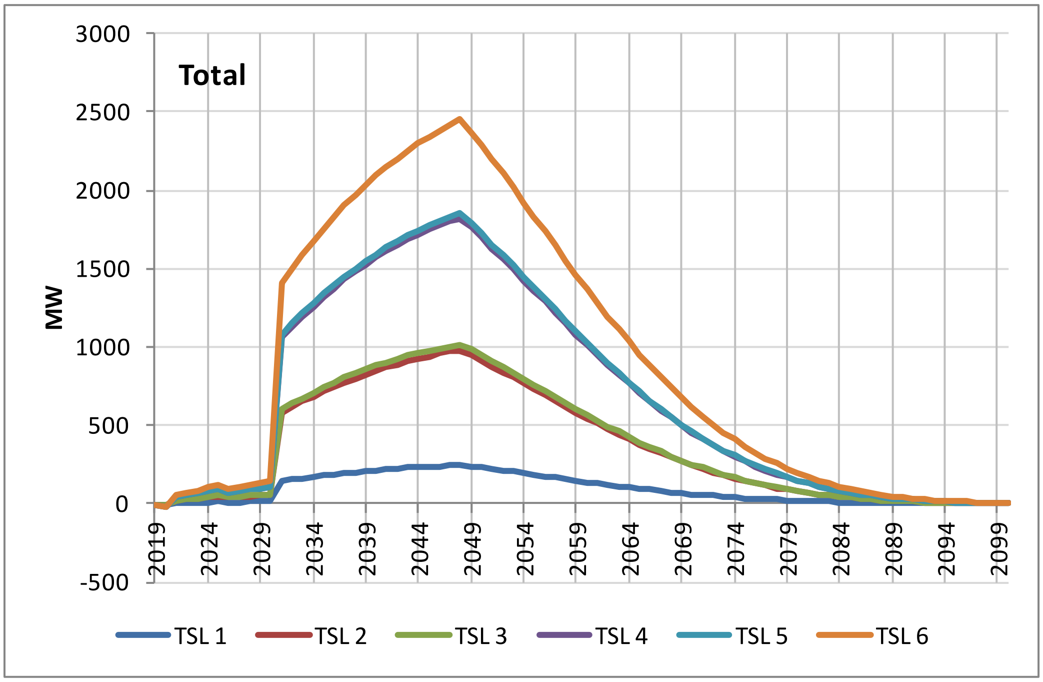

Figure 15.3.1 Furnace Fans: Total Electric Capacity Reduction

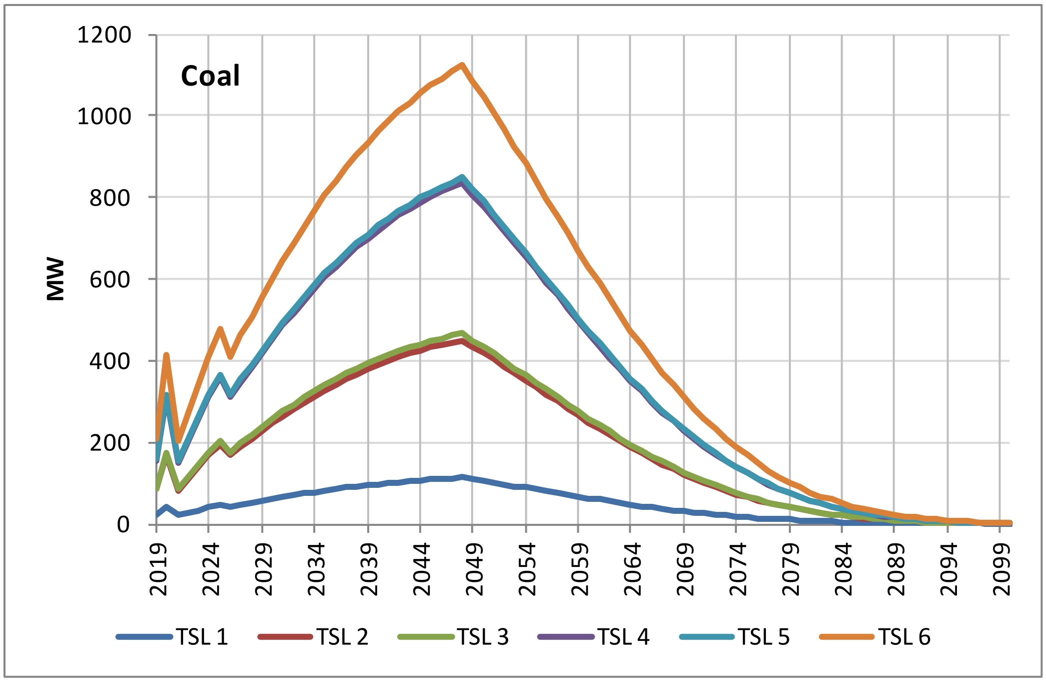

Figure 15.3.2 Furnace Fans: Coal Capacity Reduction

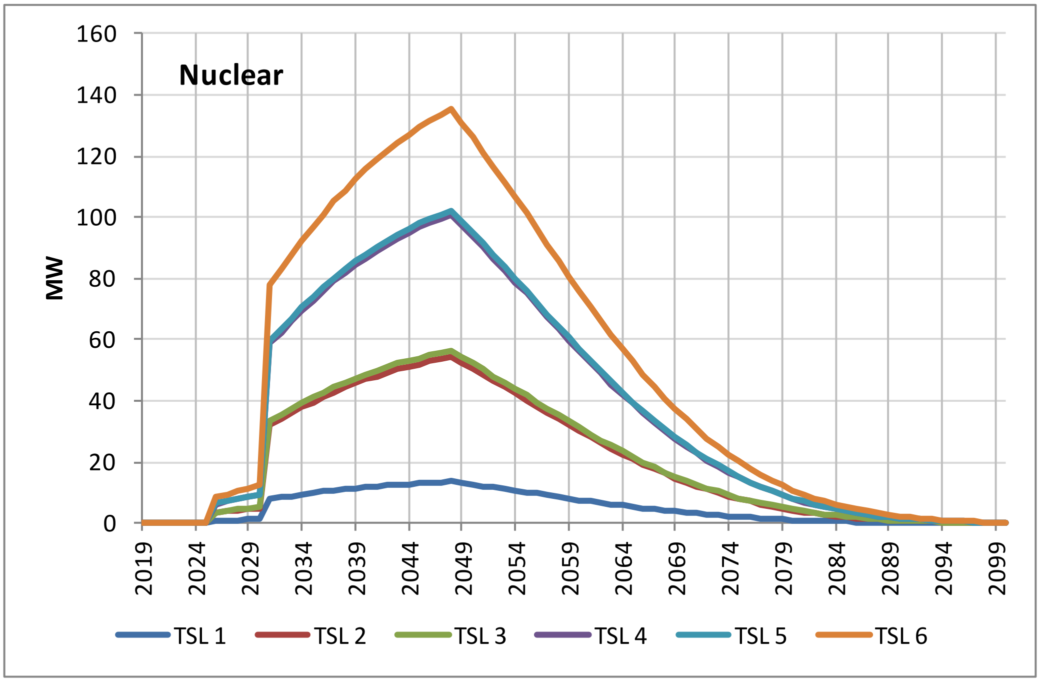

Figure 15.3.3 Furnace Fans: Nuclear Capacity Reduction

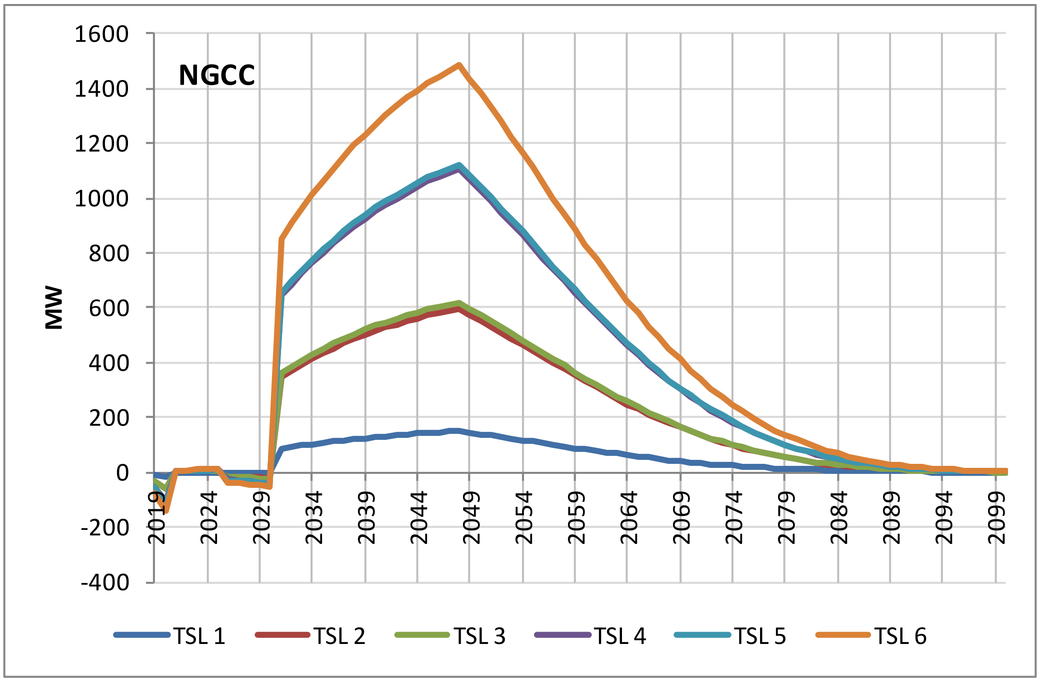

Figure 15.3.4 Furnace Fans: Gas Combined Cycle Capacity Reduction

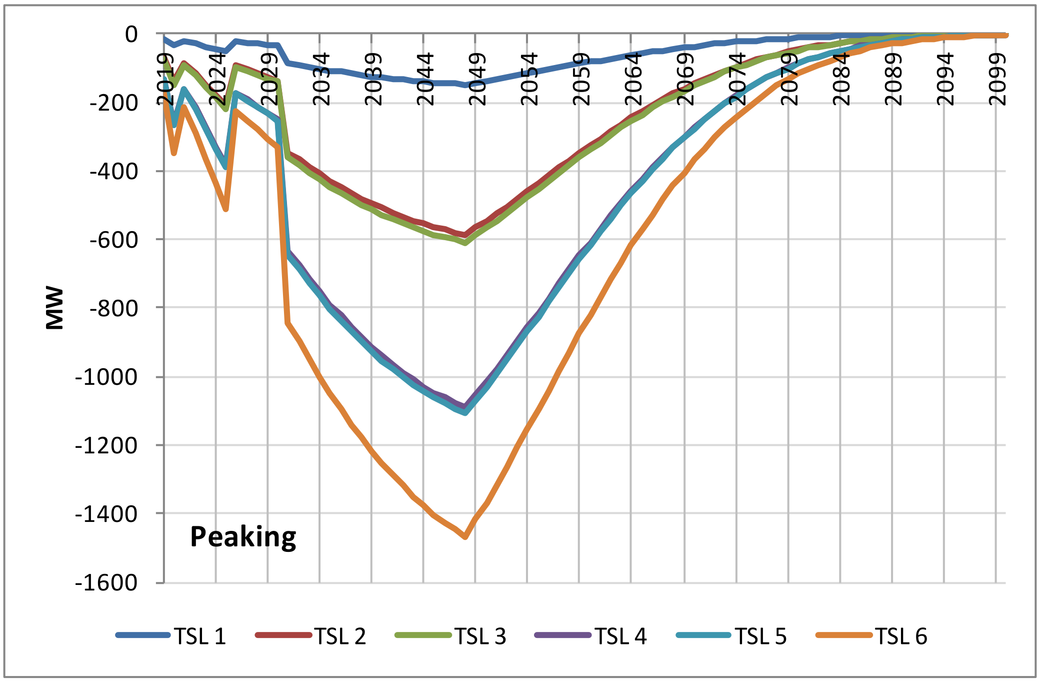

Figure 15.3.5 Furnace Fans: Peaking Capacity Reduction

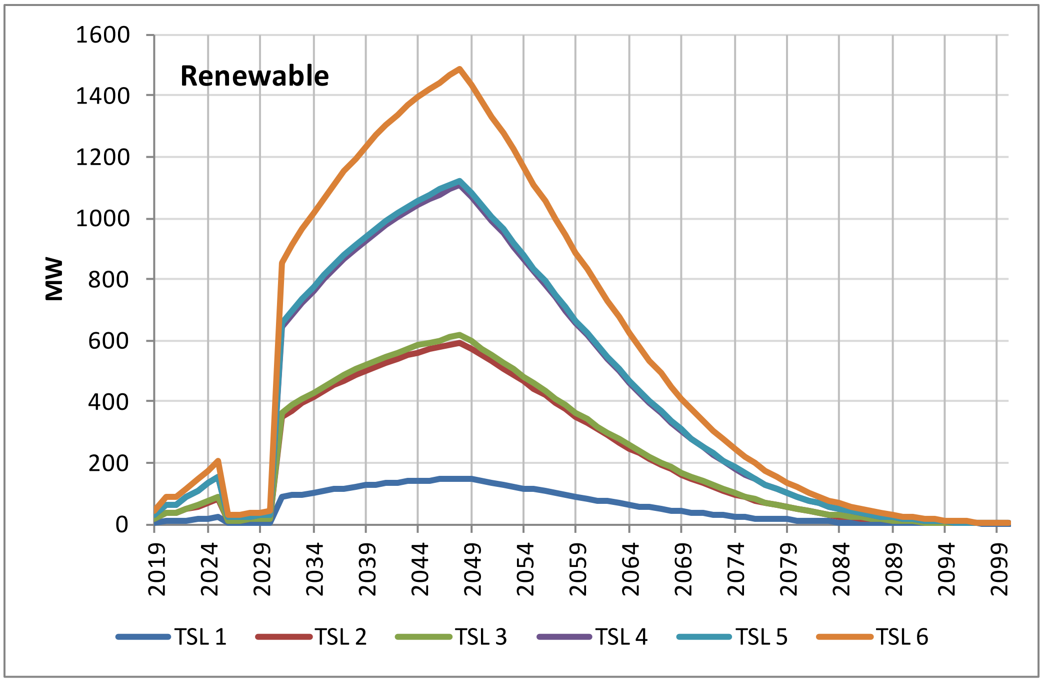

Figure 15.3.6 Furnace Fans: Renewables Capacity Reduction

15.3.2 Electricity Generation

The figures in this section show the annual change in electricity generation that result for each TSL by plant type. The change by capacity type has been calculated based on shares (percentage of generation reduction for each capacity type over total generation reduction) estimated from a NEMS-BT model run that simulated a decrement in energy demand for a load shape that approximates furnace fans. Coal-fired power plants account for most of the generation reduction.

