CHAPTER 6. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 6. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

6.1 INTRODUCTION

This chapter describes the analysis that the U.S. Department of Energy (DOE) has carried out to evaluate the economic impacts of possible energy conservation standards developed for computer room air conditioning (CRAC) equipment on individual commercial customers, henceforth referred to as *customers*. The effect of standards on customers includes a change in operating cost (usually decreased) and a change in purchase cost (usually increased). This chapter describes two metrics used to determine the effect of standards on customers:

- **Life-cycle cost (LCC)**. The total customer cost over the life of the equipment is the sum of installed cost (purchase and installation costs) and operating costs (maintenance, repair, and energy costs). Future operating costs are discounted to the time of purchase, and summed over the lifetime of equipment.
- **Payback period (PBP)**. Payback period is the estimated amount of time it takes customers to recover the assumed higher purchase price of more efficient equipment through lower operating costs.

An efficiency improvement to CRAC equipment that is financially attractive to a customer will typically be associated with a low PBP and a low LCC.

This chapter is organized as follows. The remainder of this section outlines the general approach and provides an overview of the inputs to the LCC and PBP analysis of CRAC equipment. Inputs to the LCC and PBP analysis are discussed in detail in sections 6.2 and 6.3. Results for the LCC and PBP analysis are presented in sections 6.4 and 6.5.

The calculations discussed in this chapter were performed with a series of Microsoft Excel spreadsheets available at http://www1.eere.energy.gov/buildings/appliance_standards/commercial/ashrae_products_docs_meeting.html. Instructions for using the spreadsheets are included in appendix 6A. Detailed results are presented in appendix 6B.

6.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

This section summarizes DOE's approach to the LCC and PBP analysis for CRAC equipment.

As part of the engineering analysis, various efficiency levels are ordered on the basis of increasing efficiency (decreased energy consumption) and, typically, increasing manufacturer selling price (MSP) values. For the LCC and PBP analysis, DOE chooses a maximum of five levels, henceforth referred to as *efficiency levels*, from the list of engineering efficiency levels.

Because the LCC analysis of CRAC equipment is being conducted to help determine if DOE should adopt an efficiency standard more stringent than the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard level discussed in earlier chapters, the baseline efficiency level is the ASHRAE standard for each equipment class (also see section 6.1.2). It is the least efficient and the least expensive equipment in that equipment class. The higher efficiency levels (Level 1 and up) have a progressive increase in efficiency and equipment cost from the ASHRAE level. The highest efficiency level in each equipment class corresponds to the maximum efficiency level obtainable with non-proprietary technology (see preliminary technical support document (TSD) chapter 3 for details). DOE treats the efficiency levels as *candidate standard levels*, as each higher efficiency level represents a potential new standard level.

The installed cost of equipment to a customer is the sum of the equipment purchase price and installation costs. The purchase price includes manufacturer production cost (MPC), to which a manufacturer markup, distributor's cost, and cost of delivery to the job site is applied to obtain the MSP. This value is calculated as part of the engineering analysis (chapter 3 of the TSD). DOE then applies additional markups to the equipment in order to account for the markups associated with the distribution channels for this type of equipment (chapter 5 of the TSD). Installation costs vary by state depending on the prevailing labor rates.

Operating costs for CRAC equipment are a sum of maintenance costs, repair costs, and energy costs. These costs are incurred over the life of the equipment and are, therefore, discounted to the year 2017, which is the effective date of the standards that will be established as part of this rulemaking. The sum of the installed cost and the operating cost, discounted to reflect the present value, is termed the life-cycle cost or LCC.

Generally, customers incur higher installed costs when they purchase higher efficiency equipment, and these cost increments will be partially or wholly offset by savings in the operating costs over the lifetime of the equipment. Usually, the savings in operating costs are due to savings in energy costs because higher efficiency equipment uses less energy over the lifetime of the equipment. Often, the LCC of higher efficiency equipment is lower compared to lower efficiency equipment. LCC savings are calculated for each efficiency level of each equipment class.

