# Electricity and Natural Gas Efficiency Improvements for Residential Gas Furnaces in the U.S.

***Alex Lekov, Victor Franco, Steve Meyers, James E. McMahon, Michael McNeil, and Jim Lutz***

***Lawrence Berkeley National Laboratory, Berkeley, California***

## Abstract

This paper presents analysis of the life-cycle costs for individual households and the aggregate energy and economic impacts from potential energy efficiency improvements in U.S. residential furnaces. Most homes in the US are heated by a central furnace attached to ducts for distributing heated air and fueled by natural gas. Electricity consumption by a furnace blower is significant, comparable to the annual electricity consumption of a major appliance. Since the same blower unit is also used during the summer to circulate cooled air in centrally air conditioned homes, electricity savings occur year round. Estimates are provided of the potential electricity savings from more efficient fans and motors.

Current regulations require new residential gas-fired furnaces (not including mobile home furnaces) to meet or exceed 78% annual fuel utilization efficiency (AFUE), but in fact nearly all furnaces sold are at 80% AFUE or higher. The possibilities for higher fuel efficiency fall into two groups: more efficient non-condensing furnaces (81% AFUE) and condensing furnaces (90-96% AFUE). There are also options to increase the efficiency of the furnace blower. This paper reports the projected national energy and economic impacts of requiring higher efficiency furnaces in the future. Energy savings vary with climate, with the result that condensing furnaces offer larger energy savings in colder climates. The range of impacts for a statistical sample of households and the percent of households with net savings in life cycle cost are shown.

Gas furnaces are somewhat unusual in that the technology does not easily permit incremental change to the AFUE above 80%. Achieving significant energy savings requires use of condensing technology, which yields a large efficiency gain (to 90% or higher AFUE), but has a higher cost. With respect to electricity efficiency design options, the ECM has a negative effect on the average LCC. The current extra cost of this technology more than offsets the sizable electricity savings.

## Background

The residential furnace is an appliance that provides heated air through ductwork to the space being heated. It is equipped with a blower to circulate air through the duct distribution system. In North America, most houses are heated by forced air systems. Residential furnaces, for statutory purposes, are defined as furnaces having a heat input rate of less than 225,000 Btus per hour (66,000 watts). In the United States, 70% of households have furnaces of this type.

The National Appliance Energy Conservation Act (NAECA) legislation of 1987 established the initial minimum standards for furnaces and boilers, effective in 1992. Current regulations require new residential gas-fired furnaces (not including mobile home furnaces) to meet or exceed 78% annual fuel utilization efficiency (AFUE), and in fact nearly all furnaces sold are at 80% AFUE or higher. In 2000, the U.S. Department of Energy (DOE) identified residential furnaces and boilers as priority products for an updated standards rulemaking. The analytical approach and results reported here are part of DOE's rulemaking process for the Advance Notice of Proposed Rulemaking (ANOPR), which was issued on July 29, 2004. [1]

Furnaces use electricity in addition to fossil fuel energy for combustion. Most of the electricity is used by the circulating air blower. The furnace uses electricity for other purposes as well. The combustion air is pulled through the furnace by a draft inducer fan, and a furnace also has various controls and an electronic ignitor to assure proper ignition of the fuel.

The circulating air blower of the furnace pushes cool air returning from the inhabited space of the house past the outside of the heat exchangers and supplies heated air to the house through a system of ducts. Heat is provided by burning gas and moving combustion products through the inside of the heat exchangers. The products of combustion are exhausted to the atmosphere through a flue passage connected to the heat exchangers. The amount of air the blower can force through the house's ducts depends on the pressure and flow relations of both the house and the furnace. If the house has an air-conditioner, as over three-quarters of houses with furnaces in the U.S. do, the furnace blower and the same ducts will be used to circulate cooled air. To operate properly, air-conditioners need more airflow than furnaces, so the blower motor is run at a higher speed during air-conditioning operation.

Residential furnaces are rated with annual fuel utilization efficiency (AFUE) as an efficiency descriptor. AFUE represents the equipment's performance over an entire year's heating season. It is intended to represent the effective annual operating efficiency of a furnace under dynamic conditions. It includes performance during start-up, steady-state, and cool-down operations. The AFUE is calculated from performance parameters that are measured under laboratory conditions using the DOE test procedure. [2] These include a set of temperatures, fuel consumption, and a few other performance parameters. AFUE does not account for the electricity consumption of the appliance and, therefore does not include the circulating air and combustion fan power consumption, except to account for the amount of waste heat produced by these fans.

There are two main types of residential furnaces: weatherized and non-weatherized furnaces. Weatherized furnaces are generally installed outdoors (often on rooftops), and non-weatherized furnaces are installed indoors. Manufacturers test non-weatherized furnaces as an isolated combustion system (ICS), which means it is isolated from the conditioned space where it is located and the furnace draws combustion and dilution air from the outdoors. Manufacturers test weatherized furnaces under outdoor conditions. The main difference between a weatherized furnace and a non-weatherized furnace is that the weatherized furnace is well insulated and has a weather-resistant external case. The heat loss through the jacket in a weatherized furnace is totally dissipated outside, resulting in a lower efficiency compared to an equivalent non-weatherized furnace installed indoors.

