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Consumer Life-Cycle Cost Impacts of Energy-Efficiency Standards for Residential-Type Central Air Conditioners and Heat Pumps

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ABSTRACT

In support of the federal government's efforts to raise the minimum energy-efficiency standards for residential-type central air conditioners and heat pumps, a consumer life-cycle cost (LCC) analysis was conducted to demonstrate the economic impacts on individual consumers from revisions to the standards. LCC is the consumer's cost of purchasing and installing an air conditioner or heat pump and operating the unit over its lifetime. The LCC analysis is conducted on a nationally representative sample of air conditioner and heat pump consumers, resulting in a distribution of LCC impacts showing the percentage of consumers that are either benefitting or being burdened by increased standards. Relative to the existing minimum efficiency standard of 10 SEER, the results show that a majority of air conditioner and heat pump consumers will either benefit or be insignificantly impacted by increased efficiency standards of up to 13 SEER.

INTRODUCTION

The National Appliance Energy Conservation Act (NAECA) of 1987 established energy-efficiency standards for eleven types of consumer products including single-phase, air-cooled central air conditioners and heat pumps rated with cooling capacities below 65,000 Btu/h (19,050 W) (NAECA 1987). The efficiency descriptor for central air conditioners and the cooling performance of heat pumps is the Seasonal Energy Efficiency Ratio (SEER), which is meant to represent the total cooling output (in Btu) during the annual usage period for cooling divided by the total electrical energy input (in watt-hours) during the same period. The efficiency descriptor for the heating performance of heat pumps is the Heating Seasonal Performance Factor (HSPF), which is meant to represent the total heating output (in Btu) during the annual usage period for heating divided by the total electrical energy input (in watt-hours) during the same period. Central air conditioners and heat pumps are classified into two product classes: split and single package systems. Minimum energy-efficiency standards of 10 SEER and 6.8 HSPF became effective on January 1, 1992, for split system central air conditioners and heat pumps, while standards of 9.7 SEER and 6.6 HSPF became effective on January 1, 1993, for single package systems.

NAECA also requires the consideration of new or amended standards for the products it covers. The rulemaking process for the consideration of amended standards for central air conditioners and heat pumps first began in September 1993 and eventually led to the publication of a final rule on January 22, 2001, requiring new minimum energy-efficiency standards (U.S. Office of the Federal Register 2001a).[1] This paper describes a consumer LCC analysis of central air conditioner and heat pump standards, one of several analyses used in the determination of new minimum efficiency standards for these products (U.S. DOE 2001).

APPROACH FOR LCC ANALYSIS

Life-cycle cost (LCC) is the total consumer expense over the life of the appliance, including purchase expense and operating costs (including energy expenditures). Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance. In recognition that each building

1. On April 20, 2001, the effective date of the final rule was postponed pending the outcome of petitions for administrative reconsideration and judicial review and further Federal Register notice (U.S. Office of the Federal Register 2001b).

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where central air conditioners or heat pumps are used is unique, variability and uncertainty are analyzed by performing the LCC calculations for a representative sample of individual households and commercial buildings. The analysis takes into account equipment use in commercial buildings based on the assumption that ten percent of equipment applications are in commercial buildings. The results are expressed as the number of buildings experiencing economic impacts of different magnitudes. The LCC model was developed using computer spreadsheets combined with a commercially available software add-in (CB 2000). The LCC analysis explicitly models both the uncertainty and the variability in the LCC model's inputs using Monte Carlo simulation and probability distributions. The LCC results are displayed as distributions of impacts compared to the baseline conditions. Results are based on 10,000 samples per Monte Carlo simulation run and are displayed as a frequency chart depicting the variation in LCC for each standard-level considered.

Residential Household Analysis

The LCC calculations detailed here are for a representative sample of individual households and commercial buildings. Ninety percent of equipment applications are assumed to be in households. For equipment used in households, the 1997 Residential Energy Consumption Survey (RECS) serves as the basis for determining the representative sample (U.S. DOE 1999a). The 1997 RECS is based on a sample of 5,900 households, which were surveyed for information on their housing units, energy consumption and expenditures, stock of energy-consuming appliances, and energy-related behavior. The information collected represents all households nationwide—approximately 101 million.

Of the 5900 households surveyed in the 1997 RECS, 2003 households representing 37.6% of the housing population have a central air conditioner, while 579 households representing 11.1% of housing population have an electric heat pump.[2] Using the households in RECS that utilize a central air conditioner or heat pump, LCC analyses are performed on a household-by-household basis to determine whether an increase in the minimum efficiency standard is economically justified.

Of the inputs necessary for calculating the LCC, there are four inputs (described in more detail later) that are based on data from the 1997 RECS: 1) space-conditioning annual energy consumption, 2) equipment efficiency, 3) average electricity price, and 4) marginal electricity price. All four of these inputs are used in determining the operating cost. Each household in RECS with a central air conditioner or heat pump has a unique value for the space-conditioning annual energy consumption, the equipment efficiency, the average electricity price, and the marginal electricity price. In other words, the above four variables associated with a particular RECS household are not uncertain and are, therefore, not expressed with probability distributions. Although the above four input variables are not uncertain, they are extremely variable. Due to the vast number of households considered in the LCC analysis (over 1200 for central air conditioners and over 300 for heat pumps), the range of annual energy use, equipment efficiency, average electricity price, and marginal electricity price is quite large. Thus, although the above four input variables are not uncertain for any particular household, their variability across all households contributes significantly to the range of LCCs calculated for any particular standard-level.

Commercial Building Analysis

Ten percent of residential-type (i.e., single-phase) central air conditioner and heat pump applications are assumed to be in commercial buildings. A representative sample of commercial buildings where this equipment may be applied was developed based on assumptions consistent with the process to update ASHRAE Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 1999).