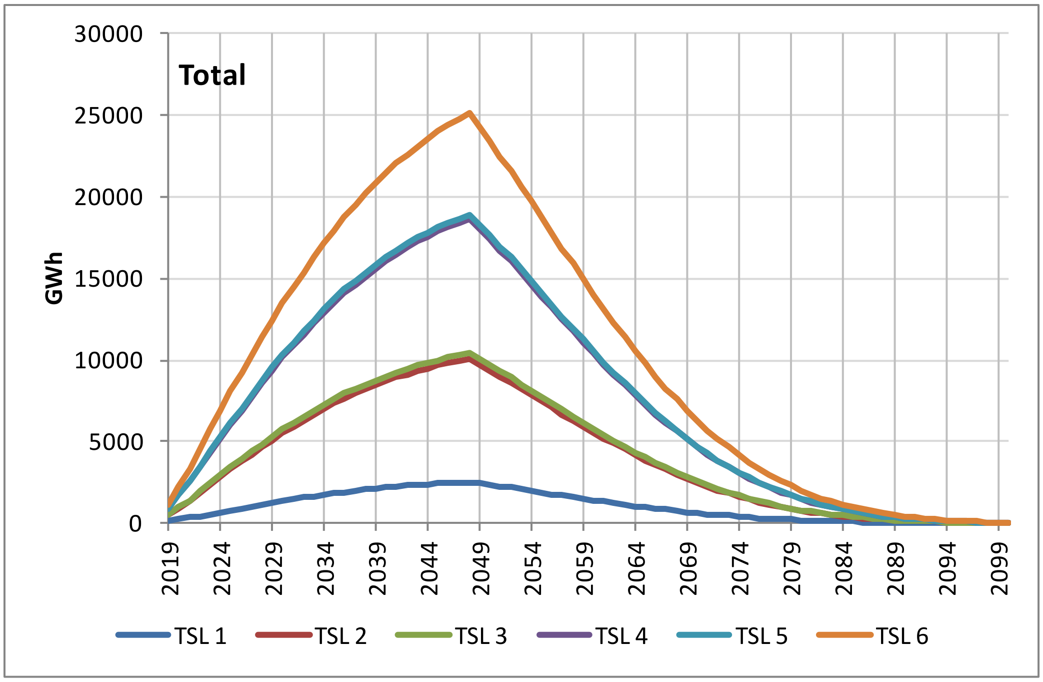

Figure 15.3.7 Furnace Fans: Total Generation Reduction

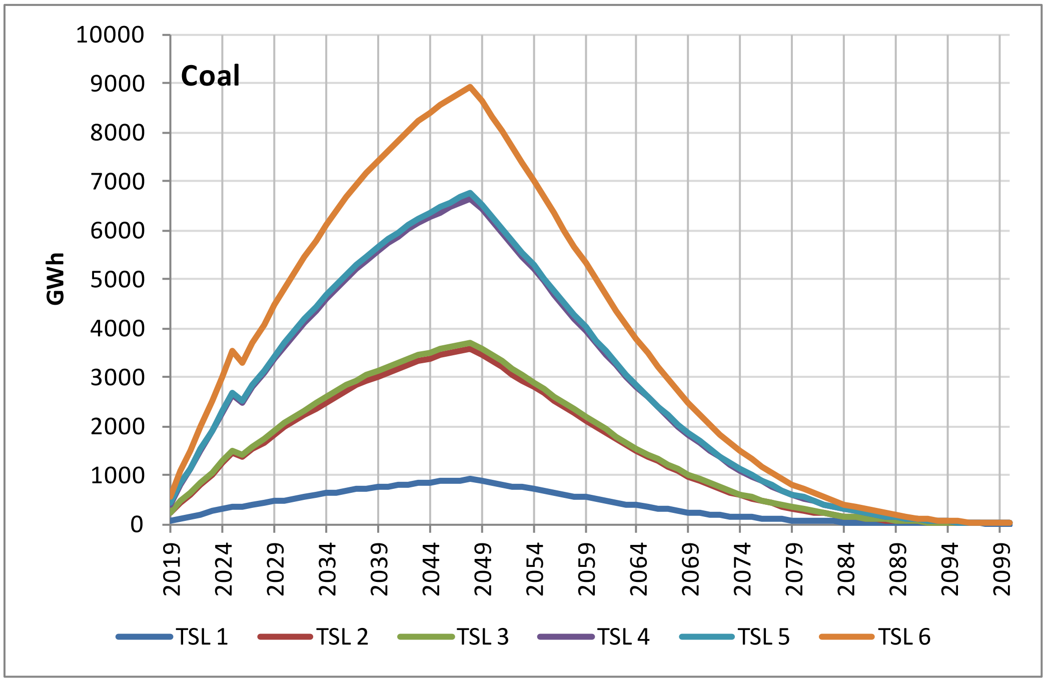

Figure 15.3.8 Furnace Fans: Coal Generation Reduction

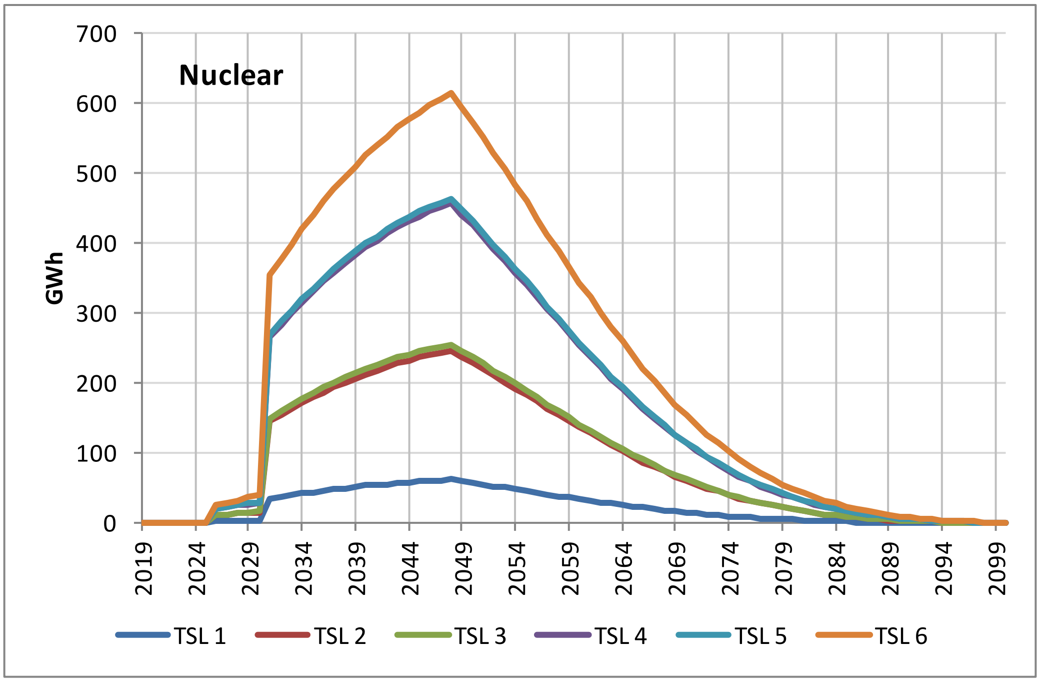

Figure 15.3.9 Furnace Fans: Nuclear Generation Reduction

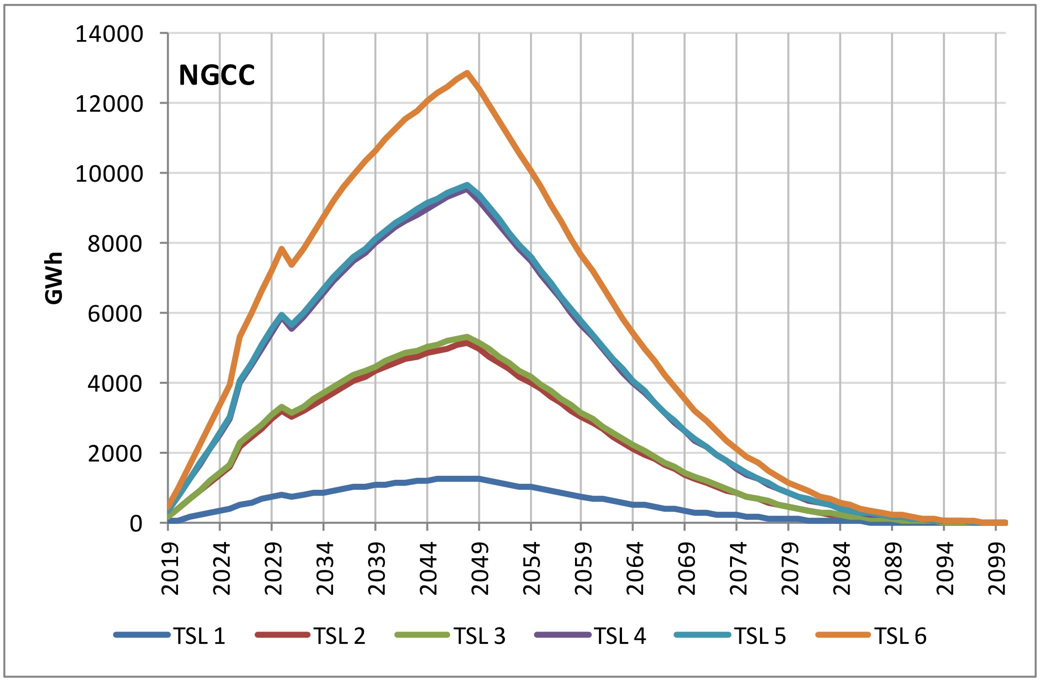

Figure 15.3.10 Furnace Fans: Gas Combined Cycle Generation Reduction

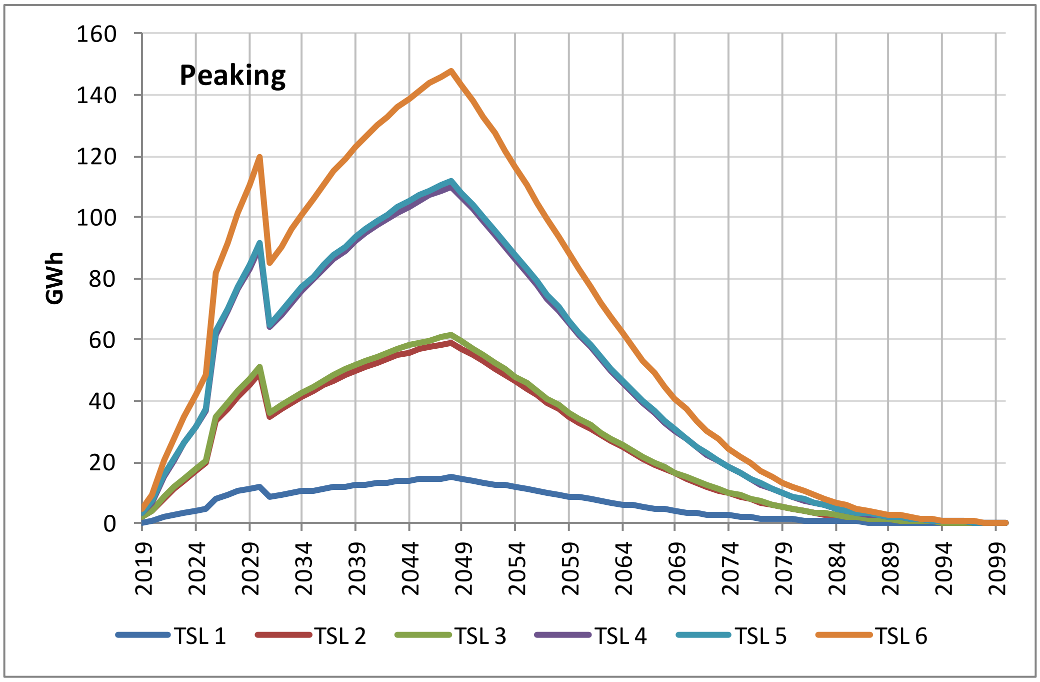

Figure 15.3.11 Furnace Fans: Peaking Generation Reduction

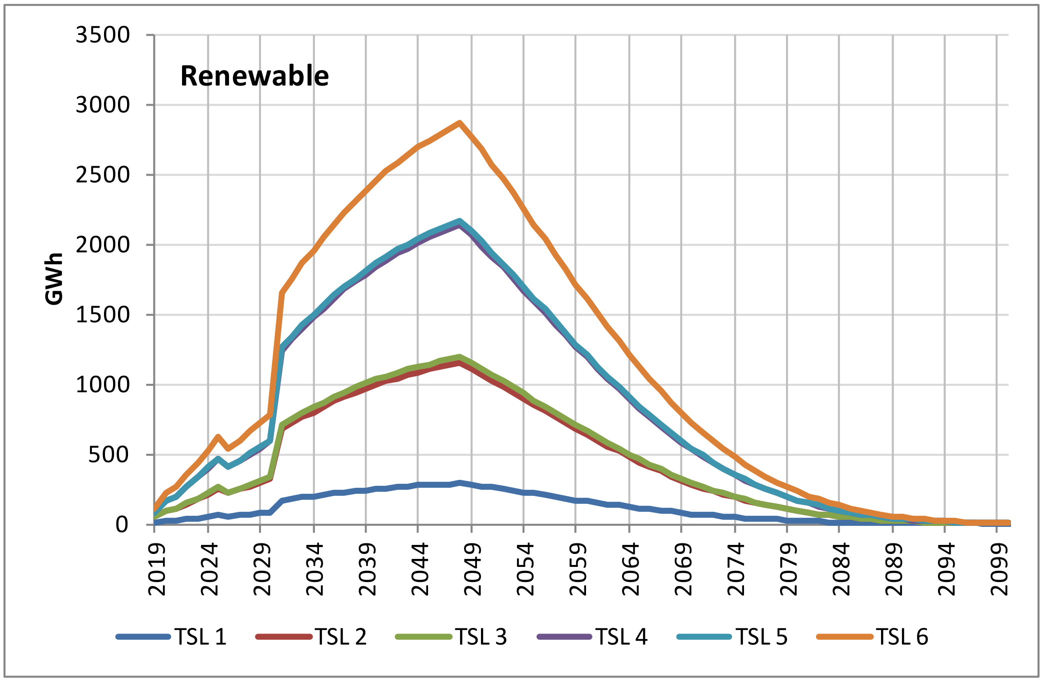

Figure 15.3.12 Furnace Fans: Renewables Generation Reduction

15.3.3 Results Summary

Table 15.3.1 presents a summary of the utility impact results for furnace fans.

Table 15.3.1 Furnace Fans: Summary of Utility Impact Results

	TSL					
	1	**2**	**3**	**4**	**5**	**6**
Installed Capacity Reduction (MW)						
2020	-3	-11	-11	-20	-20	-26
2025	12	49	51	89	91	119
2030	15	58	61	107	109	142
2035	179	716	743	1319	1339	1754
2040	213	850	882	1570	1594	2095
Electricity Generation Reduction (GWh)						
2020	225	918	959	1701	1731	2272
2025	815	3300	3437	6081	6179	8082
2030	1374	5518	5735	10144	10302	13458
2035	1832	7329	7609	13502	13706	17953
2040	2183	8699	9026	16077	16315	21450

15.4 AVOIDED CAPACITY VALUATION

Section 15.3.1 described the reduction in electricity generation capacity resulting from potential standards for furnace fans. DOE used NEMS-BT to calculate a time series of capacity additions for the standards cases and the base case. Capacity additions refer to all power plants built; they may replace retired power plants or they may add new capacity to the power system. The cost of these annual capacity additions is determined by multiplying the capacity addition (in MW) by the cost of building new capacity. Table 15.4.1 shows the plant types and their associated plant costs as estimated by EIA, as well as how DOE matched the NEMS plant types to the EIA categories.