Non-weatherized gas furnaces can be either non-condensing or condensing. When the flue temperature is substantially higher than the dew point of the combustion products, the latent heat (the heat from condensation of water vapor in the combustion products) is lost in the flue. In this case, the furnace is classified as non-condensing. The AFUE of such furnaces is generally below 83 percent AFUE. Condensing gas furnaces recover more heat from the combustion products by condensing the water vapor and can reach efficiencies as high as 96% AFUE.

Mobile home furnaces are a separate class of furnaces, due to three differences. They employ sealed combustion, pre-heat the combustion air, and have very tight space constraints. Mobile home furnaces have historically had a lower efficiency standard and were considered as a separate product in rulemakings in the early 1990s.

Approximately, 2.7 million units of non-weatherized gas furnaces were shipped in the U.S. in 2003, compared to 0.4 million units of weatherized gas furnaces and 0.14 million units of mobile home gas furnaces. Thus, we devoted most attention to non-weatherized gas furnaces.

## LCC Analysis

Life-cycle costing is a standard engineering economic approach for choosing between alternative products or designs that provide equal service to the user. It allows for a comparison between products having different initial and long-term operating costs. The goal of this LCC analysis was to calculate the LCC for alternative equipment designs in houses that are representative of those in which new furnaces will be installed. The life-cycle cost consists of two main components: (1) the cost of buying and installing a furnace, and (2) the operating costs summed over the lifetime of the equipment, discounted to the present.

To account for the uncertainty and variability in the inputs to the LCC calculation for a given household and between different households, we used a Monte Carlo simulation. A Monte Carlo simulation uses a distribution of values to allow for variability and/or uncertainty on inputs for complex calculations. For each input, there is a distribution of values, with probabilities (weighting) attached to each value. The simulations sample input values randomly from the probability distributions. For some variables, such as energy price and climate, the calculations used the values associated with each sampled household. We used Microsoft Excel spreadsheets with Crystal Ball, an add-on software, to perform the Monte Carlo analysis.

The LCC analysis estimated furnace energy consumption under field conditions for a sample of houses that is representative of U.S. homes. These conditions include outdoor climate during the heating and cooling season which influence the operating hours of the equipment.

We calculated the LCC for a representative sample of households selected from the 1997 Residential Energy Consumption Survey (RECS97). [3] We sampled one house at a time, using appropriate input values associated with each household. For each sampled household, we estimated the energy consumption of the furnace, incorporating: (1) baseline design characteristics, and (2) design options that yield higher efficiencies.

We treated a furnace in a new home differently from one purchased as replacement equipment for three reasons. First, heating equipment prices are different for new construction and retrofit applications. Equipment cost for new construction includes a builder markup and does not include sales tax. Equipment cost for replacement installations includes sales tax and does not include a builder markup. Second, the financing method (and therefore the discount rate in the LCC calculation) for new construction is usually a mortgage loan. Financing methods for replacement installations can take a variety of forms that have different interest rates. Third, new construction tends to be built with more insulation and more energy-efficient products, compared to houses that receive replacement installations, and is also concentrated in certain parts of the country. We estimated that 26% of annual shipments of non-weatherized gas furnaces are installed in new construction.

The change in LCC resulting from a change to higher-efficiency equipment is calculated relative to the base case, which represents the equipment that a house would have in the absence of any change in standards. The base case differs from the baseline which represents a model with an efficiency that just meets the existing federal minimum energy conservation standards. Thus, some houses in the base case are assumed to purchase higher-efficiency furnaces than the baseline.

**Design Options**

We calculated the impacts for furnaces incorporating a variety of design options that increase fuel and electricity use efficiency. The design options shown in Table 1 were those that met the screening criteria used in this study.

**Table 1: Design Options Considered for Non-Weatherized Gas Furnaces**

| Design Option | Fuel-saving | Electricity-saving |
|---|---|---|
| Improved Heat Exchanger Effectiveness | X | |
| Condensing Secondary Heat Exchanger | X | |
| Modulating Operation | X | X |
| Increased Motor Efficiency | | X |
| Increased Blower Impeller Efficiency | | X |

Heat exchanger effectiveness can be improved in many ways. Furnace manufacturers optimize the heat exchanger size and geometry, gas input rate, combustion air delivery system, heat transfer coefficient and heat exchanger mass, and may apply other enhancements to provide the greatest comfort, reliability, and safety.

A condensing furnace requires some extra equipment, such as an additional stainless steel heat exchanger and a condensate drain device. Condensing furnaces also require a different venting system, since the buoyancy of the flue gases is not sufficient to draw the gases up a regular chimney. Plastic through-the-wall venting systems are typically used in conjunction with condensing furnaces. Condensing furnaces present a higher initial cost, but provide significant energy-efficiency gains.

A modulating control is any control that uses either gradual or step-wise adjustment of the furnace input rate in response to changes in the heating load. Two different types of modulating controls can be applied to furnaces, two-stage and step control, to decrease fuel and electricity use. Both two-stage and step modulating gas furnaces are currently available on the market.