The PBP of higher efficiency equipment is obtained by dividing the increase in the installed cost by the decrease in annual operating cost. For this calculation, DOE uses the sum of the first year operating cost changes as the estimate of the decrease in operating cost, noting that some of the repair and replacement costs used herein are annualized estimates of costs. PBP is calculated for each efficiency level of each equipment class.

Apart from MSP, installation costs, and maintenance and repair costs, other important inputs for the LCC and PBP analysis are markups and sales tax, equipment energy consumption, electricity prices and future price trends, equipment lifetime, and discount rates.

Many inputs for the LCC and PBP analysis are estimated from the best available data in the market, and in some cases the inputs are generally accepted values in the refrigeration equipment industry. In general, there is uncertainty associated with most of the inputs because it is difficult to obtain one accurate representative value for some inputs. Therefore, DOE carries out the LCC and PBP analysis in the form of Monte Carlo simulations in which certain inputs are provided a range of values and probability distributions that account for the uncertainties. The results of the LCC and PBP analysis are presented in the form of mean and median LCC savings, percentages of customers experiencing net savings, net cost, and no impact in LCC, and median

PBP. For each equipment class, 5,000 Monte Carlo simulations were carried out. The simulations were conducted using Microsoft Excel and Crystal Ball, a commercially available Excel add-in for doing Monte Carlo simulations

LCC savings and PBP are calculated by comparing the installed costs, operating costs, and LCC values of a standards-case scenario against those of base-case scenario. The Base-case scenario is the scenario in which equipment is assumed to be purchased by customers in the absence of the proposed energy conservation standards. Because the purpose of this analysis is to determine whether efficiency levels beyond the level adopted by ASHRAE are economically justified, the Base-case scenario is the ASHRAE level. Standards-case scenarios are scenarios in which equipment is assumed to be purchased by customers after the energy conservation standards, determined as part of the current rulemaking, go into effect. The number of standards-case scenarios for an equipment class is equal to one less than the total number of efficiency levels in that equipment class because each efficiency level above the ASHRAE level represents a potential new standard. Usually, the equipment available in the market will have a distribution of efficiencies. Therefore, for both base-case and standards-case scenarios in the LCC and PBP analysis, DOE assumes a distribution of efficiencies in the market and the distribution is assumed to be spread over the first few efficiency levels in the LCC and PBP analysis (see TSD chapter 8).

Recognizing that each commercial building that uses CRAC equipment is unique, DOE analyzed variability and uncertainty by performing the LCC and PBP calculations for three types of buildings: (1) health care; (2) education; and (3) offices. Different types of businesses face different energy prices and also exhibit differing discount rates that they apply to purchase decisions.

Equipment lifetime for CRAC equipment is another input that does not justify usage of one single value for each equipment class. Therefore, for purposes of the LCC analysis, DOE assumes a distribution of equipment lifetimes between 10 and 25 years that are defined by Weibull survival functions, with an average value of 15 years.

Another important factor influencing the LCC and PBP analysis is the state in which the CRAC equipment is installed. Inputs that vary based on this factor include energy prices and sales tax. At the national level, the spreadsheets explicitly modeled variability in the model inputs for electricity price and markups using probability distributions based on the relative populations in different states and business types.

Results of the LCC and PBP analysis are presented in section 6.4 and in appendix 6B.

6.1.2 Overview of Life-Cycle Cost and Payback Period Inputs

Inputs to the LCC and PBP analysis are categorized as follows: (1) inputs for establishing the total installed cost; and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are as follows:

- *Baseline manufacturer selling price* is the price charged by the manufacturer to either a wholesaler or customer for equipment meeting baseline efficiency level. The MSP includes a manufacturer's markup, which converts the MPC to MSP.
- *Price learning* is a method of adjusting the MSP across time to account for increased efficiency in the production of CRAC equipment. It is generally assumed in DOE LCC analyses that with time and experience, the real cost of producing equipment will decrease marginally.
- *Candidate standard-level manufacturer selling price increase* is the incremental change in MSP associated with producing equipment at each of the higher efficiency levels (efficiency levels above the baseline).
- *Markups and sales tax* are the distribution channel markups and sales tax associated with converting the MSP to a customer purchase price. Figure 6.1.1 depicts these generically. Only the contractor markups and sales taxes apply to CRAC equipment. The methodology to determine markups and sales taxes is presented in TSD chapter 5.
- *Installation cost* is the cost to the customer of installing the equipment. The cost for installation is estimated as a one-time cost and is intended to represent the cost of labor. Installation overhead, and other miscellaneous materials and parts are considered in the distribution channel markups..