Table 15.4.1 Capital Costs for Electricity Generation Capacity

Plant Type	NEMS Capacity Type	Overnight Capital Cost* (2010 $/kW)
Coal (Dual Unit Advanced PC)	Coal	$2,844
Natural Gas (Conventional NGCC)	Combined Cycle	$978
Natural Gas(Conventional CT)	Combustion Turbine/Diesel	$974
Natural Gas (Advanced CT)	Distributed Generation (primarily peak-load capacity fueled by natural gas)	$665
Average Renewables	Renewable Sources (includes conventional hydroelectric, geothermal, wood, wood waste, municipal waste, landfill gas, other biomass)	$4,945

Source: Energy Information Administration, *Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010. Washington, DC.

* EIA updates its cost assumptions for electric generating capacity annually as part of the development of the *Annual Energy Outlook* (AEO). The "overnight" capital cost for a power plant is an estimate of the cost of building an entire power plant from planning through completion assuming that it is accomplished in a single day. This serves as a starting point for estimating power plant construction costs because it avoids the consideration of financing the project. The above overnight power plant costs were developed for AEO2011.

The present value of the cost of capacity additions over the period 2012-2040 was calculated for the potential standards cases and the base case using a discount rate of five percent.[d] A reduction of the net present value of the cost of capacity additions in the standards case is a positive avoided capacity benefit.

The avoided capacity benefit may result from reducing overall capacity additions compared to the base case or from delaying capacity additions. The delay in capacity additions can be isolated by adding capacity reductions from the standard to the end of the time series for standards case capacity additions. This new time series will then have the same total capacity additions as the base case while modeling the effect of the standard. The present value of this new time series will be representative of delayed capacity additions from the standard. Delaying capacity additions reduces the present value of expenditures because of the time value of money.

Table 15.4.2 shows the present value of the reduction in the cost of future capacity additions associated with each of the considered TSLs.

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[d] Although the standards for furnace fans would take effect in 2019, the power sector module in NEMS shows some changes in electric capacity in the standards case prior to 2019.

Table 15.4.2 Present Value of Reduced Costs of Electricity Generation Capacity Addition Due to Furnace Fan Standards*

TSL	Billion, 2012$
1	0.12
2	0.92
3	0.96
4	1.17
5	1.21
6	1.42

*Includes both delayed and reduced capacity impacts

Although delayed investment implies a savings in total cost, because the delay may also cause increases in other costs, the savings may be less than the savings in capital cost. For example, if the delayed investment was the replacement of an existing facility with a larger, more efficient facility, the increased cost of operating the old facility during the period of delay might offset much of the savings from delayed investment. That the project was delayed is evidence that doing so decreased overall cost, but it does not indicate that the decrease was equal to the entire savings in capital cost.

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16.1 INTRODUCTION

The U.S. Department of Energy's (DOE's) employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards, due to reallocation of the associated expenditures for purchasing and operating furnaces. Job increases or decreases reported in this chapter are separate from the direct manufacturing sector employment impacts reported in chapter 12 and reflect the employment impact of efficiency standards on all other sectors of the economy.

16.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption and, therefore, to reduce energy expenditures. The savings in energy expenditures may be spent on new investment or not at all (*i.e.,* they may remain "saved"). The standards may increase the purchase price of appliances, including the retail price plus sales tax, and increase installation costs.

Using an input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see chapter 12).

DOE notes that ImSET is not a general equilibrium forecasting model and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.[1] Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would over-estimate the magnitude of actual job impacts over the long run for this rule. As input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analyses. DOE, therefore, includes a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long-run employment impacts.

16.3 METHODOLOGY

The Department based its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1[2] (Impact of Sector Energy Technologies), as a successor to ImBuild[3], a special-purpose version of the IMPLAN[4] national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier approaches, ImSET allows for a more complete and automated analysis of the economic impacts of energy efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity, and changes in the level of spending (*e.g.,* due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affect the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial building technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (*e.g.,* changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient appliances. The increased cost of appliances leads to higher employment in the appliance manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, electric utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, electric utilities experience relative reductions in demand, which leads to reductions in utility sector investment and employment.

DOE also notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the furnace manufacturing sector estimated in chapter 12 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

16.4 SHORT-TERM RESULTS

The results in this section refer to impacts of furnace fan standards relative to the base case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs. DOE presents the summary impact.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors: the furnace production sector, the energy generation sector, and the general consumer good sector (as mentioned previously, ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the rule increases the purchase price of furnaces; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce consumer expenditures on electricity.

The reduction in electricity demand causes a reduction in employment in that sector. Finally, based on the net impact of increased expenditures on furnaces and reduced expenditures on electricity, consumer expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly. The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment. (As more workers are hired, they consume more goods, generating more employment; the converse is true for workers who are laid off.)

Table 16.4.1 presents the modeled net employment impact from the rule in 2019, rounded to the nearest ten jobs. As 100% of the furnaces under consideration are produced domestically, DOE does not evaluate import scenarios for this product.

Table 16.4.1 Net National Short-Term Change in Employment (Number of Jobs)

Trial Standard Level	2019	2024
1	100	550
2	750	4020
3	780	4170
4	1150	5440
5	1170	5540
6	2930	8290

For context, the unemployment rate was estimated to be 8.2% in June 2012; the Office of Management and Budget (OMB) currently projects that the official unemployment rate may decline to 7.3% in 2014 and drop further to 5.4% in 2019.[5] The unemployment rate in 2019 is projected to be close to "full employment." When an economy is at full employment, any effects on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

16.5 LONG-TERM IMPACTS

Due to the short payback period of energy efficiency improvements mandated by this rule, over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in appliance costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for electricity to decline over time and demand for other goods to increase. As the electricity generation sector is relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In equilibrium, this should lead to upward pressure on wages and a shift in employment away from electricity generation towards consumer goods. Note that, in a long-run equilibrium, there is no net effect on total employment, because wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will be negligible over time due to the small magnitude of the short-term effects presented in Table 16.4.1. The ImSET model projections, assuming no price or wage effects until 2024, are included in the second column of Table 16.4.1.

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CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

The U.S. Department of Energy (DOE) has determined that energy conservation standards for consumers of furnace fans constitute an "economically significant regulatory action" under Executive Order (E.O.) 12866, Regulatory Planning and Review. 58 FR 51735, Volume 58, No. 190, page 51735. (October 4, 1993). Under 10 CFR part 430, subpart C, appendix A, section III.12, DOE committed to evaluating non-regulatory alternatives to proposed standards by performing a regulatory impact analysis (RIA). 61 FR 36981, Volume 61, No. 136, page 36978. (November 15, 1996). This RIA, which DOE has prepared pursuant to E.O. 12866, evaluates potential non-regulatory alternatives, comparing the costs and benefits of each to those of the proposed standards. 58 FR 51735, page 51741. As noted in E.O. 12866, this RIA is subject to review by the Office of Management and Budget's Office of Information and Regulatory Affairs. 58 FR 51735, page 51740.

For this RIA, DOE used an integrated National Impact Analysis (NIA)-RIA model built on the NIA model discussed in chapter 10 for its analysis. DOE studied the impacts of the non-regulatory policies on the furnace fan product classes with the predominant market shares, which are non-weatherized gas furnaces, non-condensing and non-weatherized gas furnaces, condensing.

The NIA model for furnace fans was based on the NIA model that DOE used in its 2011 rulemaking for furnaces. Like the furnace NIA model, the furnace fan model splits the calculations for the Nation into two regions: North and South. While the national energy savings and net present value impacts reported in section 17.4 show results for both regions together, the inputs used to generate the changes in market share for consumer rebates and consumer and manufacturer tax credits are reported separately for each region in sections 17.3.2, 17.3.3 and 17.3.4.

DOE identified six non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency levels as the proposed standards for the products that are the subject of this rulemaking. The non-regulatory policy alternatives are listed in Table 17.1.1. DOE evaluated each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each to the effectiveness of the proposed standard. Because furnace fans are typically sold as part of furnaces, DOE did not analyze impacts from the Early Replacement policy for this product.

Table 17.1.1 Non-Regulatory Alternatives to National Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Early Replacement
Bulk Government Purchases

Sections 17.2 and 17.3 discuss the analysis of five selected policies listed above (excluding the alternatives of early replacement and no new regulatory action). Section 17.4 presents the results of the policy alternatives.

17.2 NON-REGULATORY POLICIES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the five non-regulatory policy alternatives for the identified furnace fans. DOE analyzed the product classes of non-weatherized gas furnaces (NWGF), non-condensing and NWGF, condensing, which comprise the majority of the market share of furnace fans. This section also describes the assumptions underlying the analysis.

17.2.1 Methodology

DOE used its integrated NIA-RIA spreadsheet model to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Chapter 10 of the technical support document (TSD) describes the NIA spreadsheet model. Appendix 17-A, section 17-A.3, discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of products that meet the target efficiency level, which is defined as the efficiency level in the proposed standards. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet model. The primary model inputs revised were market shares of products meeting target efficiency level. The shipments of products for any given year reflect a distribution of efficiency levels. DOE assumed that the proposed standards would affect 100 percent of the shipments of products that did not meet target level in the base case,[a] whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of furnace fans attributable to each policy alternative.

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[a] The base case for the NIA is a market-weighted average of units at several efficiency levels.

Increasing the efficiency of a product often increases its average installed cost. However, operating costs generally decrease because energy consumption declines. DOE therefore calculated an NPV for each non-regulatory alternative in the same way it did for the proposed standards. In some scenarios, increases in total installed cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would re-pay credits and rebates in some way (such as additional taxes), DOE did not include rebates or tax credits as a consumer benefit when calculating national NPV. DOE's analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPVs slightly.

The following are key measures for evaluating the impact of each alternative.

- National energy savings, given in quadrillion Btus (quads), describes the cumulative national primary energy savings for products bought during the period from the effective date of the policy (2019) through the end of the analysis period (2048).
- Net present value represents the value in 2012$ (discounted to 2012) of net monetary savings from products bought during the period from the effective date of the policy (2019) through the end of the analysis period (2048).
- DOE calculated the NPV as the difference between the present value of installed product cost and operating expenditures in the base case and the present value of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of the product.

17.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain, because they depend on program implementation, marketing efforts, and on consumers' responses to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will meet with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 17.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of new furnace fans relative to their base case efficiency scenario (which involves no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase units having the same efficiency level as required by the proposed standards (the target level). As opposed to the standards case, however, the policy cases may not lead to 100 percent market penetration of units that meet the target level.

Table 17.2.1 shows the efficiency level stipulated in the proposed standards for furnace fans for NWGF, non-condensing and NWGF, condensing.

Table 17.2.1 Trial Standard Levels for Furnace Fan Product Classes

Product Class	**Trial Standard Level 4 (Efficiency Level, Design Option)**
Non-Weatherized, Non-Condensing Gas Furnace Fan	4, Constant-torque BPM motor + multi-stage
Non-weatherized, Condensing Gas Furnace Fan	4, Constant-torque BPM motor + multi-stage

DOE assumed that the effects of non-regulatory policies would last from the effective date of standards—2019—through the end of the analysis period, which is 2048.

17.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as early replacement implemented with consumer rebates, or early replacement implemented with bulk government purchases. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive; the combined effect of several or all policies cannot be inferred from summing their results.

Section 17.4 presents graphs that show the market penetration estimated under each non-regulatory policy for the identified furnace fan product class.

17.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the five non-regulatory policy alternatives to proposed standards for furnace fans. (Because the alternative of No New Regulatory Action has no energy or NPV impacts, essentially representing the NIA base case, DOE did not perform any additional analysis for that alternative.) DOE developed estimates of the market penetration of high-efficiency products both with and without each of the non-regulatory policy alternatives.

17.3.1 No New Regulatory Action

The case in which no new regulatory action is taken with regard to the energy efficiency of furnace fans constitutes the base case, as described in chapter 10, National Impact Analysis. The base case provides the basis of comparison for all other policies. By definition, no new regulatory action yields zero energy savings and an NPV of zero dollars.

17.3.2 Consumer Rebates

DOE considered the scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing energy-efficient appliances. This policy provides a consumer rebate for purchasing furnace fans that operate at (or above) the same efficiency as stipulated in trial standards (target level).

17.3.2.1 Methodology

To inform its estimate of the market impacts of consumer rebates, DOE performed a thorough nationwide search for existing rebate programs for furnace fans. It gathered data on utility or agency rebates throughout the nation for furnace fans.

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. This study, performed by XENERGY, Inc.,[b] summarized experiences with various utility rebate programs.[1] XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,[2, 3, 4, 5, 6, 7] used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.[5] DOE decided that the most appropriate available method for this RIA analysis was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies. *Internal sources* of information encourage consumers to purchase new products primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 17-A, section 17-A.4.1, contains additional details on internal and external information diffusion.

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[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

XENERGY's model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY's model generates a set of penetration (or implementation) curves for a measure. XENERGY then calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient products driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived barriers (from no barriers to extremely high barriers) to consumer purchase of high-efficiency products.

DOE adjusted the XENERGY penetration curves based on expert advice founded on more recent utility program experience.[5, 8] DOE also devised an interpolation method to create penetration curves based on relationships between the actual base case market penetrations and actual B/C ratios. Appendix 17-A, sections 17-A.4.2 and 17-A.4.3, contain discussion on DOE's methodology for adjusting and interpolating the curves.

DOE modeled the effects of a consumer rebate policy for furnace fans by determining the increase in market penetration of products meeting the target level relative to their market penetration in the base case. It did this using the interpolated penetration curve created for furnace fans based on the XENERGY methodology to best reflect the market barrier level faced by this product class. Section 17.3.2.2 shows the interpolated curve used in the analysis.

17.3.2.2 Analysis

For the two furnace fan product classes it analyzed, DOE estimated the effect of increasing its B/C ratio via a rebate that would pay all of the increased installed cost of a unit that met the target efficiency level compared to one meeting the baseline efficiency level.[c] DOE based the rebate amounts on a sample of utility and agency rebate programs for furnace fans with ECM motors. DOE gathered data on 15 rebates for furnace fans with ECM motors initiated by 13 utilities or agencies in various States. (Appendix 17-A, section 17-A.5, identifies the rebate programs.) These rebates were offered for an efficient furnace fan component only, rather than being part of a composite rebate for a high-efficiency furnace with an ECM motor. To represent the rebate level, DOE used the simple average of the rebate amounts in these programs.