Two-stage control refers to a modulating control that cycles a burner between reduced heat input rate and off or between the maximum heat input rate and off. Two-stage controls are limited to these two operations. Step modulation can operate at a large number of heat input rate.

Furnaces that operate at substantially reduced output over longer periods of time can provide more uniform space temperatures, quieter operation, greater efficiency, and reduced emissions. Achieving these objectives requires that the combustion stoichiometry (the proper fuel/air mixture to assure clean combustion) be carefully controlled at all firing rates to assure safe operation and minimum emissions.

Most furnaces sold in the U.S. use forward-curved impellers directly driven by a permanent split capacitor (PSC) motor. Two design options to improve blower efficiency were considered: 1) an electronically commutated motor (ECM); and 2) a backward-curved blower with a modified ECM motor (BC/ECM+). ECM motors have permanent magnets on the rotor. By changing the frequency and voltage across the stator coils, the speed and torque of the motor can be adjusted. The BC/ECM+ motor operates at a higher speed, has a smaller diameter, and has improved magnets and electronics. Furnaces with ECM and BC/ECM+ blower motors take advantage of the adjustable speed and torque of ECM motors to provide constant airflow, regardless of the static pressure. Backward-curved blowers have different aerodynamic characteristics than forward-curved blowers. For each of the above designs, the burner operating hours are different, since the furnace efficiency, overall air moving efficiency, and blower motor electricity consumption are different. Therefore each design requires a different operating time to provide the same amount of heat to the same house.

**Equipment and Installation Costs**

The cost of buying and installing a furnace consists of three main elements: the manufacturing cost, markups in the distribution chain, and the installation cost.

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In order to compare the total additional consumer cost of improved equipment efficiency, a baseline design was defined for each product class. The baseline model establishes the starting point for analyzing technologies that provide energy-efficiency improvement. Based on the market assessment and input provided by manufacturers for this study, a baseline model was defined as an appliance with an efficiency at the minimum level prescribed by EPCA (78 percent AFUE for non-weatherized gas furnaces), and having commonly available features and technologies.

To estimate the manufacturing cost of alternative furnace designs for this study, several design options were evaluated that could meet each considered efficiency level. It then selected the design option(s) it believed manufacturers would most likely implement to achieve a given considered energy efficiency level. To estimate the manufacturing costs of these design options, this study relied primarily on a reverse-engineering approach. In the context of this analysis, the term reverse-engineering describes the estimation of production costs by a detailed examination of the actual furnace components.

Using the manufacturing cost as a base, we applied markups for manufacturers, wholesalers, contractors, and builders, as well as sales tax. The markups and sales tax was applied depending on the type of installation (i.e., in new construction or replacement).

The LCC analysis used manufacturing costs from the reverse-engineered cost of the baseline size furnace. To derive the manufacturing costs for the other sizes, we scaled the reverse-engineered model costs. To represent the majority of combinations of input capacity and nominal maximum airflow, we developed generic “virtual” models to represent 25 different combinations of those two variables. (We refer to these as virtual models because they are not real models on the market.) Each virtual model had its own cost and energy characteristics. The virtual models include models with the most commonly-occurring input capacities, with corresponding nominal maximum airflow rates at static pressure of 124.5 Pa [0.5 inches water gauge].

The installation cost is the cost to the consumer of installing a furnace; it covers all labor associated with the installation of a new unit or the replacement of an existing one. This includes costs of changes to the house, such as venting modifications that would be required for the installation. The estimates of installation costs vary by efficiency level. Installation of 81% AFUE equipment may require use of more expensive venting systems to prevent problems from condensation. At this efficiency level, this study estimated that 8% of installations that would require such a venting system.

The size of the equipment, the type of installation, and the installation costs depend on the households for which the equipment is bought. Characteristics listed in the RECS data set enabled us to make reasonable assumptions about these factors for each household in the analysis.

**Calculating Furnace Energy Use**

Estimating the energy consumption of alternative furnaces in the sample houses requires estimating the heating and cooling loads of each particular house. The loads represent the amount of heating and cooling required by a house to keep it comfortable for an entire year. The annual house heating load is the total amount of heat output from the furnace that the house needs for an entire year. This includes the heat from the burner and the heat generated by the inefficiencies of the blower and the blower motor. The house heating load was determined for each sampled household from the annual space heating energy consumption reported in RECS97 and the assumed characteristics of the existing furnace. The annual house cooling load is the total amount of cooling provided to the house for the entire cooling season. It includes the cooling provided by the existing air conditioner, and accounts for the waste heat from the inefficiencies of the blower and blower motor. The house cooling load was calculated from the cooling energy consumption reported in RECS97 and the assigned efficiency of the existing air conditioner.

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To estimate the energy consumption of furnaces if they used alternate designs rather than the existing equipment, the LCC analysis used representative virtual model furnaces. These virtual models incorporate typical features of currently marketed furnaces. One virtual model was created for each of 25 combinations of maximum airflow and input capacity to represent the available range of actual models. Specifications from actual models were used to determine the specifications for the corresponding virtual models. The specifications include blower size, motor size, supply air outlet area, power consumption of the draft inducer and the igniter, and several delay times.