In updating ASHRAE 90.1, 77 nationally representative commercial buildings (consisting of seven different commercial building types in eleven different regions of the country) were developed. These same 77 buildings were used for the LCC analysis allowing for a building-by-building approach to be utilized for determining whether an increase in the standard is economically justified (i.e., similar to the approach described above for households from the 1997 RECS).

The same four inputs required from the residential building analysis are necessary from the commercial building analysis in order to perform the LCC calculations. The space-conditioning energy consumption associated with each of the 77 buildings was determined through computer modeling using a building load analysis simulation tool (PNNL 2000). Information regarding equipment efficiency in commercial buildings was unavailable so all equipment were assumed to have efficiencies at the existing minimum efficiency levels.

The average and marginal electricity prices were developed through a procedure of matching building peak demand and energy usage characteristics for each of the 77 nationally representative buildings (determined from the computer modeling analysis) to actual modeled commercial tariffs and then calculating customer bills. Electricity prices are determined by dividing the customer bill (in dollars) by the building energy consumption (in kWh). The methodology for matching commercial building peak demands to modeled tariffs is explained in a 1999 DOE report on marginal energy prices (U.S. DOE 1999b). Since several tariffs were applied to each

2. The number of households actually used in the central air conditioner and heat pump LCC analyses were 1218 and 308, respectively. Some central air-conditioned households were dropped from the analysis for one or more of the following reasons: 1) the central air conditioner was not used, 2) a room air conditioner was present and used, or 3) marginal energy prices could not be determined for the household. With regard to households with heat pumps, some were dropped from the analysis for one or more of the following reasons: 1) the heat pump was not used or 2) marginal energy prices could not be determined for the household.

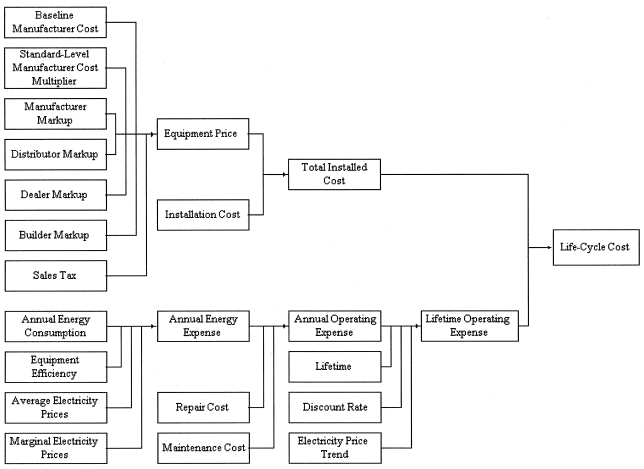

Figure 1 *Flow diagram for LCC inputs.*

building, both the average and marginal electricity rates calculated from each tariff were weighted by the number of customers covered by the tariff to come up with a *weighted-average* marginal and average rate for each building.

As with the residential buildings from the RECS sample, although the annual energy consumption, average electricity price, and marginal electricity price are not uncertain for any particular building, their variability across all buildings contributes significantly to the range of LCCs calculated for any particular standard-level.

OVERVIEW OF LCC INPUTS

Life-cycle cost is defined by the following equation:

$$LCC = IC + \Sigma \frac{OC_t}{(1+r)^t} \tag{1}$$

where

LCC = life-cycle cost,

IC = total installed cost,

Σ = sum over the lifetime, from year 1 to year N, where N = lifetime of appliance (years),

OC = operating cost,

r = discount rate, and

t = year for which operating cost is being determined.

As described in Equation 1, inputs to the LCC analysis can be categorized as follows: 1) inputs for establishing the total installed cost, otherwise known as the purchase expense, and 2) inputs for calculating the operating cost. Figure 1 graphically depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC. All of the inputs are described in detail in the following sections.

Total Installed Cost Inputs

The primary inputs for establishing the total installed cost for any particular standard-level are: 1) the baseline manufacturing cost, 2) the standard-level manufacturer cost multiplier, 3) markups and sales tax, and 4) installation price. The total installed cost is defined by the following equation:

$$IC = (mfg \cdot mm_{std} \cdot mm_{mfg} \cdot mu_{distr} \cdot mu_{deal} \cdot mu_{build} \cdot st) + inst \tag{2}$$

where

mfg = manufacturing cost of baseline (10 SEER) equipment,

mm_{std} = standard-level manufacturing cost multiplier,

mu_{mfg} = manufacturer markup,

mu_{distr} = distributer or wholesaler markup,

mu_{deal} = dealer or contractor markup,

mu_{build} = builder markup,

st = sales tax, and

$inst$ = installation cost.

Baseline Manufacturing Cost. The baseline manufacturing cost is the cost to manufacture equipment meeting existing minimum efficiency standards. The baseline costs were developed through a reverse engineering approach (U.S. DOE 2001). All costs were based on 3-ton (10.5 kW) cooling capacity systems using the refrigerant R-22.[3] The baseline manufacturing costs for split air conditioners, split heat pumps, single package air conditioners, and single package heat pumps are $394, $572, $511, and $593, respectively. Split air conditioner systems consist of condensing units combined with either evaporator coils (residing within warm-air furnaces) or fancoil units. Because of the disparate cost between the two coil types, the baseline cost for split air conditioners is a weighted-average value accounting for both system types. The costs for the other product types are represented by the above single-point values.

Standard-Level Manufacturing Cost Multiplier. This is the multiplicative factor used for calculating the manufacturing cost associated with a particular standard-level. The same reverse-engineering approach conducted for developing baseline manufacturing costs was used for determining standard-level manufacturing cost multipliers (U.S. DOE 2001). Table 1 provides the most likely multiplier values for standard-levels of 11 through 13 SEER for each of the four product classes. Also provided are the resulting manufacturing costs for the baseline and each standard-level.