DOE assumed that rebates would remain in effect at the same levels throughout the forecast period (2019–2048).

For each of the two furnace fan product classes, DOE first calculated the B/C ratio without a rebate using the difference in total installed costs and lifetime operating cost savings

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[c] The baseline technology for each product class is defined in the engineering analysis, chapter 5, as the technology that represents the basic characteristics of products in that class. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

between the unit meeting the target level and the baseline unit. It then calculated the B/C ratio given a rebate for the unit meeting the target efficiency level. Because the rebate reduced the incremental cost, the unit receiving the rebate had a larger B/C ratio. Table 17.3.1 shows the effect of consumer rebates on the B/C ratio. The B/C value for units given rebates represents a weighted average[d] of the values for the efficiency levels at or above the target level to which the rebate would apply.

Table 17.3.1 Benefit/Cost Ratios Without and With Rebates for Furnace Fans in NWGF

	NWGFnc, North	**NWGFnc, South**	**NWGFc, North**	**NWGFc, South**
B/C Ratio Without Rebate	21.4	25.6	25.7	23.5
Rebate Amount (2012$)	104.33	104.33	104.33	104.33
B/C Ratio With Rebate	145.1	154.1	111.7	104.2
Calculated Market Barrier Curve	xHigh	xHigh	High - xHigh	High - xHigh

NWGFnc = non-weatherized gas furnace, non-condensing
NWGFc = non-weatherized gas furnace, condensing

DOE used these B/C ratios along with the penetration curves shown in Figure 17.3.1 to Figure 17.3.4 to estimate the percentage of consumers who would purchase furnace fans that meet the target level both with and without a rebate incentive. The curve calculated by DOE to represent the market behavior for non-condensing furnaces for both regions was the *extremely high barriers* penetration curve. The curves calculated for condensing furnaces in both regions were between the *high barriers* and the *extremely high barriers* penetration curves.

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[d] The weighting factor is the 2019 base-case market share of each corresponding efficiency level.

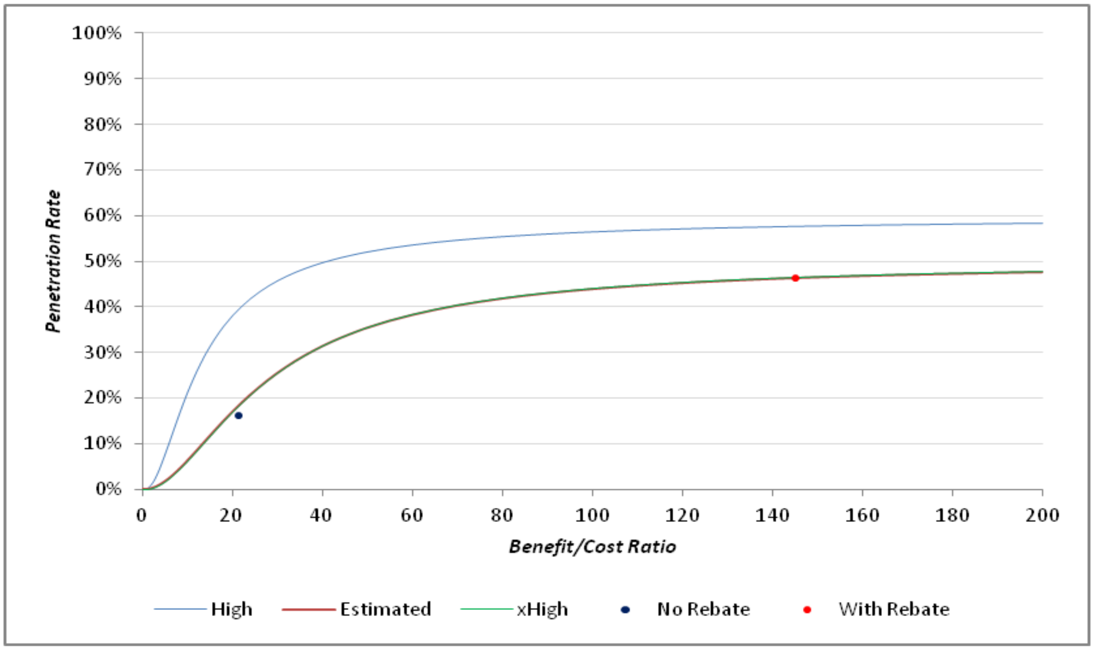

Figure 17.3.1 Market Penetration Curve for Furnace Fans in NWGF, Non-condensing, North

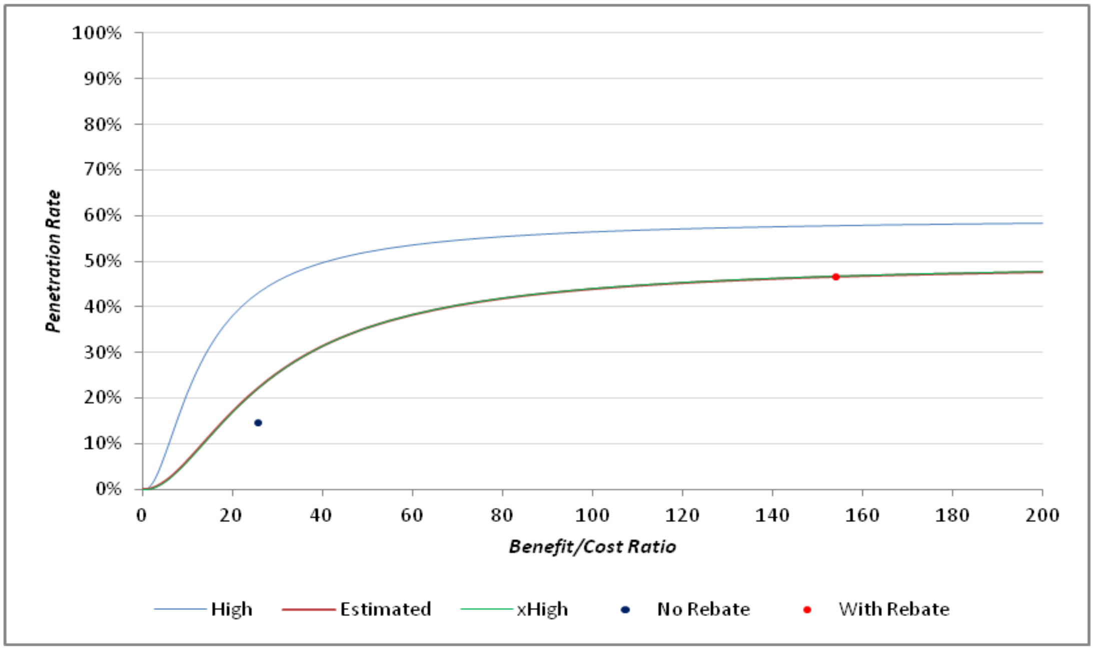

Figure 17.3.2 Market Penetration Curve for Furnace Fans in NWGF, Non-condensing, South

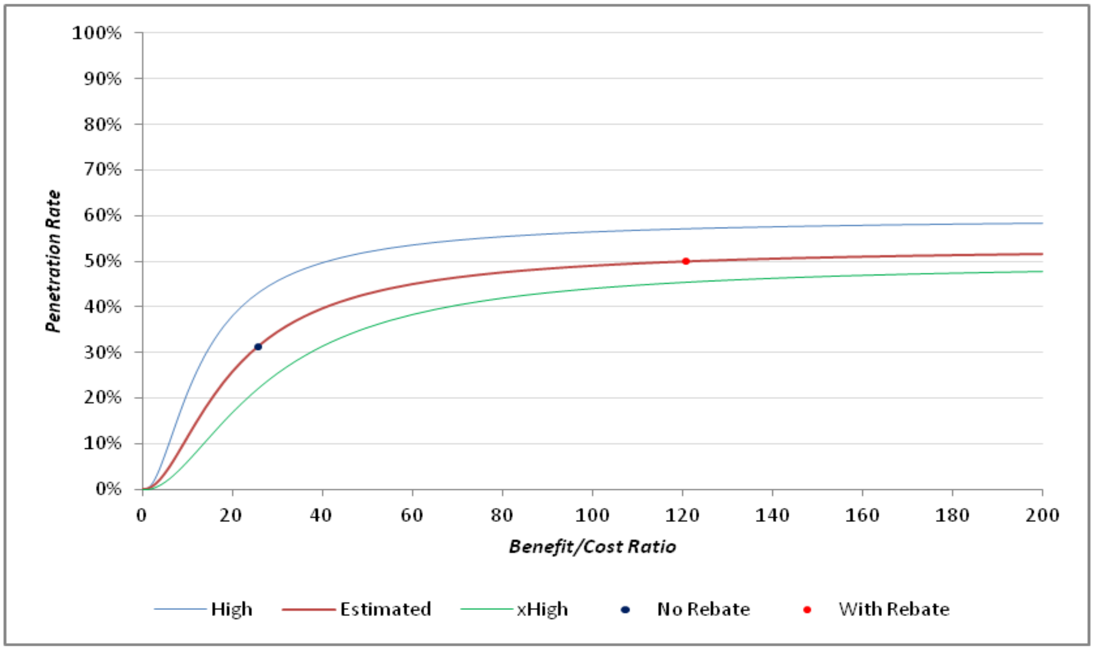

Figure 17.3.3 Market Penetration Curve for Furnace Fans in NWGF, Condensing, North

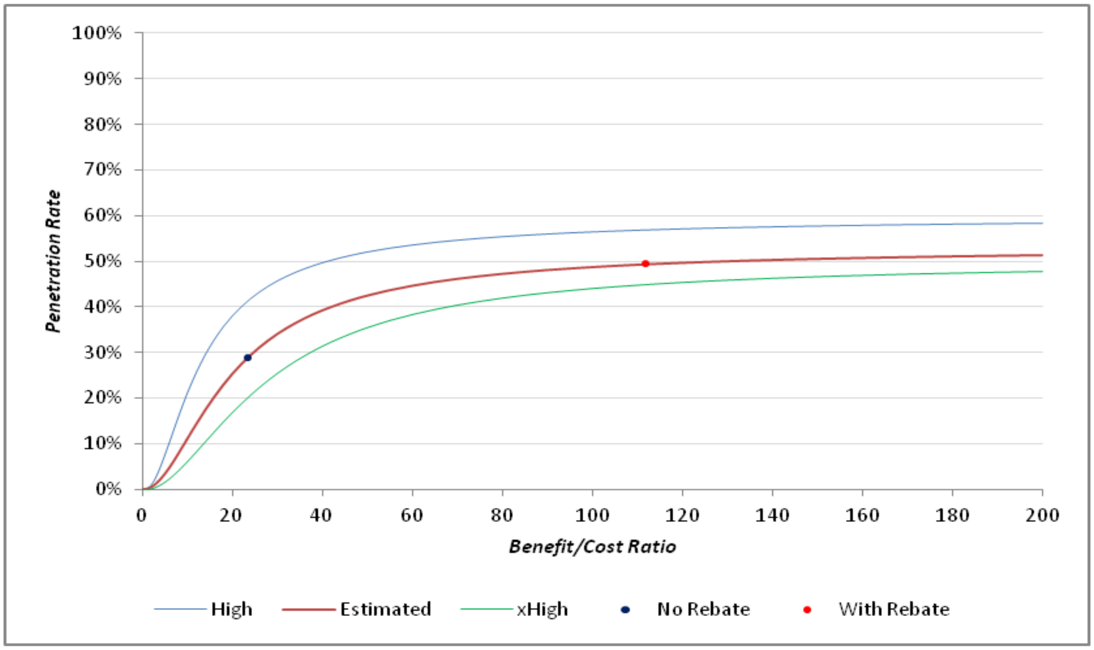

Figure 17.3.4 Market Penetration Curve for Furnace Fans in NWGF, Condensing, South

For each product class, DOE next estimated the percent increases represented by the change in penetration rate shown on the corresponding penetration curve. It then added this percent increase to the market share of units that meet the target level in the base case to obtain the market share of units that meet the target level in the rebate policy case. Table 17.3.2 summarizes the market shares for furnace fans in 2019. DOE used the resulting annual increases in market shares as inputs to represent the rebate policy case scenario in its NIA-RIA model. Appendix 17-A, Table 17-A.2.1, shows the annual market share increases due to this policy. Section 17.4 presents the resulting efficiency trends for the policy case of consumer rebates for furnace fans.

Table 17.3.2 Market Penetrations in 2019 Attributable to Consumer Rebates for Furnace Fans in NWGF

	NWGFnc, North	NWGFnc, South	NWGFc, North	NWGFc, South
Base-Case Market Share of Units that Meet Target Level	16.2	14.4	38.5	35.4
Market Share of Units that Meet Target Level With Rebates	44.2	38.9	57.2	55.9
Increased Market Share of Units that Meet Target Level With Rebates	28.0	24.5	18.7	20.5

NWGFnc = non-weatherized gas furnace, non-condensing
NWGFc = non-weatherized gas furnace, condensing

17.3.3 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy-efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.[9, 10] The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of consumer products that meet new efficiency standards, DOE assumed the amount of the tax credit would be the same as the corresponding rebate amount discussed above.

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.[11]

In preparing its assumptions, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy-efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy-efficient products, including furnace fans.[12] Those tax credits were in effect in 2006 and 2007, expired in 2008, were reinstated for 2009–2010 by the American Recovery and Reinvestment Act of 2009 (ARRA), extended by Congress for 2011 with some modifications, and expired at the end of 2011.[13, 14] The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[15] DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to furnace fans to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 17-A, section 17-A.6.1, contains more information on Federal consumer tax credits. That section includes discussion of the importance from the manufacturer and distributor perspective of the ample tax credits offered for home heating and cooling equipment (while tax credits for furnace fans were more modest) and their impact on furnace sales.

DOE also reviewed its previous analysis of Oregon's tax credits for clothes washers to provide support for its assumptions.[16] In that previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 17-A, section 17-A.6.3.

DOE applied the assumed 60 percent participation described above to the penetration rates estimated for the rebate policy to estimate penetration rates attributable to consumer tax credits. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the penetration curves selected for furnace fans.

Table 17.3.3 summarizes DOE's assumptions for furnace fans regarding the market penetration of units in 2019 that meet the target efficiency level given a consumer tax credit.

Table 17.3.3 Market Penetrations in 2019 Attributable to Consumer Tax Credits for Furnace Fans in NWGF

	NWGFnc, North	NWGFnc, South	NWGFc, North	NWGFc, South
Base-Case Market Share of Units that Meet Target Level	16.2	14.4	38.5	35.4
Market Share of Units that Meet Target Level With Tax Credits	33.0	29.1	49.7	47.7
Increased Market Share of Units that Meet Target Level With Tax Credits	16.8	14.7	11.2	12.3

DOE assumed that this policy would transform the market permanently, so that the increase in market share seen in the first year of the program would be maintained throughout the forecast period. The increased market shares attributable to consumer tax credits shown in Table 17.3.3 were used as inputs in the NIA-RIA model. Appendix 17-A, Table 17-A.2.1, shows the annual market share increases due to this policy. Section 17.4 presents the resulting efficiency trends for the policy case of consumer tax credits for furnace fans that meet the target efficiency level.