The estimation of heating and cooling loads requires calculation of the electricity consumption of the furnace blower, since waste heat from the blower and blower motor heats the house. The amount of waste heat produced depends on the overall efficiency of the blower and blower motor and the amount of electricity the blower motor consumes. The electricity consumption of a blower motor depends on the type of motor, 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, the operating conditions (the pressure and air flow) at which a particular furnace in a particular house will operate were determined. Circulating air blower motor electricity consumption at full-load steady-state is a function of airflow, external static pressure, and the overall air-moving efficiency of the furnace.

The blower moves heated air through the house whenever the furnace is on. It also operates in the cooling season (summer) if the house is air-conditioned. Since the efficiency of the blower will have different impacts on the overall energy consumption in different seasons, the electricity use calculation was carried out separately for winter and summer.

Table 2 presents the average energy calculation results from the LCC analysis. These results show 2-stage modulation reducing gas use but slightly increasing winter electricity use. (In practice, though, the reduction in gas use may not actually occur, as discussed in the Selected Issues section.) The reason for the electricity use outcome is that when the blower operates at lower speed, the blower runs for a longer period.

The 90% condensing furnaces lowers gas use by 11% relative to the 80% AFUE furnace. Note that these results do not reflect furnace performance of the various design options as it would be under identical conditions. Rather, the results are influenced by the assignment of equipment to the sample houses. The ECM option reduces total electricity use by one-third for the 80% AFUE furnace, while the backward-curved blower with a different ECM motor reduces it by 50%. Note that improving the efficiency of the blower in a gas furnace reduces electricity consumption, but slightly increases gas consumption (due to the need to make up for the reduction in heat given off by a more efficient motor).

**Table 2: Average Energy Use for Non-Weatherized Gas Furnaces in the LCC Analysis**

| Design Options | | | Annual Gas Use | Winter Electricity Use | Summer Electricity Use |
|---|---|---|---|---|---|
| **AFUE** | **Controls** | **Blower Motor Type** | GJ [MMBtu] | kWh | kWh |
| 78% | single-stage | PSC | 70.1 [66.5] | 487.3 | 153.9 |
| 80% | single-stage | PSC | 68.4 [64.9] | 475.5 | 153.9 |
| 80% | single-stage | ECM | 69.2 [65.6] | 300.2 | 115.2 |
| 80% | single-stage | BC/ECM+ | 69.5 [65.9] | 239.3 | 76.2 |
| 80% | two-stage | PSC | 67.0 [63.5] | 492.3 | 153.9 |
| 80% | two-stage | ECM | 68.5 [64.9] | 247.5 | 115.2 |
| 80% | two-stage | BC/ECM+ | 69.0 [65.4] | 201.9 | 76.2 |
| 81% | single-stage | PSC | 67.6 [64.1] | 469.8 | 153.9 |
| 90% | single-stage | PSC | 61.1 [57.9] | 421.0 | 153.9 |
| 90% | single-stage | ECM | 61.6 [58.4] | 277.8 | 115.2 |
| 90% | single-stage | BC/ECM+ | 61.8 [58.6] | 223.6 | 76.2 |
| 91% | two-stage | ECM | 60.4 [57.2] | 240.0 | 115.2 |
| 91% | two-stage | BC/ECM+ | 60.8 [57.6] | 198.6 | 76.2 |
| 92% | single-stage | PSC | 59.8 [56.6] | 412.0 | 153.9 |
| 96% | step modulation | ECM | 56.9 [54.0] | 226.3 | 76.2 |

PSC = permanent split capacitor
ECM = electronically-commutated motor
BC/ECM+ = backward-curved impeller and improved ECM

**Other Operating Cost Inputs**

In addition to annual energy consumption, calculation of operating costs requires data on the future prices of natural gas and electricity. We used marginal energy prices to calculate the cost of saved energy associated with higher-efficiency equipment. Marginal energy prices are the prices consumers pay for the last unit of energy used. We calculated average and marginal energy prices for each sample house in 1997 using RECS data. We estimated marginal energy prices from the RECS monthly billing data by a linear regression of monthly customer bills to monthly customer energy consumption for each household for which billing data were available. We divided the natural gas billing data into two seasons: winter and the rest of the year. We estimated the marginal electricity price for those two seasons as well.

We used the average and marginal prices for 1997 of each sampled house combined with the forecast annual price changes in EIA's Annual Energy Outlook 2003 (AEO2003) [4] to arrive at prices in 2012 and beyond. The projected average residential natural gas price is in the $7.81-7.91/GJ [$7.40-7.50/MMBtu] range between 2012 and 2019, but then begins to increase at a strong rate, reaching $8.44/GJ [$8.00/MMBtu] in 2025.

The maintenance cost is the annual cost of maintaining a furnace in working condition. Several groups of maintenance costs were developed. For the LCC analysis, we assumed a triangular distribution for maintenance costs to capture the variability of these costs. We assumed a minimum and maximum of 15% around the average.

The lifetime is the age at which furnaces are retired from service. For non-weatherized gas furnaces, we used an average lifetime of 20 years, with a range of 10 to 30 years.