Markups and Sales Tax. Markups and sales tax are used to convert the manufacturing cost to a consumer equipment

3. Because manufacturing costs were based only on 3-ton systems, manufacturing cost variability due to system capacity is not captured in the LCC analysis. But because RECS implicitly accounts for system capacity, the impact that system capacity has on annual energy consumption is accounted for by the LCC analysis.

TABLE 1
Standard-Level Manufacturing Cost Multipliers and Manufacturing Costs

	Split A/C		Split HP		Package A/C		Package HP	
SEER	Mfg Cost Multiplier	Mfg Cost	Mfg Cost Multiplier	Mfg Cost	Mfg Cost Multiplier	Mfg Cost	Mfg Cost Multiplier	Mfg Cost
10	1.00	$394	1.00	$572	1.00	$511	1.00	$593
11	1.12	$441	1.05	$601	1.09	$557	1.08	$640
12	1.28	$505	1.13	$646	1.16	$593	1.13	$670
13	1.44	$568	1.30	$744	1.43	$731	1.38	$818

price. Four sets of markups were defined for the LCC analysis: manufacturer markup, distributor markup, dealer markup, and builder markup.

Manufacturer markup. The manufacturer markup is the factor that converts the manufacturer cost to the cost that distributors (also known as wholesalers) pay for the equipment. Markups were derived from financial data for six publicly held air conditioner manufacturers that file annual financial reports (10-Ks) (U.S. DOE 2001). The manufacturer markups used in the LCC analysis were based on values of 1.18 and 1.41, which were assumed to be representative of 80% and 20% of the industry, respectively. A distribution consisting of the above two discrete values was used in the analysis. The resulting *weighted-average* markup equals 1.23 (80% 1.18 + 20% 1.41).

Distributor markup. The distributor markup is the factor that converts the distributor cost to the cost dealers (also known as contractors) pay for the equipment. Distributor markups were developed through an analysis of financial data for an average air-conditioning wholesale business (ARW 1998). The results of the financial analysis were validated with an econometric analysis of 1997 Census economic data of revenues and costs for warm air heating and air-conditioning equipment wholesalers (U.S. Census Bureau 2000; U.S. DOE 2001). The analysis of distributor cost data revealed a measurable difference between the *average* aggregate markup on the entire set of direct business costs and the *incremental* markup on only direct equipment costs. In other words, for an incremental increase in the cost of the equipment, the markup required to cover the incremental cost increase is distinctly different from the average markup required to cover all business costs. An *average* aggregate distributor markup was determined to be 1.37 and was assumed to cover the direct business costs that are present at the current baseline (i.e., 10 SEER) level. The *incremental* distributor markup was determined to be normally distributed, ranging from 1.03 to 1.16 (with a mean value of 1.09), and was assumed to cover incremental equipment cost increases, such as those associated with increases in equipment efficiency.

Dealer markup. The dealer markup is the factor for converting the dealer cost to the price that builders or consumers pay for the equipment. Dealer markups were developed through an analysis of financial data for an average residential air-conditioning contractor (ACCA 1995). The results of the financial analysis were validated with an econometric analysis of 1997 Census economic data of revenues and costs for the heating, ventilating, air-conditioning (HVAC) contractor industry (U.S. Census Bureau 1999; U.S. DOE 2001). The financial analysis of contractor cost data revealed a significant difference between the markup required for covering labor and equipment expenses and the markup required for covering only equipment expenses. The markup covering all business expenses was determined to be 1.53 while the markup for only equipment expenses was determined to be normally distributed ranging from 1.05 to 1.48 (with a mean value of 1.27). Because the LCC analysis breaks out the contractor's installation cost (i.e., the cost to install the equipment) from the cost that is charged for the equipment, only the markup value of 1.27 is applicable for marking up the equipment. As was done for the distributor markup, a dealer markup associated only with an *incremental* increase in equipment cost was also determined. Since the *incremental* markup was shown to be close to the *average* value of 1.27, only the *average* markup value was used in the analysis.

Builder markup. The builder markup is the factor for converting the builder cost to the price which consumers pay for the equipment and applies only to the new construction market. Based on estimated gross margins (D&B 1999; RMA 1999), a uniform range of markups from 1.20 to 1.32 (with a mean value of 1.26) were applied to the 34 percent of air conditioners and heat pumps that find their way into new construction. Since a builder markup does not apply to the remaining 66 percent of the air-conditioning market that is composed of replacement systems, the *weighted-average* builder markup for the entire market (i.e., both the new construction and replacement markets) equals 1.09 (34% 1.26 + 66% 1.00). In all cases, builders were assumed to purchase their equipment from distributors rather than directly from the manufacturer.

Sales tax. In many cases, local and state governments apply sales taxes to air conditioner purchases. A sales tax was applied to the entire dealer price yielding the retail price paid by the consumer. Sales tax rates were based on 1997 state sales tax data, 1997 local sales tax data, and 1994 state unitary shipment data (U.S. DOE 2001). The sales tax rates essentially range from a minimum of 5 percent to a maximum of 8 percent

with a mean value of 6.7 percent. The mean sales tax rate of 6.7 percent has a corresponding markup of 1.067. The above distribution of sales tax rates was applied to the 66 percent of the market where air-conditioning systems are purchased as replacement systems. For the 34 percent of units sold into the new construction market, purchasers were assumed to pay no sales tax on the equipment. The resulting *weighted-average* sales tax markup for the entire market is 1.04 (34% 1.00 + 66% 1.067).