17.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce furnace fans that meet the target efficiency level, DOE assumed that a manufacturer tax credit would lower the consumer's purchase cost by an amount equivalent to that provided by the consumer rebates or tax credits described above. DOE further assumed that manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.[e] Because the direct price effect is approximately equivalent to the announcement effect,[9] DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient products. Thus the assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.[17] Those manufacturer tax credits have been in effect for dishwashers, clothes washers and refrigerators produced beginning in 2009. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 17-A, section 17-A.6.2, presents details on Federal manufacturer tax credits.

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[e] Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

DOE applied the assumption of 30 percent participation to the penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, the Department incorporated the assumptions for consumer response to financial incentives from the penetration curve selected for furnace fans.

Table 17.3.4 summarizes DOE's assumptions for furnace fans regarding the market penetration of units in 2019 meeting the target efficiency level given a manufacturer tax credit.

Table 17.3.4 Market Penetrations in 2019 Attributable to Manufacturer Tax Credits for Furnace Fans in NWGF

	NWGFnc, North	NWGFnc, South	NWGFc, North	NWGFc, South
Base-Case Market Share of Units that Meet Target Level	16.2	14.4	38.5	35.4
Market Share of Units that Meet Target Level With tax credits	24.6	21.8	44.1	41.6
Increased Market Share of Units that Meet Target Level With tax credits	8.4	7.4	5.6	6.1

DOE assumed that this policy would transform the market permanently, so that the increases in market share seen in the first year of the program would be maintained throughout the forecast period. The increased market shares attributable to a manufacturer tax credit shown in Table 17.3.4 were used as inputs in the NIA-RIA model. Appendix 17-A, Table 17-A.2.1, shows the annual market share increases due to this policy. Section 17.4 presents the resulting efficiency trends for the policy case of manufacturer tax credits for furnace fans.

17.3.5 Voluntary Energy Efficiency Targets

For each product, DOE assumed that voluntary energy efficiency targets would be achieved as manufacturers gradually stopped producing units that operated below the target efficiency level. DOE assumed that the impetus for phasing out production of low-efficiency units would be a program similar to the ENERGY STAR labeling program conducted by the Environmental Protection Agency (EPA) and DOE. The ENERGY STAR program specifies the minimum energy efficiencies that various products must have to receive the ENERGY STAR label. ENERGY STAR encourages consumers to purchase efficient products via marketing that promotes consumer label recognition, various incentive programs that adopt the ENERGY STAR specifications, and manufacturers' promotion of their qualifying appliances. ENERGY STAR projects market penetration of compliant appliances and estimates the percentage of sales of compliant appliances that are attributable to the ENERGY STAR program.

Researchers have analyzed the ENERGY STAR program's effects on sales of several consumer products. Program efforts generally involve a combination of information dissemination and utility or agency rebates. The analyses have been based on State-specific data on percentages of shipments of various appliances that meet ENERGY STAR specifications. The analyses generally have concluded that the market penetration of ENERGY STAR-qualifying appliances is higher in regions or States where ancillary promotional programs have been active.[18, 19, 20]

Since ENERGY STAR does not have a program aimed at furnace fans, DOE based its estimates of market penetration on its previous estimates of the impact of a voluntary energy efficiency targets program on shipments of non-weatherized gas furnaces. DOE chose gas furnaces since its market shares track those of furnace fans. In its prior analysis DOE estimated the percentage of market shares attributable to the existing ENERGY STAR program for each product for 1996 –2025.[21] DOE assumed that furnace fans would experience these levels of annual increases in market penetration beginning in 2019 and lasting throughout the forecast period. DOE added those percent increases to the market shares of furnace fans that met the target level in the RIA base case, starting in 2019, to obtain the annual market shares of units meeting the target efficiency level in the voluntary energy efficiency targets policy case.

DOE estimated that the program developed in support of the voluntary energy efficiency targets policy would increase market shares of efficient units. Appendix 17-A, Table 17-A.2.1, shows the annual market share increases due to this policy used as inputs to the NIA-RIA model. Section 17.4 presents the resulting efficiency trends for the policy case of voluntary energy efficiency targets for furnace fans that meet the target efficiency level.

17.3.6 Early Replacement

The non-regulatory policy of early replacement refers to a program to replace residential appliances before the ends of their useful lives. The purpose of such a policy is to replace old, inefficient units with higher efficiency units. The economic feasibility of early replacement depends on the vintage of the unit being replaced, the installed cost of the new unit, and the energy cost savings.

Furnace fans are typically purchased as part of a residential furnace or HVAC (heating, ventilating and air conditioning) unit. While furnace fans may be replaced or retrofit into heating systems, DOE assumed that the practice of early retrofit was limited and thus that the energy savings would be minimal. Therefore it did not analyze the Early Replacement policy for this product.

17.3.7 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of products that meet the target efficiency level. Combining the market demands of multiple public sectors also can provide a market signal to manufacturers and vendors that some of their largest customers seek products that meet an efficiency target at favorable prices. Such a program also can induce “market pull,” whereby manufacturers and vendors would achieve economies of scale for high efficiency products.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on numbers of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of this policy on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other equipment. FEMP, however, does not track purchasing data, because of the complex range of purchasing systems, large number of vendors, and so on. States, counties, and municipalities have demonstrated increasing interest and activity in “green purchasing." Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.[22, 23]

DOE assumed that government agencies, such as the Department of Housing and Urban Development, would administer bulk purchasing programs for furnace fans (which are usually specified as part of a furnace purchase). The policy also would be incorporated into the FEMP program. The FEMP program does not currently have procurement guidelines in place for furnace fans.

DOE reviewed its own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.[24] Based on this study, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in at least 80 percent of government-purchased furnace fans meeting target efficiency levels.

DOE assumed that bulk government purchases would affect a subset of housing units for which government agencies purchase or influence the purchase of furnace fans as part of gas furnace purchases. This subset consists primarily of public housing and housing on military bases. DOE defined this subset based on the American Housing Survey (AHS) for 2011, which identified 2.24 million households, or about 1.7 percent of all U.S. households, as publicly owned housing. (The AHS reports 132.4 million U.S. households.)[25] The 2009 Residential Energy Consumption Survey (RECS 2009) reported that 26 percent of publicly owned households had gas furnaces.[26] DOE therefore estimated that 0.4 percent of U.S. housing units represent publicly owned households using furnace fans as part of gas furnaces; this constituted the population to which this policy would apply.

DOE estimated that, starting in 2019, each year of a bulk government purchase policy would result in an increasing percent of shipments of government-purchased units beyond the base case would meet target efficiency levels. DOE estimated that within 10 years (by the end of 2027), bulk government purchasing programs would result in 80 percent of the furnace fan market for publicly owned housing meeting the target level. DOE modeled the bulk government purchase program assuming that the market share for each product achieved in 2027 would be maintained throughout the rest of the forecast period. Appendix 17-A, section 17-A.2, shows the annual market share increases due to this policy used as inputs to the NIA-RIA model. Section 17.4 below presents the resulting efficiency trends for the policy case of bulk government purchase of furnace fans.

17.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 17.4.1 to Figure 17.4.4 show the effects of each non-regulatory policy on market penetration for furnace fans for non-weatherized gas furnaces. The graphs show the impacts for the North and South regions for furnace fans in NWGF, condensing and for NWGF, non-condensing furnaces. Relative to the base case, the policy cases increase the market shares that meet the target level. Recall that the proposed standards (not shown in the figures) would result in a 100-percent market penetration of products that meet the target efficiency level.

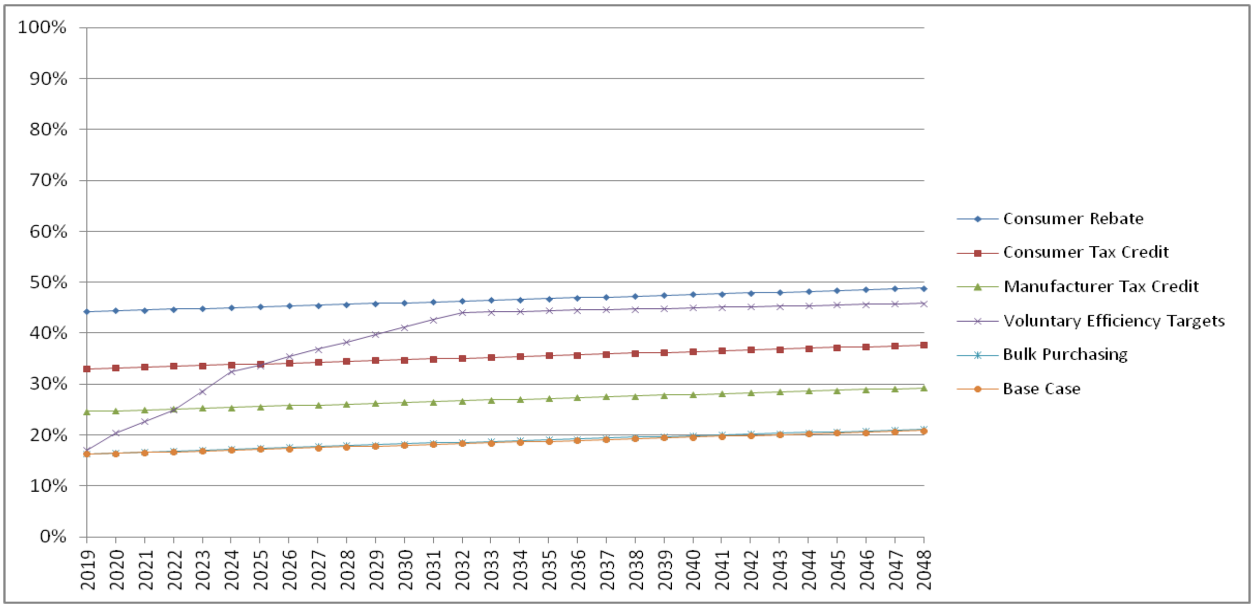

Figure 17.4.1 Market Penetration of Furnace Fans in NWGF, Non-condensing Meeting the Target Level in Policy Cases, North

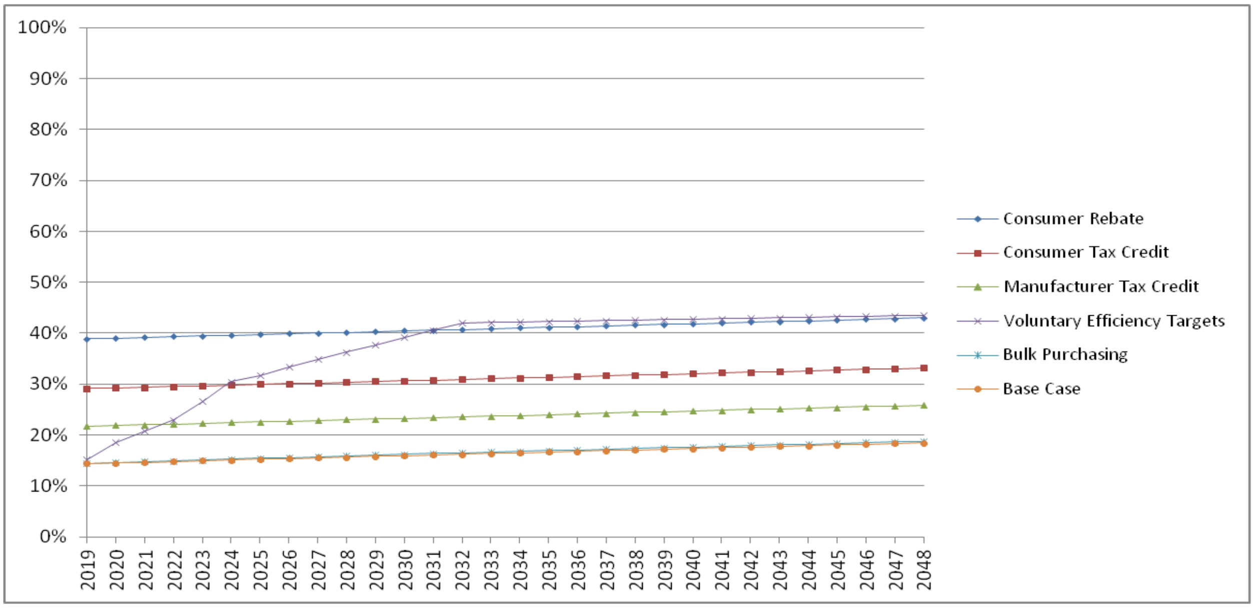

Figure 17.4.2 Market Penetration of Furnace Fans in NWGF, Non-condensing Meeting the Target Level in Policy Cases, South

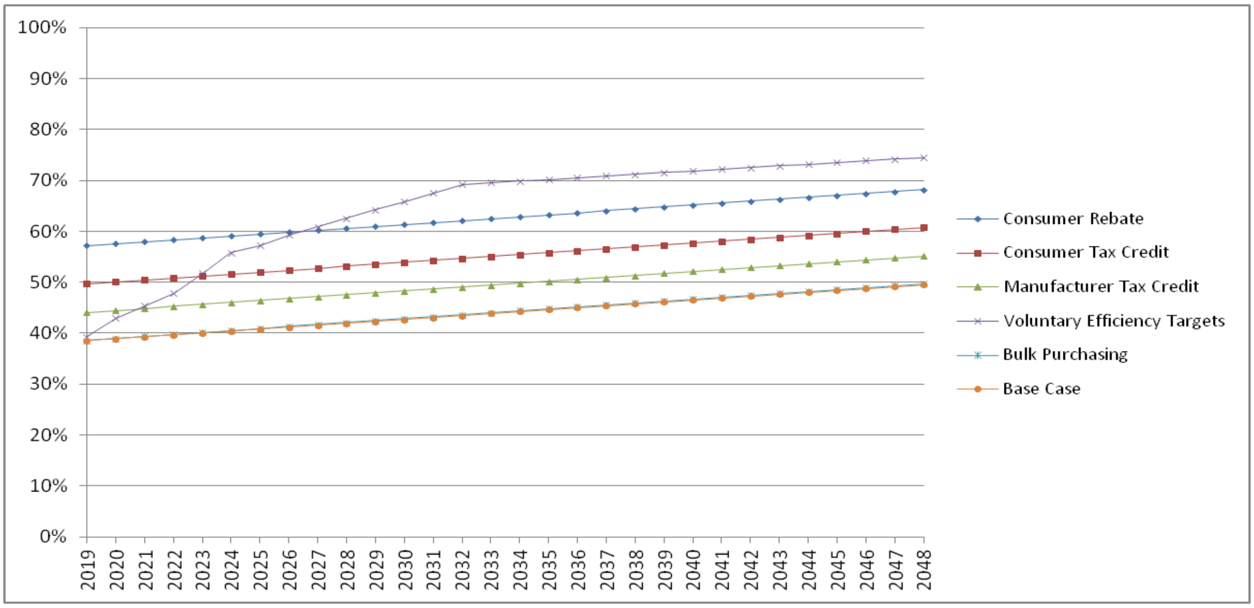

Figure 17.4.3 Market Penetration of Furnace Fans in NWGF, Condensing Meeting the Target Level in Policy Cases, North