We derived the discount rates for the LCC analysis from estimates of the finance cost to purchase furnaces. Following financial theory, the finance cost of raising funds to purchase furnaces can be interpreted as: (1) the financial cost of any debt incurred to purchase equipment, principally interest charges on debt, or (2) the opportunity cost of any equity used to purchase equipment, principally interest earnings on household equity. Consumers use different methods to purchase equipment for new and existing homes. Furnaces purchased for new homes are financed with home mortgages. Furnaces for existing homes (replacement equipment) are purchased using a variety of household debt and equity sources. We used different discount rates corresponding to the finance cost of new construction and replacement installations.

We estimated the discount rate for equipment in new housing based on mortgage interest rate data provided in the Federal Reserve Boards' Survey of Consumer Finances (SCF). [5] This survey indicates that mortgage rates carried by homeowners in 1998 averaged 7.9%. After adjusting for inflation and interest tax deduction, real after-tax interest rates on mortgages averaged 4.2%.

In the residential sector, replacement equipment is usually purchased using cash or some form of credit. One approach for deriving an average discount rate is to identify the types of credit used to purchase a given type of equipment (e.g., dealer installment loan, credit card), the associated interest rates, and the shares of each credit type in total replacement purchases. Such information is difficult to come by, however, and there are reasons to favor an alternative approach. When a household makes a major appliance purchase, the short-term effect may be an increase in debt if the purchase is financed with a dealer loan or credit card, or a decrease in cash if the product is purchased with cash. However, financial theory suggests that in the medium-term, households should tend to rebalance their overall equity/debt portfolio to maintain approximately the same relative shares of different equity/debt classes. According to this line of reasoning, the appropriate opportunity cost (or discount rate) for purchase of major appliances should reflect a household's overall equity/debt portfolio, and not simply the financial or opportunity cost of the debt or equity used to purchase the equipment.

The types of equity and debt likely to be affected by appliance purchases include second mortgages, credit cards, transaction accounts, certificates of deposit (CDs), U.S. savings bonds, stocks, and mutual funds. We estimated the shares of each type in the total household equity and debt portfolio from SCF data and estimated interest or return rates associated with these equity and debt classes from a variety of sources. The weighted-average real interest rate across all types of household debt and equity used to purchase replacement furnaces is 6.7%.

**Payback Period Inputs**

Numerically, the simple payback period (PBP) is the ratio of the increase in purchase (and installation) price to the decrease in annual operating expenditures (including maintenance). We made the comparisons based on replacing the base case furnace with a furnace incorporating another efficiency level. Payback periods are expressed in years. A payback period of three years means that the increased purchase price for the energy-efficient furnace is equal to three times the value of reduced operating expenses in the year of purchase; in other words, the increased purchase price is recovered in three years because of lower operating expenses.

The data inputs to the PBP calculation are the cost of the equipment to the customer and the annual (first-year) operating expenditures. The PBP calculation uses the same inputs as the LCC analysis, except that energy price trends and discount rates are not required. Since the PBP is a "simple" payback, the required energy prices are only for the year in which a new standard is to take effect—in this case the year 2012.

**LCC and PBP Results**

For each of the efficiency level, we calculated LCC savings and payback period relative to the base case equipment assigned to each house. The average LCC is the present value of total customer expense over the life of the furnace, including purchase expense and operating costs, which include energy expenditures. Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment. We used a distribution of discount rates as described in Other Operating Costs Inputs section. The average LCC savings represent the LCC difference between the new standard being set at the specific efficiency level and the base case assigned to the household. For each efficiency level, we calculated the fraction of households which will either decrease (net benefit), or increase (net cost), or exhibit no change (no impact). No impacts occur when the equipment efficiencies of the base case forecast already equal or exceed the considered efficiency level standard. The median payback results are calculated by taking the median simple payback for households impacted by the new standard.

Table 3 shows LCC and payback results for non-weatherized gas furnaces. Going to 2-stage modulation results in positive average LCC savings, but, in practice, the reduction in gas use may not occur, as discussed in the Selected Issues section. The 81% AFUE level shows basically no change in average LCC. The 90% AFUE condensing furnace has a negative average LCC impact, but it does have a benefit for houses in colder climates.

**Table 3: LCC and PBP Results for Non-Weatherized Gas Furnaces**

| | LCC | | | | | Payback |
|---|---|---|---|---|---|---|
| **Efficiency Levels*** | **Average LCC** | **Average Savings** | **Net Cost** | **No Impact** | **Net Benefit** | **Median**** |
| | 2001$ | 2001$ | % | % | % | years |
| 78% Baseline | $9,966 | | | | | |
| 80% | $9,795 | $0 | 0% | 99% | 1% | 2.1 |
| 80% 2-stage | $9,718 | $41 | 33% | 27% | 40% | 8.6 |
| 81% | $9,789 | -$3 | 32% | 27% | 41% | 8.8 |
| 90% Condensing | $9,917 | -$154 | 56% | 26% | 18% | 17.9 |
| 92% Condensing | $9,924 | -$166 | 60% | 15% | 25% | 16.1 |
| 96% Condensing | $10,724 | -$954 | 89% | 2% | 9% | 32.3 |

* All efficiency levels include a PSC blower motor, except for 96% AFUE, which includes step modulation and ECM motor.
** Median payback for different efficiency levels is calculated based on a sample of households that are impacted by the new standard. The number of households in each sample differs at each efficiency level.