The primary inputs for calculating the operating costs are as follows:

- *Equipment energy consumption*: Consumption is the total annual energy consumed by CRAC equipment in kilowatt-hours. This value is calculated as part of the engineering analysis for each candidate standard level in each equipment class.
- *Electricity prices*: Electricity prices used in the analysis are the price per kilowatt-hour in cents or dollars paid by each customer for electricity. Electricity prices are determined using average commercial electricity prices in each state, as determined from the Energy Information Administration (EIA) data for 2010. The 2010 average commercial prices derived were modified to reflect the fact that the three types of businesses analyzed pay electricity prices that are different from the average commercial prices. Details on the development of electricity prices and the data sources used are found in section 6.2.3.1.1.
- *Electricity price trends*: The EIA's *Annual Energy Outlook 2011*[1] *(AEO2011)* is used to forecast electricity prices. For the results presented in this chapter, DOE used the regional prices from the *AEO2011* reference case to forecast future electricity prices.
- *Maintenance costs:* Estimated as an annual expense, equal to a percentage of the total MSP, representing the labor and materials costs associated with maintaining the operation of the equipment. Maintenance includes activities such as cleaning heat exchanger coils, checking refrigerant charge levels, and replacing filters, and other routine measures to keep the equipment running efficiently.
- *Repair costs*: The cost for repairs is estimated as an annual expense, equal to a percentage of the total MSP, derived to represent the labor and materials costs associated with repairing or replacing components that have failed.
- *Equipment lifetime*: The age at which the CRAC equipment is retired from service.

- *Discount rate*: The rate at which future costs are discounted to establish their present value. It is calculated as the weighted average cost of capital for each of the three types of businesses assumed to have the computer rooms cooled by CRAC equipment.

Figure 6.1.1 depicts the relationships between the installed cost and operating cost inputs for the calculation of the LCC and PBP. Table 6.1.1 summarizes the characteristics of the inputs to the LCC and PBP analysis and lists the corresponding reference chapter in the TSD for details on the calculation of the inputs.

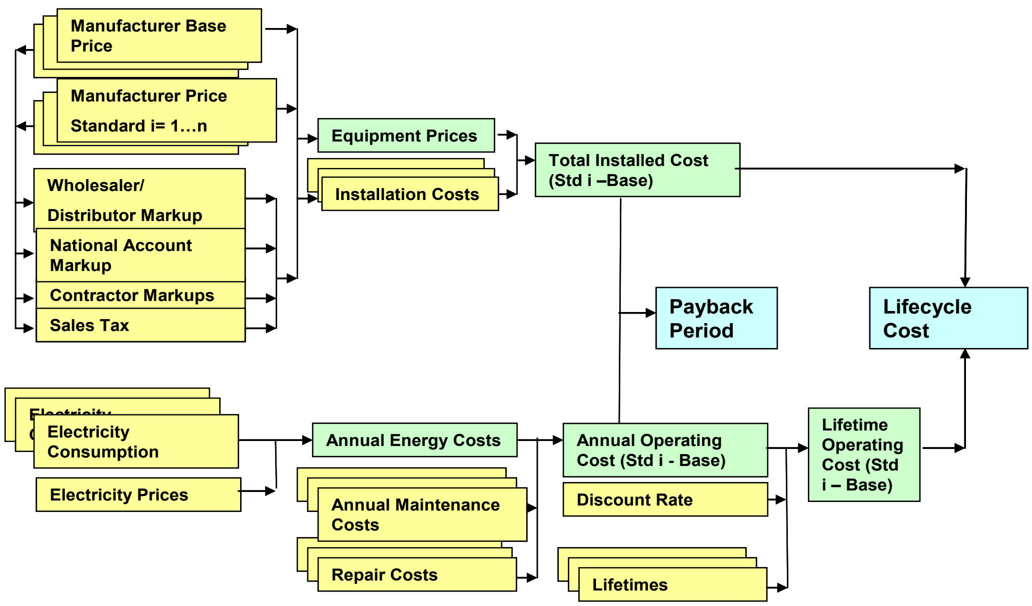

Figure 6.1.1 Flow Diagram of Inputs for the Determination of Life-Cycle Cost and Payback Period