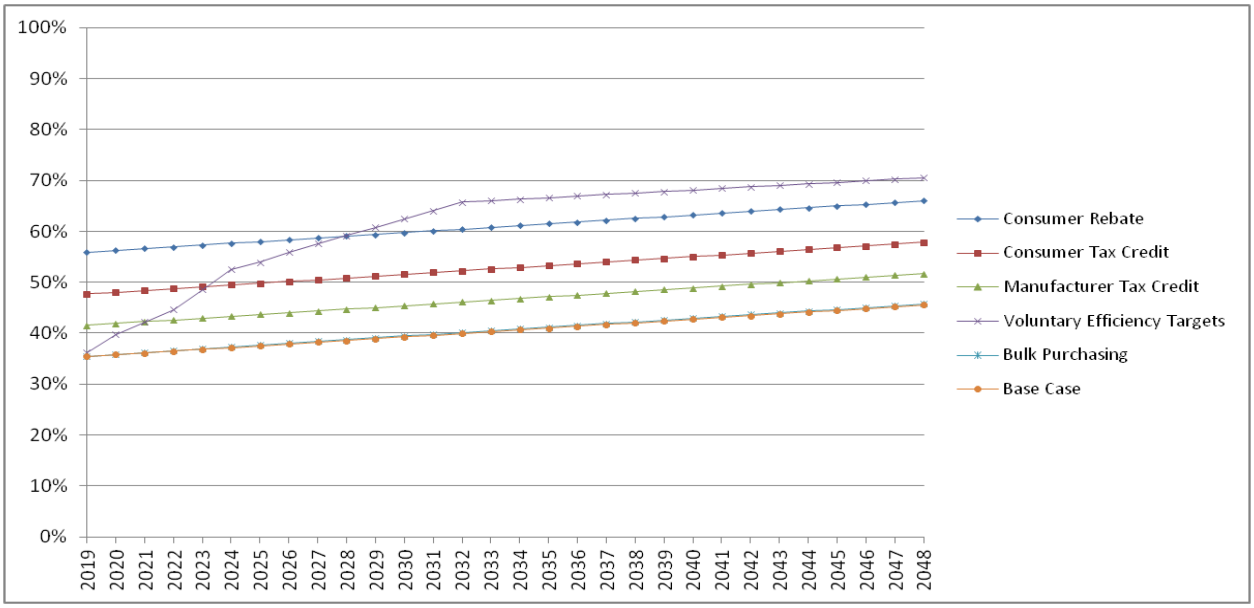

Figure 17.4.4 Market Penetration of Furnace Fans in NWGF, Condensing Meeting the Target Level in Policy Cases, South

Table 17.4.1 and Table 17.4.2 show the national energy savings and net present value (NPV) for five non-regulatory policies analyzed in detail for furnace fans. The target level for each policy equals the efficiency level in the corresponding proposed standard. The national energy savings and NPV reported in the table represent the projected impacts for the North and South regions combined.

The case in which no regulatory action is taken with regard to furnace fans constitutes the base case (or "No New Regulatory Action" scenario), in which energy savings and NPV are zero by definition. For comparison, the tables include the impacts of the proposed standards. Energy savings are given in quadrillion British thermal units (quads). The NPVs shown in Table 17.4.1 and Table 17.4.2 are based on two discount rates, 7 percent and 3 percent.

The non-regulatory policies with the highest projected cumulative energy savings are consumer rebates and voluntary energy efficiency targets, while bulk government purchases have a small impact on energy use and NPV.

Table 17.4.1 Impacts of Non-Regulatory Alternatives for Furnaces Fans for NWGF, Non-Condensing (TSL 4)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2012$ 7% Discount Rate	Net Present Value* billion 2012$ 3% Discount Rate
Consumer Rebates	0.611	0.744	2.559
Consumer Tax Credits	0.367	0.449	1.541
Manufacturer Tax Credits	0.184	0.226	0.772
Voluntary Energy Efficiency Targets	0.492	0.493	1.909
Bulk Government Purchases	0.006	0.006	0.023
Proposed Standards	1.861	3.713	11.093

*For products shipped 2019 – 2048

Table 17.4.2 Impacts of Non-Regulatory Alternatives for Furnaces Fans for NWGF, Condensing (TSL 4)

Policy Alternative	Primary Energy Savings quads	Net Present Value* billion 2012$ 7% Discount Rate	Net Present Value* billion 2012$ 3% Discount Rate
Consumer Rebates	0.727	0.813	3.008
Consumer Tax Credits	0.436	0.488	1.806
Manufacturer Tax Credits	0.218	0.244	0.902
Voluntary Energy Efficiency Targets	0.811	0.754	3.136
Bulk Government Purchases	0.006	0.006	0.022
Proposed Standards	2.003	3.908	12.226

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APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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APPENDIX 17-A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

17-A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- XENERGY penetration curves used to analyze consumer rebates, including:
    - Background material,
    - DOE's adjustment of these curves for this analysis, and
    - DOE's method for interpolating the curves;
- Detailed tables of rebates offered for the considered products; and
- Background material on Federal and state tax credits for appliances.

17-A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

For the consumer rebate, consumer tax credit, manufacturer tax credit, voluntary energy efficiency targets and bulk purchasing policies, Tables 17-A.2.1 to 17-A.2.4 show the annual increases in market shares for furnace fans in non-weatherized gas furnaces (NWGF), non-condensing and condensing, in the North and South regions, meeting target efficiency levels. DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 17-A.2.1 Annual Increases in Market Shares Attributable to Rebate, Tax Credit, Voluntary EE Targets, and Bulk Purchasing Policies for Furnace Fans in NWGF, Non-condensing, North

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2019	28.0	16.8	8.4	0.8	0.0
2020	28.0	16.8	8.4	4.0	0.1
2021	28.0	16.8	8.4	6.1	0.1
2022	28.0	16.8	8.4	8.2	0.1
2023	28.0	16.8	8.4	11.7	0.1
2024	28.0	16.8	8.4	15.4	0.2
2025	28.0	16.8	8.4	16.4	0.2
2026	28.0	16.8	8.4	18.1	0.2
2027	28.0	16.8	8.4	19.3	0.3
2028	28.0	16.8	8.4	20.6	0.3
2029	28.0	16.8	8.4	21.9	0.3
2030	28.0	16.8	8.4	23.2	0.3
2031	28.0	16.8	8.4	24.5	0.3
2032	28.0	16.8	8.4	25.8	0.3
2033	28.0	16.8	8.4	25.7	0.3
2034	28.0	16.8	8.4	25.7	0.3
2035	28.0	16.8	8.4	25.6	0.3
2036	28.0	16.8	8.4	25.6	0.3
2037	28.0	16.8	8.4	25.5	0.3
2038	28.0	16.8	8.4	25.5	0.3
2039	28.0	16.8	8.4	25.4	0.3
2040	28.0	16.8	8.4	25.4	0.3
2041	28.0	16.8	8.4	25.3	0.3
2042	28.0	16.8	8.4	25.3	0.3
2043	28.0	16.8	8.4	25.2	0.3
2044	28.0	16.8	8.4	25.2	0.3
2045	28.0	16.8	8.4	25.1	0.3
2046	28.0	16.8	8.4	25.1	0.3
2047	28.0	16.8	8.4	25.1	0.3
2048	28.0	16.8	8.4	25.0	0.3

Table 17-A.2.2 Annual Increases in Market Shares Attributable to Rebate, Tax Credit, Voluntary EE Targets, and Bulk Purchasing Policies for Furnace Fans in NWGF, Non-condensing, South

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2019	24.5	14.7	7.4	0.8	0.0
2020	24.5	14.7	7.4	4.0	0.1
2021	24.5	14.7	7.4	6.1	0.1
2022	24.5	14.7	7.4	8.2	0.1
2023	24.5	14.7	7.4	11.7	0.1
2024	24.5	14.7	7.4	15.4	0.2
2025	24.5	14.7	7.4	16.4	0.2
2026	24.5	14.7	7.4	18.1	0.2
2027	24.5	14.7	7.4	19.3	0.3
2028	24.5	14.7	7.4	20.6	0.3
2029	24.5	14.7	7.4	21.9	0.3
2030	24.5	14.7	7.4	23.2	0.3
2031	24.5	14.7	7.4	24.5	0.3
2032	24.5	14.7	7.4	25.8	0.3
2033	24.5	14.7	7.4	25.7	0.3
2034	24.5	14.7	7.4	25.7	0.3
2035	24.5	14.7	7.4	25.6	0.3
2036	24.5	14.7	7.4	25.6	0.3
2037	24.5	14.7	7.4	25.5	0.3
2038	24.5	14.7	7.4	25.5	0.3
2039	24.5	14.7	7.4	25.4	0.3
2040	24.5	14.7	7.4	25.4	0.3
2041	24.5	14.7	7.4	25.3	0.3
2042	24.5	14.7	7.4	25.3	0.3
2043	24.5	14.7	7.4	25.2	0.3
2044	24.5	14.7	7.4	25.2	0.3
2045	24.5	14.7	7.4	25.1	0.3
2046	24.5	14.7	7.4	25.1	0.3
2047	24.5	14.7	7.4	25.1	0.3
2048	24.5	14.7	7.4	25.0	0.3

Table 17-A.2.3 Annual Increases in Market Shares Attributable to Rebate, Tax Credit, Voluntary EE Targets, and Bulk Purchasing Policies for Furnace Fans in NWGF, Condensing, North

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2019	18.7	11.2	5.6	0.8	0.0
2020	18.7	11.2	5.6	4.0	0.0
2021	18.7	11.2	5.6	6.1	0.1
2022	18.7	11.2	5.6	8.2	0.1
2023	18.7	11.2	5.6	11.7	0.1
2024	18.7	11.2	5.6	15.4	0.1
2025	18.7	11.2	5.6	16.4	0.1
2026	18.7	11.2	5.6	18.1	0.1
2027	18.7	11.2	5.6	19.3	0.2
2028	18.7	11.2	5.6	20.6	0.2
2029	18.7	11.2	5.6	21.9	0.2
2030	18.7	11.2	5.6	23.2	0.2
2031	18.7	11.2	5.6	24.5	0.2
2032	18.7	11.2	5.6	25.8	0.2
2033	18.7	11.2	5.6	25.7	0.2
2034	18.7	11.2	5.6	25.7	0.2
2035	18.7	11.2	5.6	25.6	0.2
2036	18.7	11.2	5.6	25.6	0.2
2037	18.7	11.2	5.6	25.5	0.2
2038	18.7	11.2	5.6	25.5	0.2
2039	18.7	11.2	5.6	25.4	0.2
2040	18.7	11.2	5.6	25.4	0.2
2041	18.7	11.2	5.6	25.3	0.2
2042	18.7	11.2	5.6	25.3	0.2
2043	18.7	11.2	5.6	25.2	0.2
2044	18.7	11.2	5.6	25.2	0.2
2045	18.7	11.2	5.6	25.1	0.2
2046	18.7	11.2	5.6	25.1	0.2
2047	18.7	11.2	5.6	25.1	0.2
2048	18.7	11.2	5.6	25.0	0.2

Table 17-A.2.4 Annual Increases in Market Shares Attributable to Rebate, Tax Credit, Voluntary EE Targets, and Bulk Purchasing Policies for Furnace Fans in NWGF, Condensing, South

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2019	20.5	12.3	6.1	0.8	0.0
2020	20.5	12.3	6.1	4.0	0.0
2021	20.5	12.3	6.1	6.1	0.1
2022	20.5	12.3	6.1	8.2	0.1
2023	20.5	12.3	6.1	11.7	0.1
2024	20.5	12.3	6.1	15.4	0.1
2025	20.5	12.3	6.1	16.4	0.1
2026	20.5	12.3	6.1	18.1	0.2
2027	20.5	12.3	6.1	19.3	0.2
2028	20.5	12.3	6.1	20.6	0.2
2029	20.5	12.3	6.1	21.9	0.2
2030	20.5	12.3	6.1	23.2	0.2
2031	20.5	12.3	6.1	24.5	0.2
2032	20.5	12.3	6.1	25.8	0.2
2033	20.5	12.3	6.1	25.7	0.2
2034	20.5	12.3	6.1	25.7	0.2
2035	20.5	12.3	6.1	25.6	0.2
2036	20.5	12.3	6.1	25.6	0.2
2037	20.5	12.3	6.1	25.5	0.2
2038	20.5	12.3	6.1	25.5	0.2
2039	20.5	12.3	6.1	25.4	0.2
2040	20.5	12.3	6.1	25.4	0.2
2041	20.5	12.3	6.1	25.3	0.2
2042	20.5	12.3	6.1	25.3	0.2
2043	20.5	12.3	6.1	25.2	0.2
2044	20.5	12.3	6.1	25.2	0.2
2045	20.5	12.3	6.1	25.1	0.2
2046	20.5	12.3	6.1	25.1	0.2
2047	20.5	12.3	6.1	25.1	0.2
2048	20.5	12.3	6.1	25.0	0.2

17-A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA[a] model approach that built on the NIA model discussed in Chapter 10 and documented in Appendix 10-A.The resulting integrated NIA-RIA model featured both the NIA analysis inputs and results and the RIA inputs and had the capability to generate results for each of the RIA policies. A separate module produced results summaries for the tables and figures in the RIA document. For the RIA methodology documentation in chapter 17, section 17.3, the module created summaries of parameters calculated by the model for the consumer rebates policy, generated its penetration curves (discussed in section 17-A.4.3 below) and reported market share impacts for the rebate and tax credit policies by product class. For the RIA results reported in chapter 17, section 17.4, the module produced graphs of the market share increases resulting from each of the policies analyzed and created summary tables for the national energy savings and net present value results. This module also generated tables of market share increases for each policy reported in section 17-A.2 of this Appendix.

17-A.4 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates policy. Next it discusses the adjustments it made to the maximum penetration rates. It then presents the method it developed to create interpolated penetration curves for each specific product class and efficiency level in the analysis. The resulting curves for the NWGF product classes are in chapter 17, section 17.3.2.2.

17-A.4.1 Introduction

XENERGY, Inc.[b], developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.[1] The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.[2, 3, 4] One study records researchers' attempts to investigate the factors that drive diffusion processes.[5] Because a new product generally has its own distinct characteristics, few studies have been able conclusively to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

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[a] NIA = national impact analysis; RIA = regulatory impact analysis

[b] XENERGY is now owned by KEMA, Inc. (www.kema.com)

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time. What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.[3] The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.[4,5]

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.[4,5] If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 17-A.4.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 17-A.4.1).