Table 4 shows LCC and payback results non-weatherized gas furnaces with efficiency levels that include electricity design options. The electronically-commutated motor (ECM) and BC/ECM+ options have a negative effect on the average LCC. Yet, when these options are used with two-stage modulation the LCC results are not as negative and in the case of the 80% AFUE 2-stage modulation with BC/ECM+, the average LCC savings is slightly positive. Therefore, the current extra cost of these technologies more than offsets the sizable electricity savings.

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**Table 4: LCC and PBP Results for Non-Weatherized Gas Furnaces; Electricity Design Options**

| | LCC | | | | | Payback |
|---|---|---|---|---|---|---|
| **Efficiency Levels** | **Average LCC** | **Average Savings** | **Net Cost** | **No Impact** | **Net Benefit** | **Median*** |
| | 2001$ | 2001$ | % | % | % | years |
| 78% Baseline | $9,966 | | | | | |
| 80% PSC | $9,795 | $0 | 0% | 99% | 1% | 2.1 |
| 80% ECM | $9,873 | -$59 | 60% | 27% | 14% | 23.0 |
| 80% BC/ECM+ | $9,822 | -$21 | 51% | 27% | 23% | 17.2 |
| 80% 2-stage, ECM | $9,795 | -$13 | 48% | 27% | 26% | 15.4 |
| 80% 2-stage, BC/ECM+ | $9,782 | $1 | 45% | 27% | 28% | 14.3 |
| 90% PSC | $9,917 | -$154 | 56% | 26% | 18% | 17.9 |
| 90% ECM | $10,007 | -$226 | 66% | 15% | 19% | 21.5 |
| 90% BC/ECM+ | $9,957 | -$180 | 63% | 15% | 22% | 19.1 |
| 91% 2-stage, ECM | $9,898 | -$141 | 58% | 15% | 26% | 16.5 |
| 91% 2-stage, BC/ECM+ | $9,878 | -$118 | 58% | 15% | 27% | 16.2 |

## Analysis of National Impacts

This section describes the estimation of national energy savings (NES) and the net value to consumers from new furnace efficiency standards. For specific efficiency levels, it describes: 1) cumulative NES in the considered period (2012–2035), and 2) the net present value (NPV) of efficiency standards for consumers, accounting for products installed in the period considered. The NPV represents the difference between the present value of operating cost savings and increased installed costs.

### National Energy Savings

We calculated annual NES as the difference between: annual energy consumption (AEC) in the base case forecast (without new standards), and AEC in a case with new standards. Cumulative energy savings are the sum over 2012 to 2035 of the annual national energy savings. We calculated the national annual energy consumption by multiplying the number of existing furnaces (by vintage) by the unit energy consumption (UEC) (also by vintage).

The UEC is the site energy (natural gas and electricity) consumed by a furnace per year. The annual gas consumption is directly related to the efficiency AFUE of the unit. Using the energy consumption calculations described in the LCC section, we determined the national average annual natural gas consumption that corresponds to each AFUE level. The UES used in the NES model is the average value from the energy consumption calculations that correspond to each AFUE level.

The NES model considers non-condensing and condensing gas furnaces market segments separately. The average current AFUE (based on data from the Gas Appliance Manufacturers Association) is approximately 80 percent for non-condensing furnaces and 93 percent for condensing types. [6] Most non-condensing furnaces operate at 80 percent AFUE and most condensing furnaces operate at either 90 or 92 percent AFUE, with just a few percent of market share at other values. There is a limited amount of historical efficiency data available for furnaces, but the evidence suggests that there has been little change since the early 1990s within non-condensing and condensing market segments. Therefore, the base case forecast assumes that current efficiencies remain constant.

We forecasted the share of condensing furnaces in the base case using the average growth rate in 1991–2000. The share grows from 23% in 2000 to 27.4% in 2012 and 30.4% in 2020.

For non-weatherized gas furnaces, we forecasted shipments as a function of new construction and expected replacements. In the standards case, the shipments model takes into account that, increased installed cost of more-efficient gas-fired equipment will cause some customers to purchase electric rather than gas equipment. Therefore, projected shipments of gas equipment are lower in the higher-efficiency cases, and there is a corresponding increase in electric heating equipment shipments.

The stock in a given year is the number of units shipped from earlier years that survive (remain in use) in the given year. The NES model keeps track of the number of units shipped each year, and the average UEC of each cohort. The effect of standards is to raise the minimum efficiency to the target level. The fraction of the market already at or above the standard level is not affected by the standards. We assumed that the units have an increasing probability of retiring as they age. The survival function is the probability of survival as a function of years-since-purchase.