Installation Cost. The installation cost is the cost to the consumer of installing the equipment. It represents all costs required to install the equipment other than the marked-up equipment cost. The installation cost includes labor, overhead, and any miscellaneous materials and parts such as linesets. Thus, the total installed cost equals the consumer equipment price (manufacturer cost multiplied by the various markups and sales tax) plus the installation cost. Installation costs were determined by subtracting calculated consumer equipment prices from total installed cost data. Total installed cost data were collected from public and private sources (U.S. DOE 2001). The installation costs to install a minimum efficiency (i.e., 10 SEER) split air conditioner, split heat pump, package air conditioner, and package heat pump were determined to be $1,279, $2280, $1,367, and $2,160, respectively.[4] Due to the large variability in installation costs, the representative cost for each product class was assumed to vary by ±20%. A triangular distribution was created for each product class assuming low and high values that were 20% less and 20% greater, respectively, than the above representative installation costs. Probabilities of zero percent were assigned for the low and high installation cost values. For all product classes, the installation cost was assumed to stay constant as efficiency increases.

Operating Cost Inputs

The operating cost is the sum of the energy cost, repair cost, and maintenance cost. The primary inputs for establishing the energy cost for any particular standard-level are: 1) the annual energy consumption, 2) the equipment efficiency, 3) average electricity price, and 4) marginal electricity price. Electricity price trends are used for forecasting future average and marginal electricity prices and, in turn, future energy costs. The annual operating cost is defined by the following equation:

$$OC = (EC_{cool} + EC_{heat}) + RC + MC \tag{3}$$

where

EC_{cool} = annual energy cost associated with operating central air conditioners and heat pumps during the cooling season,

EC_{heat} = annual energy cost associated with operating heat pumps during the heating season (does not apply to central air conditioners),

RC = the annual repair cost associated with component failure, and

MC = the annual service cost for maintaining equipment operation.

The annual energy cost for space-cooling and space-heating are defined by the following equations:

$$EC_{cool} = UEC_{base_c} \cdot EL_{avg} - (UEC_{base_c} - UEC_{std_c}) \cdot EL_{marg} \tag{4}$$

$$EC_{heat} = UEC_{base_h} \cdot EL_{avg} - (UEC_{base_h} - UEC_{std_h}) \cdot EL_{marg} \tag{5}$$

Where

UEC_{base_c} = annual space-cooling energy consumption associated with the baseline efficiency level (i.e., 10 SEER),

UEC_{std_c} = annual space-cooling energy consumption associated with a standard-level,

UEC_{base_h} = annual space-heating energy consumption associated with the baseline efficiency level (i.e., 10 SEER),

UEC_{std_h} = annual space-heating energy consumption associated with a standard-level,

EL_{avg} = average electricity price, and

EL_{mrg} = marginal electricity price.

For the case where the energy cost is being determined for the baseline efficiency level, the second expression in Equation 4 and Equation 5 is zero since UEC_{base} equals UEC_{std}. It is also worth noting that the annual energy savings associated with a standard-level is multiplied by the marginal electricity price rather than the household's average electricity price. The marginal electricity price and its determination are presented later.

Although not required to calculate the annual operating cost, the discount rate and equipment lifetime are two more inputs that are required to calculate the equipment's annual operating costs over its entire life.

Annual Energy Consumption. For central air conditioners, the annual energy consumption is the annual site energy use associated with providing space-cooling. For heat pumps, the annual energy consumption is the annual site energy use associated with providing both space-cooling and space-heating. For households, the annual energy consumption is provided from data in the 1997 Residential Energy Consumption Survey (RECS). Each household has a specific annual energy consumption associated with the equipment that is determined from the household's utility bill using a

4. Because calculated heat pump consumer equipment prices are only marginally higher than those for air conditioners, derived installation costs for heat pumps and air conditioners are desperate due to the large difference in their total installed costs.

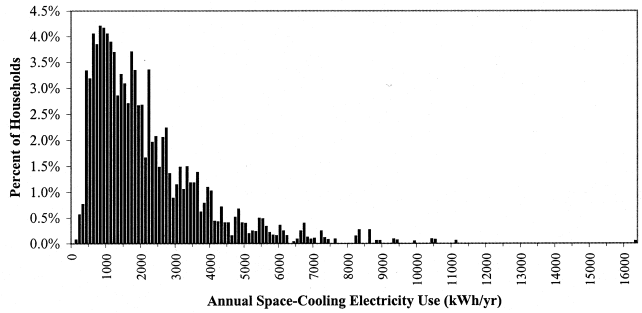

Figure 2 *Percentage of households with central A/C by annual space-cooling energy consumption.*

conditional demand analysis.[5] For those households surveyed in RECS with either a central air conditioner or heat pump, the estimated annual energy consumption corresponds to the household's stock equipment, specifically its efficiency. For equipment used in commercial buildings, the annual energy consumption is determined through computer simulations of 77 nationally representative commercial buildings.

Central air conditioner and heat pump efficiencies associated with the equipment stock in the above households and commercial buildings were used to calculate the annual consumption for the baseline efficiency level and each standard-level. As expressed in the following equations, the ratio of a building's stock efficiency to either the baseline efficiency level or the standard-level efficiency is multiplied by the stock equipment's annual energy consumption to arrive at the annual energy consumption associated with the baseline or standard-level equipment.

$$UEC_{base/std_c} = UEC_{stock_c} \cdot \frac{SEER_{stock}}{SEER_{base/std}} \tag{6}$$

$$UEC_{base/std_h} = UEC_{stock_h} \cdot \frac{HSPF_{stock}}{HSPF_{based/std}} \tag{7}$$

Where

UEC_{base/std_c} = annual space-cooling energy consumption associated with the baseline or standard-level equipment,

UEC_{stock_c} = annual space-cooling energy consumption associated with the stock equipment,

$SEER_{stock}$ = the SEER associated with the stock equipment,

$SEER_{base/std}$ = the SEER associated with the baseline or standard-level equipment,

UEC_{base/std_h} = annual space-heating energy consumption associated with the baseline or standard-level heat pump,

UEC_{stock_h} = annual space-cooling energy consumption associated with the stock heat pump,

$HSPF_{stock}$ = the HSPF associated with the stock heat pump, and

$HSPF_{base/std}$ = the HSPF associated with the baseline or standard-level heat pump.