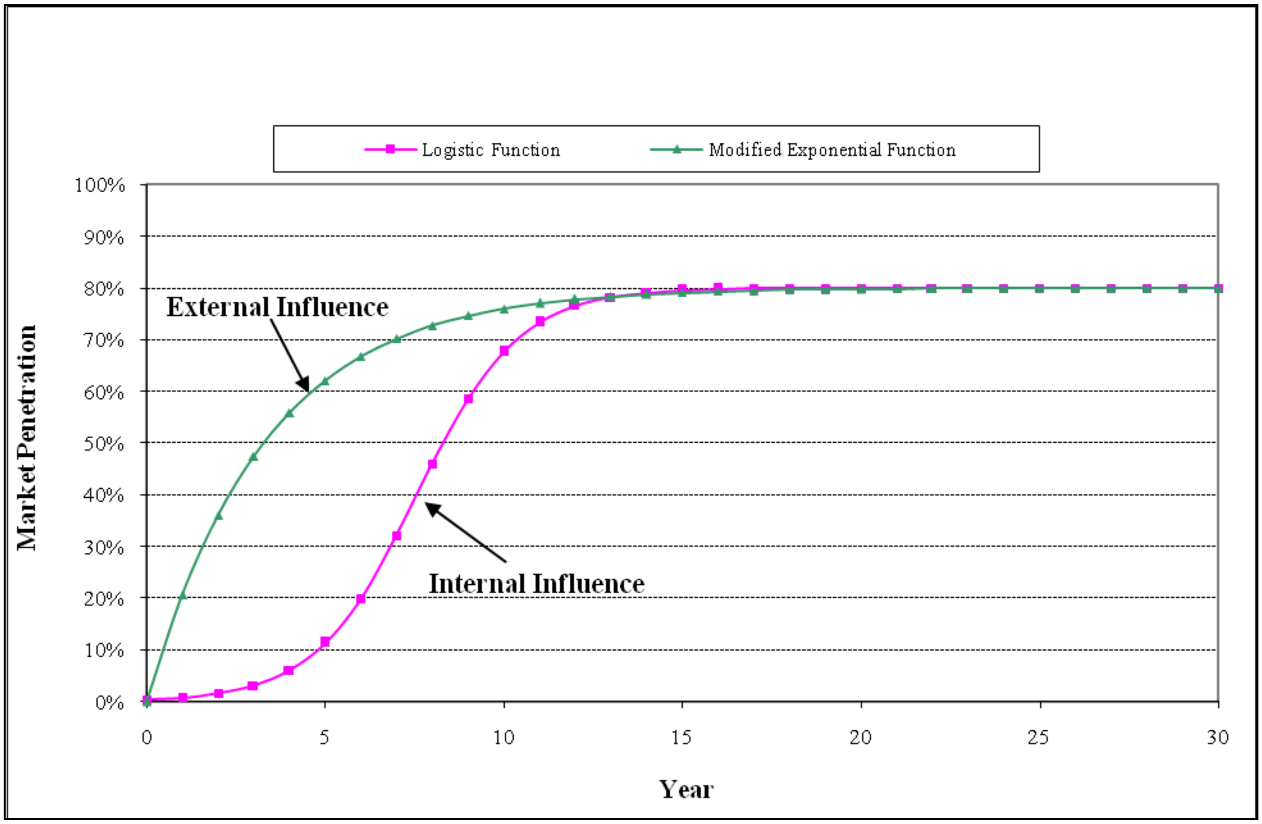

Figure 17-A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

17-A.4.2 Adjustment of XENERGY Penetration Curves

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.[6] The experiences with utility programs since the XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such that the policy case market share cannot be great than 100 percent, as might occur for products with high base case market shares of the target-level technology.

17-A.4.3 Interpolation of Penetration Curves

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.[c] The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.[1] Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.[d] They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

This section presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The following describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

17-A.4.3.1 Market Implementation Rate Function and Curves

The XENERGY curves employ the following functional form to estimate the percentage of the informed market[e] that will accept each energy-efficiency measure based on the participant's benefit/cost ratio:

$$\mathrm{imp(bc)} = \frac{\mathrm{max}}{\left(1 + \mathrm{e}^{-\ln\left(\frac{\mathrm{bc}}{4}\right)}\right) \cdot \left(1 + \mathrm{e}^{-\mathrm{fit} \cdot \ln(\mathrm{mid} \cdot \mathrm{bc})}\right)} \qquad [1]$$

where:

imp	implementation rate
bc	benefit/cost ratio
max	maximum annual acceptance rate for the technology
mid	inflection point of the curve
fit	parameter that determines the general shape (slope) of the curve.

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[c] The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

[d] DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets can be considered proportional to the rebate impacts.

[e] The *informed market* refers to the portion of the market aware and informed about the energy efficiency measure.

In recent efficiency standards rulemakings, DOE has been adopting a slightly different functional form of Equation [1], where the constant value 1/4 is replaced by a parameter *r*. By introducing this parameter in Equation [1] and rewriting it without the exponential and logarithmic operators, the market implementation rate of rebate programs can be evaluated using the following equation:

$$imp(bc) = \frac{max}{\left(1 + \frac{1}{r \cdot bc}\right) \cdot \left(1 + (mid \cdot bc)^{-fit}\right)} \qquad [2]$$

In XENERGY's report, Equation [1] is used to generate five primary (reference) curves. These curves produce initial theoretical results that are calibrated to actual measure implementation results associated with the first year of major utility energy efficiency programs. Different curves, generated using distinct values of the parameters *max*, *mid*, *fit* and *r*, reflect different levels of market barriers for different efficiency measures.

DOE has been using similar curves in the appliance efficiency standards rulemaking. The curves characterize market implementation rates for five reference levels of market barriers: *No Barriers*, *Low Barriers*, *Moderate Barriers*, *High Barriers,* and *Extremely High Barriers*. Figure 17-A.4.2 presents the five reference curves.

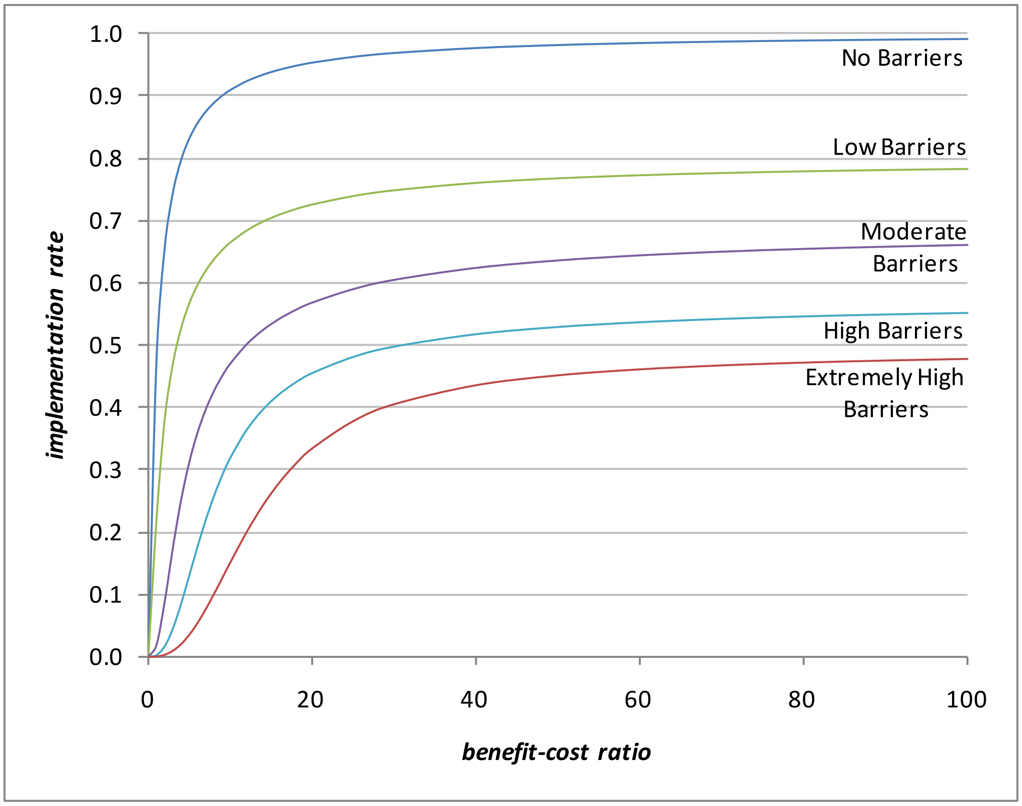

Figure 17-A.4.2 Market Implementation Curves for Five Market Barriers Reference Levels

The reference curves build on the following functional form:

$$imp(b_d, bc) = \frac{max_d(b_d)}{(1 + r_d(b_d) \cdot bc) \cdot (1 + (mid_d(b_d) \cdot bc)^{-fit_d(b_d)})} \qquad [3]$$

where:

b_d = [barrier type]

and $max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$ and $r_d(b_d)$ are as shown in Table 17-A.4.1. The four parameters are also presented in Figure 17-A.4.3 as discrete-value functions.

Table 17-A.4.1 Parameter Values for Reference Curves

	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
max_d	1.0	0.8	0.7[f]	0.6[f]	0.5 [f]
mid_d	10	2	0.3	0.1	0.04
fit_d	1	1.7	1.7	1.7	1.7
r_d	1	0.5	0.25	0.25	0.25

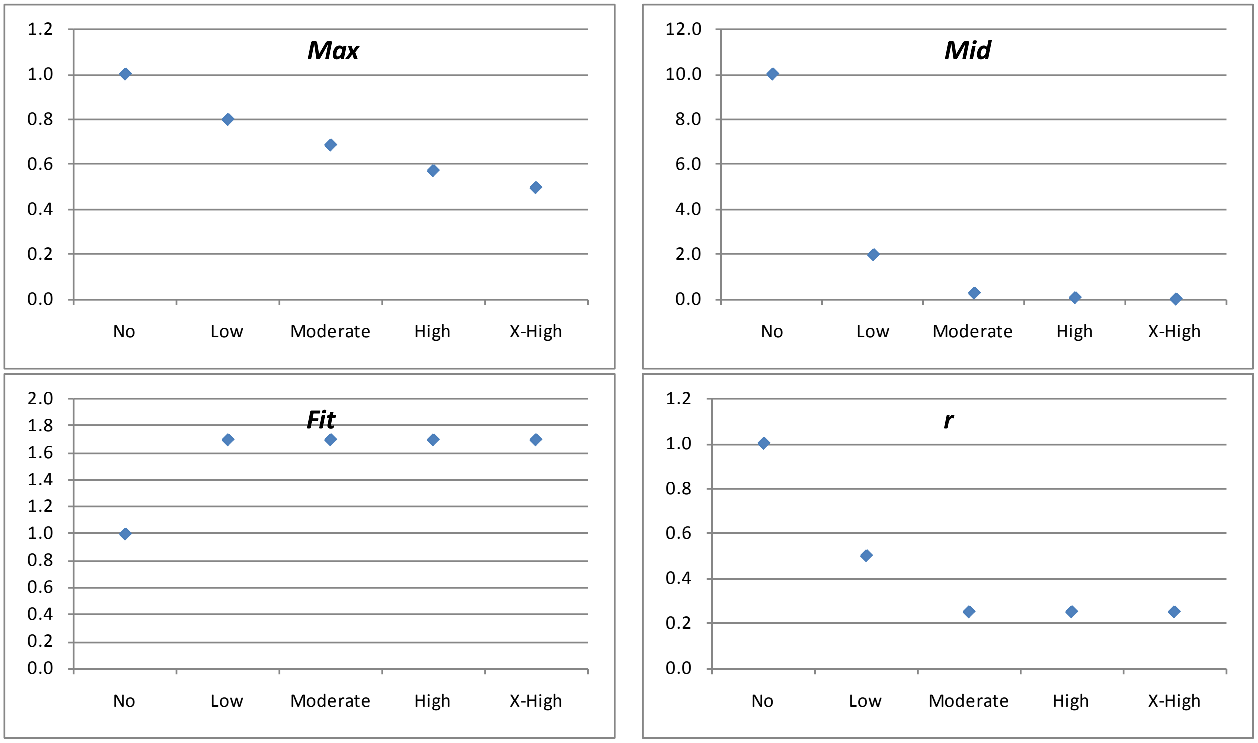

Figure 17-A.4.3 Discrete-value Functions of Parameters Driving Implementation Curve Shape

To estimate the barrier level of a given market, in the past DOE sought the reference curve that most closely represented the pair (base case market share, benefit/cost ratio) of the technology corresponding to the mandatory standard's chosen efficiency level. It then estimated

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[f] DOE adopted these parameters for the Refrigeration Products RIA, as discussed in section 17-A.4.2, after consultation with the implementation curve authors. For the RIAs for the earlier rulemaking for Cooking Products and Commercial Clothes Washers the *max* value adopted for the *moderate barriers* and *high barriers* market barrier levels was 0.5. RIAs developed during prior rulemakings for Furnaces and Boilers, Commercial Unitary Air Conditioners and Heat Pumps, and Distribution Transformers used a *max* value of 0.8 for all but the *no barriers* curve, based on the original penetration curve values from XENERGY's report.

the effect of a rebate program on the technology market penetration using that curve. For this estimation, DOE calculated the increase in market share that an increase in the benefit/cost ratio – driven by a rebate program – would produce. It then assumed that the relative increase in market share calculated from the reference curve was a *proxy* to the effects of a rebate program on the studied market.

17-A.4.3.2 Calibrating the Market Implementation Rate Function

The procedure previously described lacks accuracy when the studied market penetration point based on the actual benefit/cost ratio does not lie close to one of the reference curves. This section presents an interpolation approach to eliminate such inaccuracy. The interpolation process provides intermediate, continuous values for the four parameters (*max*, *mid*, *fit* and *r*) driving the market implementation curves. These intermediate values are obtained after linear interpolation of their corresponding reference values.

The four parameters (*max*, *mid*, *fit* and *r*) were previously defined as discrete-value functions ($max_d(b_d)$, $mid_d(b_d)$, $fit_d(b_d)$ and $r_d(b_d)$) of the market barriers level (Table 17-A.4.1, Figure 17-A.4.2). To facilitate the interpolation, it is necessary to transform the four discrete-value functions into continuous functions, the latter being thus capable of associating each of the four parameters to a real number denoting the market barrier level ($b_c \in \mathrm{R}$). A numeric, continuous scale for the market barriers level is proposed, ranging from 0 to 5 ($b_c \in [0,5]$). The correspondence between the discrete-values of market barrier levels and b_c are shown in Table 17-A.4.2

Based on the continuous-value market barriers level, the parameters *max*, *mid*, *fit* and *r* are interpolated using the following functions:

$$max_c(b_c) = \propto_{max}(b_c) \cdot b_c + \beta_{max}(b_c) \qquad [4]$$

$$mid_c(b_c) = \propto_{mid}(b_c) \cdot b_c + \beta_{mid}(b_c) \qquad [5]$$

$$fit_c(b_c) = \propto_{fit}(b_c) \cdot b_c + \beta_{fit}(b_c) \qquad [6]$$

$$r_c(b_c) = \propto_{r}(b_c) \cdot b_c + \beta_{r}(b_c) \qquad [7]$$

where $\propto_x (b_c)$ and $\beta_x(b_c)$ are shown in Table 17-A.4.3.