In determining national annual energy consumption, we initially calculated the annual energy consumption at the site. We then calculated primary (source) energy consumption from site energy consumption by applying a conversion factor to account for losses associated with the generation, transmission, and distribution of electricity and gas. We used annual site-to-source conversion factors based on the Lawrence Berkeley National Laboratory (LBNL) version of the National Energy Modeling System (NEMS), which corresponds to DOE’s Energy Information Administration (EIA’s) Annual Energy Outlook 2002 (AEO2002). [7] The factors used are marginal values, which represent the response of the system to an incremental decrease in consumption. Primary energy for electricity generation is about three times site energy. Natural gas losses include pipeline leakage, pumping energy, and transportation fuel.  Primary energy for natural gas is about 90% of site energy.

**Consumer Impacts: Net Present Value**

The NPV is the difference between the present value of operating cost savings (PVS), which includes energy and maintenance costs, and the present value of increased installed costs (PVC), which includes equipment and installation. We determined PVC for each year from the effective date of the standard to 2035 and calculated PVS for each year from the effective date of the standard to the last year when units purchased in 2035 are retired. The NPV of the standards is the sum over all years of the difference between PVS and PVC.

The average installed cost for the base case forecast and each efficiency level in 2012 comes from the LCC analysis. Because of the uncertainty concerning future trends in furnace manufacturing, we assumed no change in average real equipment costs at each efficiency level after 2012.

The total incremental cost of equipment between a standards case forecast and the base case forecast depends on the average incremental cost of each unit, and on any changes in shipments. In addition, for the portion of the market expected to switch to electric equipment in the standards case, we accounted for the cost differential of electric equipment versus a gas furnace and air conditioner combination.

The annual operating cost savings to consumers are equal to the difference between site annual gas and electricity consumption in the base case forecast and a standards case forecast, multiplied by the respective marginal energy price. We accounted for the operating cost of additional electric heating equipment purchased instead of gas-fired equipment in standards cases.

The savings calculation uses the marginal price for gas and electricity. For the years after 2025, we applied the average annual growth rate in 2010–2025 for gas and heating oil prices and the average annual growth rate in 2015–2025 for electricity prices.

The discount factor is the factor by which monetary values in one year are multiplied in order to determine the present value. We used both a 3 percent and a 7 percent real discount rate in accordance with the

Office of Management and Budget's (OMB) guidelines. [8] We defined the present year to be 2001, for consistency with the year in which the manufacturer cost data were collected.

To illustrate the basic inputs to the NPV calculations, Figure 1 presents the non-discounted annual installed cost increases and annual operating cost savings at the national level for the 81 percent AFUE non-weatherized gas furnace (single-stage). The figure also shows the net savings, which is the difference between the savings and costs for each year. The annual equipment cost is the increase in equipment price for products purchased each year over the period 2012–2035. The annual operating cost savings is the savings in operating costs for products operating in each year. The NPV is the difference between the cumulative annual discounted savings and the cumulative annual discounted costs.