For household stock equipment, data from both the 1997 RECS and the industry's trade association were used to specify equipment efficiency by using historical shipment-weighted efficiency data (ARI 1999) and matching the appropriate efficiency to the specified equipment age in RECS. For equipment used in commercial buildings, equipment efficiencies were assumed to be equal to the existing minimum efficiency standards (i.e., 10 SEER) because the age of equipment in commercial buildings was not known. Thus, in the case of commercial buildings, both the stock annual energy consumption and efficiency are equal to the baseline values.

As a result of conducting the LCC analysis on a building-by-building basis, the range of annual energy consumption used in the LCC analysis is quite large. In order to give an idea of how large the range is, Figure 2 is provided to show the weighted distribution of the stock annual space-cooling energy use for those RECS households with a central air conditioner. Comparable data have also been generated for central air conditioners in commercial buildings as well as heat pumps in both households and commercial buildings (U.S. DOE 2001).

Table 2 summarizes the range of annual energy consumption and equipment efficiency used in the LCC analysis for households and commercial buildings. Provided are the minimum, *weighted-average*, and maximum values. Values are irrespective of whether the product type is a split or single package system.

Average Electricity Price. The average electricity price is the mean price paid for all electricity. For households, it is the price paid by the 1997 RECS households examined. For commercial buildings, it is the price paid by each of the 77 nationally representative buildings modeled. Distributions of average electricity prices were prepared for the 1997 RECS households with central air conditioners and with heat pumps. Because the average electricity price reported in RECS is the average price for the local utility and not the household's own average price, average electricity prices were calculated directly from household billing data. The distribution of average electricity prices for those households with central air conditioners range from a 4.4 to 20.3 ¢/kWh with a *weighted-average* value of 8.90 ¢/kWh. The distribution of prices for

5. Conditional demand analysis is a particular from of multiple regression analysis used to disaggregate the total amount of a particular household's energy consumption for a particular fuel into its end-use energy consumption.

TABLE 2
Household Stock and Commercial Building Baseline Annual Energy Consumption and Efficiency

	Annual Energy Use (kWh/yr)						Efficiency		
	Household			Commercial Bldg			Household		
	CAC	Heat Pump		CAC	Heat Pump		CAC	Heat Pump	
Value	UEC_{stock_c}	UEC_{stock_c}	UEC_{stock_h}	UEC_{base_c}	UEC_{base_c}	UEC_{base_h}	$SEER_{stock_c}$	$SEER_{stock_c}$	$HSPF_{stock_c}$
Min	57	0	174	2,067	2,067	75	5.30	5.30	4.46
Wght-Avg	2,132	2,585	3,921	5,824	5,824	2,654	9.13	9.32	6.77
Max	16,286	11,576	17,272	12,571	12,571	9,633	15.20	15.20	9.67

those households with heat pumps range from 3.8 to 13.0 ¢/kWh with a *weighted-average* value of 7.39 ¢/kWh. All electricity prices are for the year 1998 in 1998$.

The procedure for developing average electricity prices for the 77 nationally representative commercial buildings matches each building's space-conditioning load and demand (determined from the computer modeling analysis) to actual modeled commercial tariffs. Customer energy bills are then calculated for the building on a monthly basis. The monthly bill (in 1998$) is divided by the monthly energy consumption (in kWh) to come up with an average monthly electricity price (in $/kWh). An annual average electricity price is determined by averaging the twelve monthly average electricity rates. Since several tariffs were applied to each building, the average electricity price calculated from each tariff was weighted by the number of customers covered by the tariff to come up with a *weighted-average* electricity rate for each building. The distribution of average electricity prices for commercial buildings using either central air conditioners or heat pumps is much narrower than those for households. The prices range from 7.8 to 8.1 ¢/kWh with a *weighted-average* value of 7.95 ¢/kWh. All electricity price are for the year 1998 in 1998$.

Marginal Electricity Price. Marginal electricity prices are the prices faced by households or commercial buildings for the last kWh of electricity purchased. A household's or commercial building's marginal price can be higher or lower than its average price, depending on the relationship between the block rate price structure facing the building and the size of customer charges and/or other charges included in the buildings's electricity bill.

For households, marginal electricity prices were estimated directly from RECS household data by calculating the slopes of regression lines that relate customer bills and customer usage. The slopes of the regressions for four "summer" months (June to September) and, separately, for the remaining ("winter") months were calculated (U.S. DOE 1999b). The "summer" and "winter" prices were weighted appropriately in order to reflect their seasonal energy use. Simulated household cooling and heating loads based on computer modeling of residential buildings were used to establish the appropriate seasonal weighing factors (Ritschard et al. 1992). The distribution of marginal electricity prices for those households with central air conditioners ranges from 3.2 to 20.7 ¢/kWh with a *weighted-average* value of 8.62 ¢/kWh. The distribution of prices for those households with heat pumps ranges from 3.1 to 13.3 ¢/kWh with a *weighted-average* value of 6.86 ¢/kWh. All electricity prices are for the year 1998 in 1998$.

For commercial buildings, marginal electricity prices for space cooling were developed from energy bills for space cooling for both the baseline case (i.e., 10 SEER) and a standard case. The difference in the space-cooling energy bills (in dollars) is divided by the usage difference (in kWh) to give a "marginal" rate of $/kWh for the increment of space-cooling energy saved. For purposes of simplifying the analysis, only a standard-level increase of 20% (i.e., 12 SEER) was considered. Thus, the space-cooling marginal rate developed for a 20% increase in the standard was assumed to be applicable for all standard-level cases. The distribution of marginal electricity prices for commercial buildings using either central air conditioners or heat pumps (in the cooling-mode) is much narrower than those for households. The prices range from 7.8 to 8.9 ¢/kWh with a *weighted-average* value of 8.08 ¢/kWh. All electricity prices are for the year 1998 in 1998$. Since detailed building loads and demands were not available for space heating, marginal electricity prices for space heating could not be developed. Thus, average electricity prices were used to determine the energy costs associated with the operation of heat pumps during the space-heating season.