Table 6.1.1 Summary Information of Inputs for the Determination of Life-Cycle Cost and Payback Period

Input	Description	TSD Chapter Reference
	Total Installed Cost Primary Inputs	
Baseline MSP	Varies with equipment class.	Chapter 3
Candidate standard-level MSP increases	Vary with equipment class and candidate standard level within an equipment class.	Chapter 3
Markups and sales tax	Vary with location (state) where equipment is installed.	Chapter 5
Installation price	Varies with equipment class location (state) where equipment is installed.	Chapter 6
	Operating Cost Primary Inputs	
Equipment energy consumption	Varies with equipment class and candidate standard level within an equipment class.	Chapter 4
Electricity prices	Vary with location, building type.	Chapter 6
Electricity price trends	Vary with location (regional) and price scenario.	Chapter 6
Maintenance costs	Vary with location.	Chapter 6
Repair costs	Vary with equipment class, candidate standard level within equipment class and location.	Chapter 6
Lifetime	Assumed in a range of 10 to 25 years with an average value of 15 years.	Chapters 3, 6
Discount rate	Varies with type of business.	Chapter 6

All of the inputs depicted in Figure 6.1.1 and summarized in Table 6.1.1 are discussed in sections 6.2 and 6.3.

ASHRAE released a new version of ASHRAE Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, on October 29, 2010. Each time ASHRAE Standard 90.1is amended with respect to such equipment for each type of equipment, the Energy Policy Conservation Act (42 U.S.C. 6311−6316; EPCA) directs that if ASHRAE Standard 90.1 is amended,[a] DOE must adopt amended energy conservation standards at the new efficiency level in ASHRAE Standard 90.1, unless clear and convincing evidence supports a determination that adoption of a more stringent efficiency level as a national standard would produce significant additional energy savings and be technologically feasible and economically justified. (42 U.S.C. 6313(a)(6)(A)(ii)(II)) If DOE decides to adopt as a national standard the efficiency levels specified in the amended ASHRAE Standard 90.1, DOE must establish such standard not later than 18 months after publication of the amended industry standard. (42 U.S.C. 6313(a)(6)(A)(ii)(I)) If DOE determines that a more stringent standard is appropriate, DOE must establish an amended standard not later than 30 months after publication of the revised ASHRAE Standard 90.1 (42 U.S.C. 6313(a)(6)(B)), and that such standard goes into effect not later than four years after publication in the Federal Register. (42 U.S.C. 6313(a)(6)(D))

Standards set by this rulemaking are scheduled to go into effect on October 29, 2013 if DOE adopts the revised ASHRAE standard and April 29, 2017 if DOE were to propose a rule prescribing energy conservation standards higher than the efficiency levels contained in ASHRAE Standard 90.1-2010. EPCA requires that DOE publish a final rule adopting more stringent standards than those in ASHRAE Standard 90.1-2010 within 30 months of ASHRAE action (*i.e.,* by April 2013). Thus, four years from April 2013 would be April 2017, which would be the anticipated effective date for DOE adoption of more stringent standards. For purposes of this LCC analysis of comparing different efficiency levels, it is assumed that the year of sale for the CRAC equipment is 2017.

Table 6.1.2 shows the five efficiency levels for CRAC equipment class Air Cooled <65 kBtu/hr equipment class, obtained from the engineering analysis (ASHRAE plus four additional levels). This table represents the current (2011) technology levels modeled for Air Cooled <65 kBtu/hr equipment on the market. As previously explained, DOE assumed that the ASHRAE standard would represent the minimum efficiency level of the market for this unit and that it would remain so. In order to approximate this state of market technology, DOE assumed the efficiency levels shown in Table 6.1.2 for Air Cooled <65 kBtu CRAC equipment in U.S. average climate conditions.