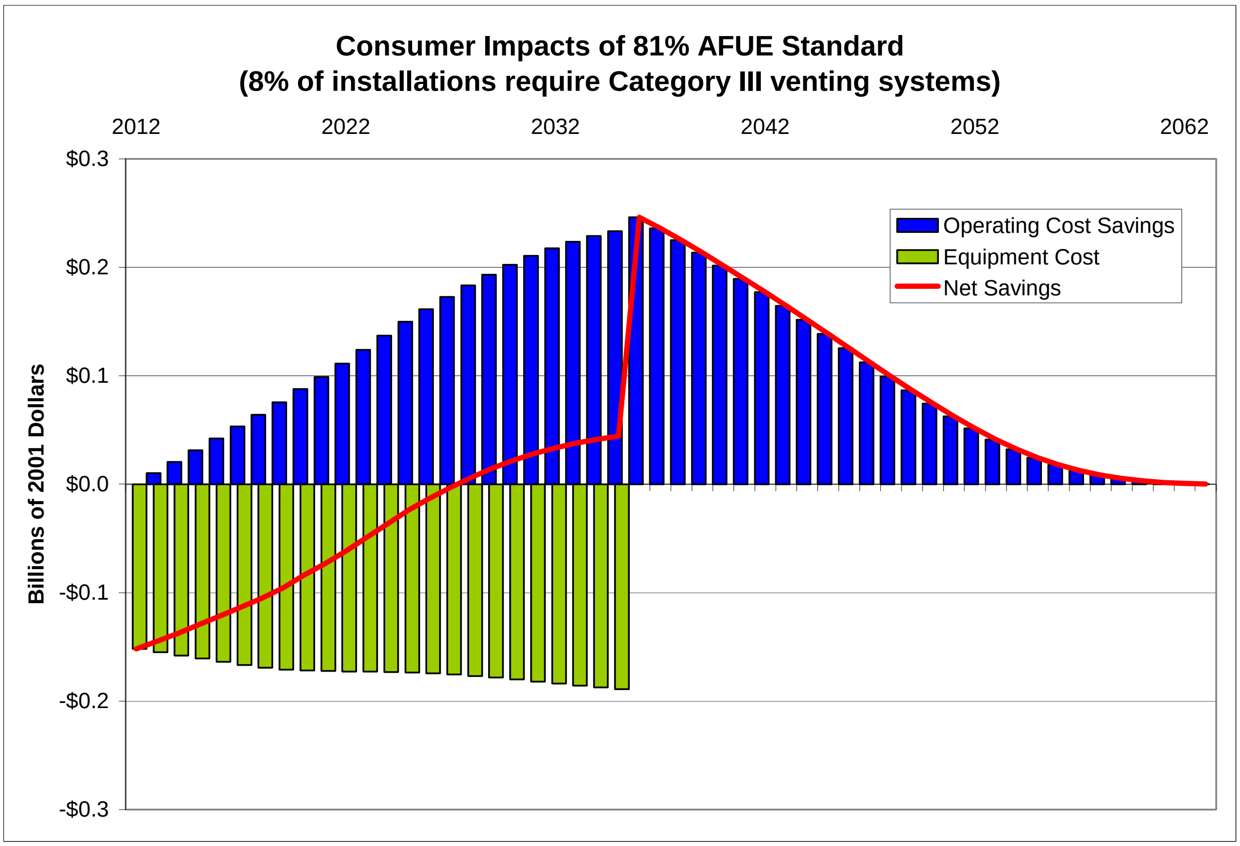


**Figure 1: Non-discounted Annual Installed Cost Increases and Annual Operating Cost Savings at the National Level for the 81 percent AFUE Non-Weatherized Gas Furnace**

### NES and NPV Results

The NES model offers a range of possible outputs all of which depend on the inputs used on deriving the results. Table 5 shows the NES and NPV results for non-weatherized gas furnaces for various AFUEs. Since few furnaces sold are less than 80% AFUE, there is little to be gained by a standard at this level. The 81 percent AFUE level has positive energy savings, but the NPV is negative at 7% discount rate and barely positive at 3%. The 90 percent AFUE level has substantial energy savings. It has a negative NPV at 7% discount rate, but a large positive NPV at 3%. At the 80% AFUE level, the ECM option has small energy savings, but either slightly negative or positive NPV.

**Table 5: Cumulative National Energy Savings and Consumer Net Present Value for Non-Weatherized Gas Furnaces**

| AFUE | Controls | Motor Type | NES (EJ [Quads]) | NPV (billion 2001 $) | |
|---|---|---|---|---|---|
| | | | | 3% Discount Rate | 7% Discount Rate |
| 80% | single-stage | PSC | 0.03 [0.03] | 0.15 | 0.05 |
| 80% | two-stage | ECM | 0.07 [0.06] | 0.09 | -0.02 |
| 81% | single-stage | PSC | 0.46 [0.44] | 0.04 | -0.29 |
| 90% | single-stage | PSC | 4.33 [4.10] | 5.11 | -0.56 |
| 91% | two-stage | ECM | 5.78 [5.48] | 3.96 | -2.20 |
| 96% | step modulation | ECM | 7.54 [7.15] | -14.53 | -11.61 |

## Selected Issues

Two important issues that arose in the analysis are (1) the limits to improving the efficiency of non-condensing gas furnaces due to the costs of providing appropriate venting to avoid condensation problems; and (2) the energy impacts of modulating operation.

As mentioned earlier, installation of 81% AFUE equipment may require use of stainless-steel material venting systems to prevent problems from condensation. The conditions which determine the type of venting system are defined based on the operating pressure and temperature in the vent. An 81% AFUE efficiency level is close to the limit (for non-condensing furnaces) at which the temperature of the flue gases is sufficiently low to cause condensation in the vent system. U.S. National Fuel Gas Code (NFGC) [9] venting tables describe the configuration of these systems in terms of length and diameter of the vents. In the analysis reported here, to insure safe operation, we estimated 8% of installations of 81% AFUE equipment would require stainless-steel venting system. For this fraction of the installations, the analysis assigned the appropriate cost.

In the case of modulating furnaces, the DOE test procedure calculates the fuel energy consumption at maximum input capacity mode, while during the actual operation the modulating furnaces operate largely in reduced input capacity mode (about 90%-100% of the time). This test procedure assumption causes overestimation of the calculated fuel energy savings. Therefore, the gas use for modulating furnaces in actual usage may not decline as shown in Table 2. Note that a currently proposed update of the ASHRAE test procedure corrects this problem. [10]

## Conclusion

Gas furnaces are somewhat unusual in that the technology does not easily permit incremental change to the AFUE above 80%. The results indicate that for non-weatherized gas furnaces, the 81 percent AFUE level has positive energy savings, but the NPV is negative at 7% discount rate and barely positive at 3%. This level shows basically no change (-0.03%) in average LCC.

Achieving significant energy savings requires use of condensing technology, which yields a large efficiency gain (to 90% or higher AFUE), but has a higher cost. The 90 percent AFUE level has substantial national energy savings. It has a negative NPV at 7% discount rate, but a large positive NPV at 3%. The condensing furnace has a negative impact on average LCC, but has a positive LCC impact for some households (mainly those in colder climates). This result suggests that some States in cold climates may benefit from establishing a furnace efficiency standard at 90% AFUE.

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With respect to electricity efficiency design options, the ECM has a negative effect on the average LCC. The current extra cost of this technology more than offsets the sizable electricity savings.

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