Electricity Price Trend. The electricity price trend estimates the relative change in electricity prices for future years out to the year 2030. For purposes of the LCC analysis, a projected trend in national average electricity prices is applied to each household's and commercial building's energy prices. In the life-cycle cost (LCC) spreadsheets, the Reference Case from the *Annual Energy Outlook 2000* (DOE 1999c) was used to forecast electricity prices into the future (U.S. DOE 1999c). By the year 2020, the *AEO 2000* Reference Case forecasts residential electricity prices to decline to 87% of the 1997 price.

Maintenance Costs. Maintenance costs are those costs associated with maintaining the operation of the equipment (e.g., cleaning heat exchanger coils, checking refrigerant charge levels). Data from an HVAC service company (Service

Experts 1997) were used to establish maintenance costs. Based on the collected data, 73 percent of consumers are assumed to incur no service cost while 27 percent of consumers are assumed to incur an annual service cost of $135. The *weighted-average* maintenance cost from this distribution is $36. Maintenance costs are assumed to apply to all product types (split or package systems, air conditioners or heat pumps) and are assumed to remain unchanged with increased efficiency. The rationale for unchanging costs being that the general maintenance of more efficient products should not be impacted by the more sophisticated components that they contain.

Repair Costs. The repair cost is the cost to the consumer for replacing or repairing components that have failed in the space-conditioning equipment. For baseline equipment and standard-level equipment exceeding 13 SEER, the annualized repair cost was assumed to equal half the consumer equipment price divided by the average equipment lifetime. Equipment with efficiencies of 11 through 13 SEER were assumed to incur a 1% increase in repair cost over the minimum efficiency level (10 SEER). The rationale for assuming essentially flat repair costs through efficiencies up to and including 13 SEER pertains to the level of technology being used at these system efficiency levels. Through 13 SEER, system technology generally does not incorporate sophisticated electronic components, which are believed to incur higher repair costs. Increases in SEER are generally achieved through more efficient single-speed compressors or more efficient and/or larger heat exchanger coils. Systems with efficiencies beyond 13 SEER start to incorporate modulating blowers or compressors, which are generally believed to be more susceptible to failure.

Lifetime. The lifetime is the age at which the central air conditioner or heat pump is retired from service. A detailed survey of 2,184 heat pump installations in a seven-state region of the United States was used to estimate equipment lifetime (Bucher et al. 1990). The survey established a retirement function covering the first 19 years of the product's life. In order to complete the entire retirement function, an extrapolation was used based on estimates performed by others (Hiller 1990). Although the survey was conducted only on heat pumps, the retirement function was used as the basis for estimating central air conditioner product lifetime in addition to the lifetime of heat pumps. The retirement function reveals that equipment lifetimes can range from 1 to 24 years with a resulting *weighted-average* value of 18.4 years. The heat pump survey also indicates that essentially all heat pump owners replace their original compressor once in the lifetime of the system. In accordance with the survey data, compressors were assumed to be replaced in the 14th year of the system's life. Because more efficient systems were assumed to use more efficient and, thus, more expensive compressors, the compressor replacement cost was assumed to increase as system efficiency increases.

Discount Rate. The discount rate is the rate at which future expenditures are discounted to establish their present value. In establishing a distribution of discount rates, the air-conditioning market was divided into two segments: 1) those systems sold to the new construction market or to existing households without air-conditioning that are performing significant home upgrades and 2) those units purchased as replacement systems. For the former market segment, discount rates were based upon the type of financing utilized at the time of purchase (e.g., new and second mortgages or home equity lines of credit). For equipment purchased to replace old or failed equipment where cash or some form of credit is used to finance the acquisition, it was assumed that it is more appropriate to establish how the purchase affects a consumer's overall household financial situation. For example, even though the purchase might be financed through a dealer loan or some other short-term financing vehicle, the more probable effect of the purchase is to either cause the consumer to incur additional credit card debt or forego investment in some type of savings-related asset.

Based on the above methodology, discount rates vary greatly. The resulting distribution of rates encompass values as low as zero percent (for cash purchases) and as high as 20 percent (for lost investment opportunities). Details regarding the development of the distribution of rates can be found elsewhere (U.S. DOE 2001). The distribution of discount rates that were developed yielded average values of 4.2 and 6.3 percent for the new construction/home upgrade and replacement markets, respectively, resulting in a *weighted-average* value of 5.6 percent for the entire market.

LCC RESULTS

As stated earlier, the Monte Carlo method of analysis relying on a random sampling from probability distributions was used to conduct the LCC analysis. The following results presented here are based on 10,000 samples per Monte Carlo run.

Baseline LCC

The first step in developing LCC results is to develop the baseline LCC for each of the four product classes. For this analysis, the baseline LCC is based on *average* electricity prices from each RECS household or modeled commercial building. The change in LCC for various standard-levels (to be presented later) is based on *marginal* electricity prices. As an example, the frequency chart for system air conditioners is shown in Figure 3 to provide an idea of the range of possible baseline LCCs for any product class. A frequency chart shows the distribution of LCCs with its corresponding probability of occurrence. The baseline efficiency level is assumed to equal the existing minimum energy efficiency standard. For split system and single package air conditioners, this means the baseline efficiency level is set to 10 SEER. For split system and single package heat pumps, the baseline efficiency levels are set to 10 SEER for the cooling performance and 6.8 HSPF