The continuous-value functions defined for *max*, *mid*, *fit* and *r*, as expressed by Equations [4]-[7], are then substituted in Equation [3], leading to the following functional form for the market implementation rate of rebate programs:

$$imp(b_c, bc) = \frac{max_c(b_c)}{(1 + r_c(b_c) \cdot bc) \cdot (1 + (mid_c(b_c) \cdot bc)^{-fit_c(b_c)})} \qquad [8]$$

Table 17-A.4.2 Correspondence between Discrete and Continuous Values of Market Barrier Levels

	Market Barriers Level				
	No Barriers	*Low Barriers*	*Moderate Barriers*	*High Barriers*	*Extremely High Barriers*
b_c	0.0	1.0	2.5	4.0	5.0

Table 17-A.4.3 Coefficients of Continuous-value Functions of *max*, *mid*, *fit* and *r*

	Market Barriers Level Intervals			
	No-Low Barriers $b \in [0,1]$	*Low-Moderate Barriers* $b \in [1,2.5]$	*Moderate-High Barriers* $b \in [2.5,4]$	*High-Extremely High Barriers* $b \in [4,5]$
Max				
$\propto_{max}(b_c)$	-0.200	-0.075	-0.075	-0.075
$\beta_{max}(b_c)$	1.000	0.875	0.875	0.875
Mid				
$\propto_{mid}(b_c)$	-8.000	-1.133	-0.133	-0.060
$\beta_{mid}(b_c)$	10.000	3.133	0.633	0.340
Fit				
$\propto_{fit}(b_c)$	0.700	0.000	0.000	0.000
$\beta_{fit}(b_c)$	1.000	1.700	1.700	1.700
R				
$\propto_{r}(b_c)$	-0.500	-0.167	0.000	0.000
$\beta_{r}(b_c)$	1.000	0.667	0.250	0.250

Figure 17-A.4.4 presents the four continuous-value functions.

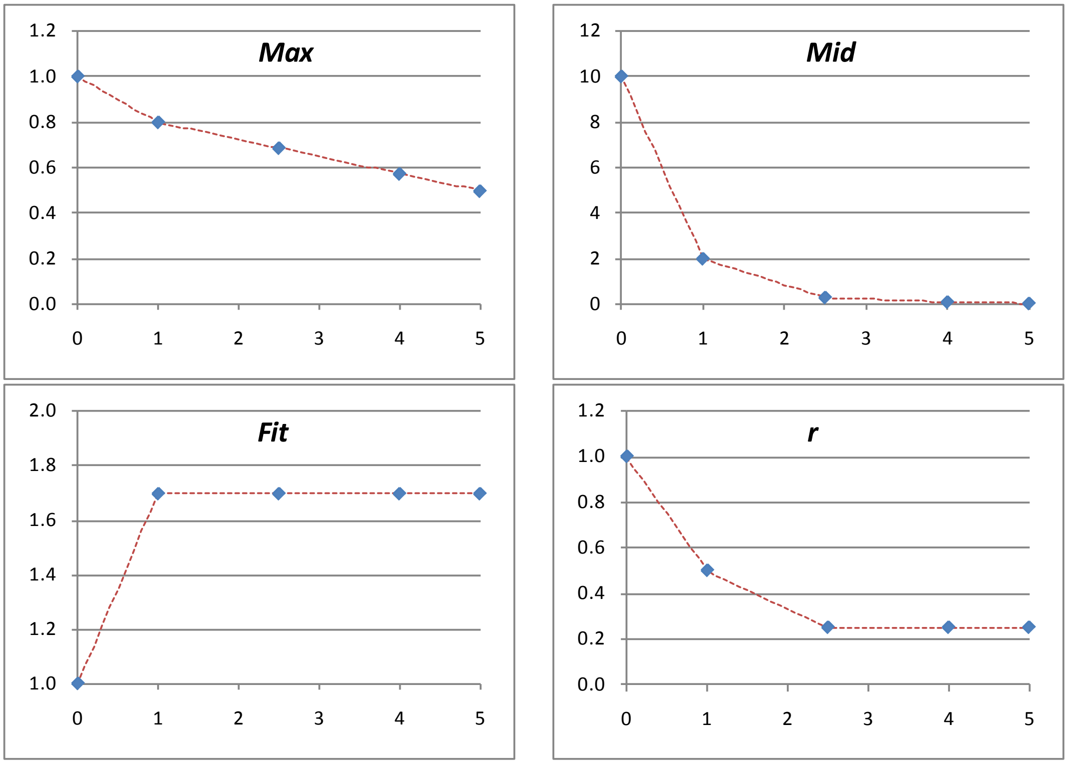

Figure 17-A.4.4 Continuous-value Functions of Parameters Driving Implementation Curve Shape

Hence, estimating the market effects of a rebate program relies on finding the interpolated implementation curve that best represents the studied market. In other words, it involves finding b_c such that the pair $(imp(b_c,bc), bc)$ equals the pair (base case market share, benefit/cost ratio) of the technology corresponding to the mandatory standard's efficiency level. Once the appropriate value of b_c is found (e.g. $b_c = \mathrm{b}_\mathrm{c}^*$), the market penetration of the technology under a rebate program can be calculated by the following equation:

$$imp(\mathrm{b}_\mathrm{c}^*, \mathrm{bc}^*) = \frac{max_c(\mathrm{b}_\mathrm{c}^*)}{(1 + r_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*) \cdot (1 + (mid_c(\mathrm{b}_\mathrm{c}^*) \cdot \mathrm{bc}^*)^{-fit_c(\mathrm{b}_\mathrm{c}^*)})} \qquad [9]$$

where:

b_c^* market barriers level corresponding to the studied market
bc^* benefit/cost ratio with rebate.

17-A.4.3.3 Limits to the Interpolation Approach

The approach presented above increases the accuracy of the estimate of the market implementation rate resulting from a rebate program. Consequently, it improves the analysis of the market effects of rebate programs. However, whereas it is feasible to develop interpolated implementation curves between the reference ones, there is no empirical support to extrapolate them beyond the *No Barriers* and the *Extremely High Barriers* curves. In fact, the theoretical boundaries for the market barriers level would be:

(a) Zero Barriers (b_0): With the assumption of the rational consumer, a tiny increase in the benefit/cost ratio of a technology with that ratio greater than 1 would be sufficient to make the technology widely adopted.[g] This would result in the following implementation rate function:

$$imp(b_0, bc) = \begin{cases} 0, & bc < 1 \\ 1, & bc > 1 \end{cases}$$

(b) Infinite Barriers (b_∞): In this case, even an extremely high benefit/cost ratio would not be sufficient to cause the market to adopt a technology. This would result in the following implementation rate function:

$$imp(b_\infty, bc) = 0, \forall bc$$

However, notwithstanding the existence of such theoretical boundaries, the analysis of market implementation rates in cases of markets where the base case market share is either higher than the market share in the *No Barriers* curve (for the corresponding benefit/cost ratio), or lower than the one in the *Extremely High Barriers* curve (idem), should follow the former analysis approach (as described at the end of section 17-A.4.3.2). It should rely, respectively, on the *No Barriers* or the *Extremely High Barriers* curves to estimate a relative market increase due to the rebate program.

17-A.5 CONSUMER REBATE PROGRAMS

DOE performed a search for rebate programs that offered incentives for furnace fans alone, as distinguished from rebates for entire gas furnace units. Some organizations nationwide, comprising electric utilities and regional agencies, offer rebate programs for furnace fans using ECM motors. Table 17-A.5.1 provides the organizations' names, states, rebate amounts and program websites. If there is more than one entry for an organization, it offers different rebates in different states. DOE then calculated the average rebate amount from the sample of 15 rebates from 13 organizations. The average rebate amount for furnace fans with ECM motors, given in 2012$ at the end of the table, is a simple average of the individual amounts for units meeting that efficiency level (rather than being population-weighted).

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[g] When the benefit/cost ratio is 1 the participant is indifferent to adopting the technology or not, and the implementation rate, in this case, would be undetermined.

Table 17-A.5.1 Rebates for Furnace Fans using ECM Motors

Utility	State	Rebate $	Website
Austin Utilities	Minnesota	$50	http://www.austinutilities.com/pages/residential_conserve_incentives.asp
Consumers Energy	Michigan	$100	https://www.consumersenergy.com/eeprograms/RRebateChart.aspx?id=4123
Dayton Power & Light	Ohio	$100	http://www.dpandl.com/save-money/residential/heating-cooling-rebates-for-your-home/heating-rebates/
Duquesne Light Company	Pennsylvania	$65	https://www.duquesnelight.com/wattchoices/default.cfm?tab=1&win=main
Efficiency Smart	Ohio	$100	http://www.efficiencysmart.org/About_Us/news/12-09-12/Efficiency_Smart_Introduces_Four_Additional_Residential_Rebate_Offers.aspx
Efficiency Vermont	Vermont	$100	http://www.efficiencyvermont.com/for_my_business/ways-to-save-and-rebates/hvac/rebates/all_rebates.aspx
Long Island Power Authority	NY	$100	http://www.lipower.org/residential/efficiency/appliances/furnace.html
MidAmerican ENERGY	Iowa	$50	http://www.midamericanenergy.com/ee/include/pdf/ia_res_equip_brochure.pdf
MidAmerican ENERGY	South Dakota	$50	http://www.midamericanenergy.com/ee/include/pdf/sd_res_equip_brochure.pdf
Minnesota Power	Minnesota	$250	http://www.mnpower.com/powerofone/one_home/hvac/specials/resources/ECM-Offers-Guide.pdf
Minnesota Power	Minnesota	$150	http://www.mnpower.com/powerofone/one_home/hvac/specials/resources/ECM-Offers-Guide.pdf
Rochester Public Utilities	Minnesota	$50	http://www.rpu.org/your-home/rebates-programs/conserve-and-save.html
Alexandria Light and Power	Minnesota	$150	http://www.alputilities.com/residential/rebates.php
Central Hudson Gas & Electric	NY	$200	http://www.savingscentral.com/residential.html
Owatonna Public Utilities	Minnesota	$50	http://www.owatonnautilities.com/residential-customers/residential-rebates/home-heating
Average Rebate Amount	$104.33		

17-A.6 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

17-A.6.1 Federal Tax Credits for Consumers of Residential Appliances

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas, oil and propane furnaces and boilers; furnace fans; and/or gas, oil, or electric heat pump water heaters in new or existing homes.[7, 8] These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).[9] There was a $1,500 cap on the credit per home, including the amount received for insulation, windows, and air and duct sealing. Congress extended this provision for 2011, with some modifications to eligibility requirements, and reductions in the cap to $500 per home. The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.[7, 10]
The tax credit for furnace fans was $50 in 2011, after which it expired.

The importance of the Federal tax credits has been emphasized in research in the residential heating industry on the impacts of the relatively large credits that were available for HVAC (heating, ventilating, and air conditioning) equipment. In a survey of HVAC distributors conducted by Vermont Energy Investment Corporation, respondents indicated that the ample credit had had a notable impact on sales of higher-efficiency heating and cooling equipment. Some distributors combined the Federal tax credits with manufacturer rebates and utility program rebates for a greater consumer incentive. However, when the amount of the Federal tax credit was reduced, smaller utility rebate incentives had not induced the same levels of equipment sales increases. The decrease in incentive size from a $1,500 cap in 2009-2010 to a $500 cap in 2011, during a period when the economy continued to be sluggish, resulted in a decline in total sales of residential HVAC products. Distributors stated that an incentive needed to cover 25 to 75 percent of the incremental cost of the efficient equipment to influence consumer choice. The industry publication "2011 HVAC Review and Outlook" noted a decline in sales of air conditioning units with >14 SEER in 2011 and a return in sales of units with >16 SEER to 2009 levels (after an increase in 2010). The large majority of distributor observed no impacts from the utility programs with their lower rebate amounts available in 2011. Distributors also commented on the advantages of the Federal tax credit being nationwide in contrast to utility rebate programs that target regional markets.[11, 12]

In an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, *Residential Energy Credits.*[13] It also estimated the percentage of taxpayers with entries under Form 5695's section 3, *Residential energy property costs*, line 3b, *qualified natural gas, propane, or oil furnace or hot water boiler*. DOE reasoned that the percentage of taxpayers with an entry on Line 3b could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for furnaces during the initial program years. DOE found that of all residential taxpayers filing tax returns, 0.8 percent in 2006 and 0.6 percent in 2007, claimed a credit for a furnace or boiler. DOE further found that the percentages of those filing Form 5695 for any qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.[14, 15, 16] For those three years - 1979, 1980, and 1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in chapter 17, section 17.3.3, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each product class. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

17-A.6.2 Federal Tax Credits for Manufacturers

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.[17] The Emergency Economic Stabilization Act of 2008[18] amended the credits and extended them through 2010. The credits were extended again to 2011 with modifications in the eligibility requirements. Manufacturer tax credits were extended again, by the American Taxpayer Relief Act of 2012, for clothes washers, refrigerators, and dishwashers manufactured between January 1, 2012 and December 31, 2013.[19]

Manufacturers who produce these appliances receive the credits for increasing their production of qualifying appliances. These credits had several efficiency tiers in 2011. For 2012-2013, credits for the higher tiers remain but were eliminated for the lowest (least efficient) tiers for clothes washers and dishwashers.[10] The credit amounts applied to each unit manufactured. The credit to manufacturers of qualifying clothes washers, refrigerators and dishwashers was capped at $75 million for the period of 2008-2010. However, the most efficient refrigerator (30%) and clothes washer (2.2 MEF/4.5 wcf) models was not subject to the cap. The credit to manufacturers was capped at $25 million for 2011, with the most efficient refrigerators (35%) and clothes washers (2.8 MEF/3.5 WCF) exempted from this cap.[20]

17-A.6.3 State Tax Credits

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Kentucky, Michigan and Indiana began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in chapter 17, section 17.3.3, on tax credit data for clothes washers.) Montana's Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trends and found them congruent with its analysis of Oregon's clothes washer tax credits.

Oregon's Residential Energy Tax Credit (RETC) was created in 1977. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, which significantly increased participation in the program. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. Beginning in 2012 a Tax Credit Extension Bill (HB3672) eliminated refrigerators, clothes washers, dishwashers, air conditioners, and boilers from the RETC program, leaving credits for water heaters, furnaces, heat pumps, tankless water heaters, and heat pump water heaters.[21, 22] Those technologies recognized by the Oregon Department of Energy as "premium efficiency" are eligible for tax credit of $0.60 per kWh saved in the first year (up to $1,500).[21, 23]

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.[24] The tax credit covers various residential energy and water efficient products, including split system central air conditioning; package system central air conditioning; split system air source heat pumps; package system heat pumps; natural gas, propane, or oil furnaces; hot water boilers; advanced main air circulating fans; heat recovery ventilators; gas, oil, or propane water heaters; electric heat pump water heaters; low-flow showerheads and faucets; light fixtures; and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to $150) to 25 percent (up to $500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

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