TABLE 3
Baseline LCC: Mean, Median, Minimum, and Maximum Values

Product Class	Minimum	Median	Mean	Maximum
Split A/C	$2,206	$4,637	$5170	$21,508
Split Heat Pump	$3,521	$8,464	$9,679	$36,901
Package A/C	$2,535	$5,126	$5,629	$24,781
Package Heat Pump	$3,282	$9,164	$9,626	$41,377

TABLE 4
Average LCC Savings and Percent of Buildings Achieving LCC Savings

	Split A/C		Split HP		Package A/C		Package HP	
SEER	Avg LCC Savings	Percent with Savings	Avg LCC Savings	Percent with Savings	Avg LCC Savings	Percent with Savings	Avg LCC Savings	Percent with Savings
11	$75	56%	$209	92%	$78	56%	$207	87%
12	$113	51%	$365	89%	$163	61%	$421	92%
13	$113	45%	$372	73%	$29	36%	$353	69%

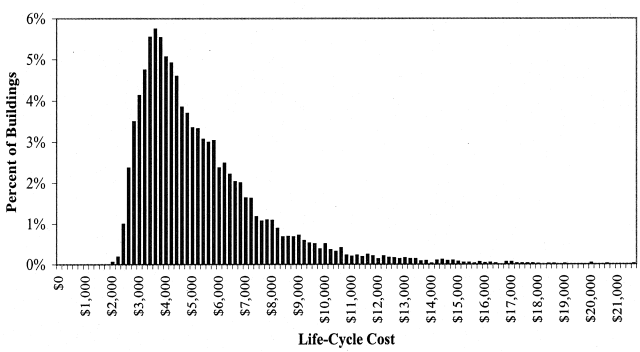

Figure 3 *Split A/C: percent of buildings by life-cycle cost, baseline.*

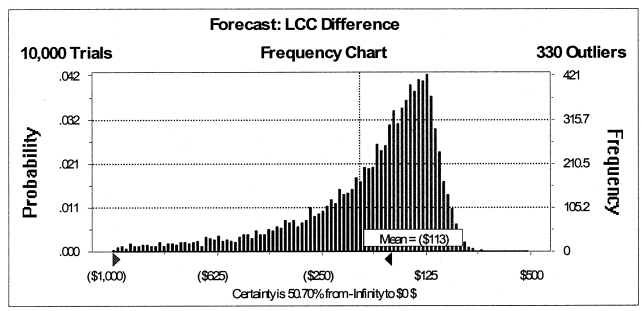

Figure 4 *Split A/C, 12 SEER: frequency chart of LCC difference.*

for the heating performance. Table 3 summarizes the baseline distributions for all four product classes by showing the mean, median, minimum, and maximum LCCs.

Change in LCC Due to Standards

The changes in LCC are presented as differences in the LCC relative to the baseline central air conditioner or heat pump design. The primary results are presented with a frequency chart showing the distribution of LCC differences with the corresponding probability of occurrence. The frequency chart provides the mean LCC difference along with the percent of the population for which the LCC will decrease.

As an example, the frequency chart for the 12 SEER standard-level for split system air conditioners is provided in Figure 4. The y-axes show the number of buildings ("Frequency" at right y-axis) and percent of all buildings ("Probability" at left y-axis). Of the10,000 buildings that were examined ("10,000 trials"), almost all the results are displayed ("330 outliers"). The x-axis is the difference in LCC between a baseline efficiency level and a higher standard-level (in this example, 12 SEER). The x-axis begins with negative values on the left, which indicate that standards for those buildings provide savings (reduced LCC). Reduced LCC occurs when reduced operating expenses more than compensate for increased purchase expense. LCC differences range from reductions of $1000 (at the left) to increases of $275 (at the right) depending upon the building. (The minimum and maximum values cannot be read with precision from the graph, but rather, the program provides them in a statistical summary.) The mean change (reduction of $113) is shown in a text box next to a vertical line at that value on the x-axis. The phrase "Certainty is 50.70% from -Infinity to $0" means that 50.70 percent of buildings will have a reduced LCC with a 12 SEER standard-level compared to the baseline efficiency level (i.e., 10 SEER).

TABLE 5
Percent of Air Conditioner and Heat Pump Consumers with Net Savings, No Significant Impacts, and Net Costs

Product Class	LCC Category	Percent/Savings	Standard-Level		
			11 SEER	12 SEER	13 SEER
Split A/C	Net Savings	Percent >2%	28%	35%	34%
		Avg LCC Savings	$305	$453	$589
	No Significant Impact	Percent ± 2%	70%	40%	27%
		Avg LCC Savings	$10	$-18	$-11
	Net Costs	Percent >2%	2%	25%	39%
		Avg LCC Savings	$-118	$-158	$-217
Split HP	Net Savings	Percent >2%	40%	58%	52%
		Avg LCC Savings	$409	$591	$742
	No Significant Impact	Percent ± 2%	60%	42%	42%
		Avg LCC Savings	$77	$58	$2
	Net Costs	Percent >2%	0%	0%	6%
		Avg LCC Savings	$0	$0	$-259
Package A/C	Net Savings	Percent >2%	27%	40%	28%
		Avg LCC Savings	$313	$460	$632
	No Significant Impact	Percent ± 2%	72%	51%	20%
		Avg LCC Savings	$-9	$-13	$-16
	Net Costs	Percent >2%	1%	9%	52%
		Avg LCC Savings	$-120	$-140	$-275
Package HP	Net Savings	Percent >2%	39%	66%	50%
		Avg LCC Savings	$426	$606	$775
	No Significant Impact	Percent ± 2%	61%	34%	38%
		Avg LCC Savings	$65	$62	$1
	Net Costs	Percent >2%	0%	0%	12%
		Avg LCC Savings	$0	$-214	$-299

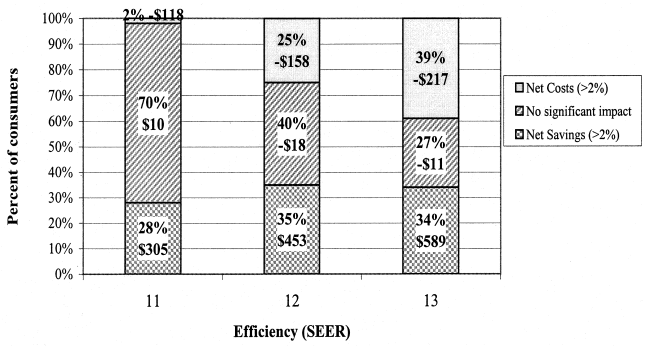

Figure 5 *Percent of split A/C consumers with net savings, no significant impacts, and net costs.*

Table 4 summarizes the LCC difference results for standard-levels of 11 through 13 SEER for all four product classes. Provided for each standard-level are the average LCC savings with the corresponding percentage of buildings achieving LCC savings.

LCC Results Based on ± 2 Percent Threshold

As provided in Table 4, the LCC results show the percent of buildings with reduced LCC. But considering that the baseline LCC for each product class is significantly greater than the LCC differences, it is more useful to demonstrate which consumers experience significant net LCC savings or costs due to a higher standard-level. "Significant" is defined as those consumers experiencing net LCC savings or costs that are greater than two percent of the baseline LCC (U.S. Office of the Federal Register 2001a). For central air conditioners, this translates to an LCC change of approximately $100 or an annual change of approximately $5 over the lifetime of the system. The mean baseline LCCs for split system air conditioners, split system heat pumps, single package air conditioners, and single package heat pumps as provided in Table 3 are $5,170, $9,679, $5,629, and $9,626, respectively. The corresponding two percent threshold at which consumers are considered to be significantly impacted by a standard-level are $103, $194, $113, and $193, respectively.

Figure 5 depicts the LCC results for split system air conditioners based on the above defined two percent threshold. Figure 5 shows the subset or percentage of consumers at each standard-level who are impacted in one of three ways: consumers who achieve *significant* net LCC savings (i.e., LCC savings greater than two percent of the baseline LCC), consumers who are impacted in an insignificant manner by having either a small reduction or small increase in LCC (i.e., within ± two percent of the baseline LCC), or consumers who achieve a *significant* net LCC increase (i.e., an LCC increase exceeding two percent of the baseline LCC). Accompanying each percentage value in each of the figures is the average LCC savings or increase that corresponds to each subset of consumers. For example, in the case of the 12 SEER standard-level, the percentage of consumers with significant net savings is 35 percent and the corresponding average LCC savings for those consumers is $453.

Table 5 summarizes the LCC results in tabular form based on the two percent threshold concept for all product types.

The implications of the two percent threshold concept in analyzing the LCC results is significant. Namely, a lower percentage of consumers are negatively impacted by a standard-level as only those consumers who bear LCC increases that are greater than two percent of the baseline LCC are considered to be adversely affected. For example, in the case of the 12 SEER standard-level for split system air conditioners, although 49 percent of consumers bear an LCC increase, only 25 percent are actually viewed as being adversely impacted as only these consumers bear an LCC increase that is beyond the two percent threshold.

In analyzing the LCC results using the two percent threshold concept, only the 13 SEER standard-level for *single package air conditioners* yields LCC distributions that result in a majority of consumers being adversely impacted (i.e., 52 percent of consumers at 13 SEER bear LCC net increases). With this exception and the 13 SEER standard-level for *split system air conditioners* where a large minority of consumers (39 percent) are adversely impacted, all other standard-levels for all product classes yield an overwhelming majority of consumers who either achieve significant LCC savings or are insignificantly impacted.

CONCLUSIONS

By using an approach where LCC calculations are performed on a building-by-building basis and the variability and uncertainty of inputs are characterized with probability distributions when appropriate, a distribution of LCC results can be generated to show explicitly the percentage of consumers that are benefitting from an increase in minimum efficiency standards for central air-conditioning and heat pump equipment. By using a concept where only those consumers bearing LCC increases of greater than two percent of the baseline (i.e., minimum efficiency) LCC are considered to be adversely impacted, a majority of air conditioner and heat pump consumers either benefit or are insignificantly impacted by increased standard-levels of 11 through 13 SEER.

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DISCUSSION

Georgi Kazachki, Senior Research Engineer, Arcadis, Durham, NC: 1) When was the work completed relative to the October 2001 meeting at DOE on SEER 13 vs. SEER 12? Was the work available to the broad public? 2) How can you explain the negative position of ARI toward SEER 13 with respect to the outcome from your work which, in my understanding, supports the acceptance of SEER 13 almost as well as SEER 12?

Greg Rosenquist: Assuming that the October 2001 meeting being referred to is DOE's Public Hearing regarding energy efficiency standards for central air conditioners and heat pumps, the life-cycle cost analysis, as well as all other analyses conducted for DOE's standards rulemaking, were completed prior to DOE's publication of the July 25, 2001 Supplemental Notice of Proposed Rulemaking (SNOPR). The technical support document (TSD) describing all rulemaking analyses, as well as spreadsheet tools used in generating the analysis results for the TSD, were made available to the public via DOE's Office of Building, Research, and Standards web site at the same time the SNOPR was published. Only staff at the Air-Conditioning and Refrigeration Institute (ARI) can explain their position on DOE's analysis of updated energy efficiency standards for central air conditioners and heat pumps. Although the life-cycle cost analysis indicates that a SEER 13 standard level may be an appropriate minimum efficiency standard for some product classes, the setting of the standard is dependent on more than just the results of the life-cycle cost analysis. Several analyses are conducted to help DOE determine the appropriate level for updating the standard. These other analyses include the following: engineering, national energy savings, manufacturer impact, electric utility impact, environmental impact, and regulatory impact. The SNOPR describes how DOE weighs the various analysis results to determine the appropriate efficiency level for the updated standard.