[a] Although EPCA does not explicitly define the term "amended" in the context of ASHRAE Standard 90.1, DOE provided its interpretation of what would constitute an "amended standard" in a final rule published in the *Federal Register* on March 7, 2007 (hereafter referred to as the March 2007 final rule). 72 FR 10038. In that rule, DOE stated that the statutory trigger requiring DOE to adopt uniform national standards based on ASHRAE action is for ASHRAE to change a standard for any of the equipment listed in EPCA section 342(a)(6)(A)(i) (42 U.S.C. 6313 (a)(6)(A)(i)) by increasing the energy efficiency level for that equipment type. *Id.* at 10042. In other words, if the revised ASHRAE Standard 90.1 leaves the standard level unchanged or lowers the standard, as compared to the level specified by the national standard adopted pursuant to EPCA, DOE does not have the authority to conduct a rulemaking to consider a higher standard for that equipment pursuant to 42 U.S.C. 6313(a)(6)(A).

Table 6.1.2 Electricity Use in Air Cooled <65 kBtu/hr CRAC Equipment by Efficiency Level

Efficiency Level	Electricity Consumption *kWh/yr*
ASHRAE Standard	27,406
Level 1	25,293
Level 2	23,506
Level 3	21,973
Level 4	20,646

6.2 LIFE-CYCLE COST INPUTS

6.2.1 Definition

LCC is the total customer cost over the life of a piece of equipment, including purchase cost and operating costs (energy costs, maintenance costs, and repair costs). Future operating costs are discounted to the time of purchase and summed over the lifetime of the equipment. LCC is defined by Eq. 6.1:

$$LCC = IC + \sum_{t=1}^{N} OC_t / (1+r)^t$$

Eq. 6.1

Where:

LCC = life-cycle cost ($),
IC = total installed cost ($),
N = lifetime of equipment (years),
OC_t = operating cost ($) of the equipment in year t,
r = discount rate, and
t = year for which operating cost is being determined.

Because DOE gathered most of its data for the LCC analysis in 2011, DOE expresses all costs in 2011$. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. In the LCC analysis, the first year of equipment purchase is assumed to be 2017.

6.2.2 Total Installed Cost Inputs

The total installed cost to the customer is defined by Eq. 6.2:

$$IC = EQP + INST$$

Eq. 6.2

Where:

EQP = customer purchase price for the equipment ($), and
$INST$ = installation cost or the customer price to install equipment ($).

The equipment price is based on the distribution channel through which the customer purchases the equipment, as discussed in TSD chapter 5.

The remainder of this section provides information about the variables DOE used to calculate the total installed cost for CRAC equipment. Table 6.2.1 shows inputs for the determination of total installed cost.

Table 6.2.1 Inputs for Total Installed Costs

Baseline manufacturer selling price ($)
Price learning coefficient
Candidate standard-level manufacturer selling price increases ($)
Mechanical contractor markup
Sales tax ($)
Installation cost ($)

6.2.2.1 Baseline Manufacturer Selling Price

The baseline MSP is the price charged by manufacturers and distributors for CRAC equipment for existing efficiency levels (for equipment classes with no standards). The MSP includes manufacturer markup, distributor cost, and costs of delivery to the job site that are applied to convert the MPC to an MSP. DOE developed MSP values for the 15 primary equipment classes (see TSD chapter 3). Table 6.2.2 shows the set of 15 primary equipment classes that DOE evaluated during the preliminary analysis of the current rulemaking.

Table 6.2.2 Equipment Classes Evaluated for the CRAC Equipment Standard Life-Cycle Cost and Payback Period Analysis

Description (Cooling Method, Size)	Abbreviation
Air Cooled < 65 kBtu	AC < 65
Air Cooled 65–240 kBtu	AC 65–240
Air Cooled > 240 kBtu	AC > 240
Water Cooled < 65 kBtu	WC < 65k
Water Cooled 65–240 kBtu	WC 65–240
Water Cooled > 240 kBtu	WC > 240
Water Cooled w/ FE <65 kBtu	WC w/FE < 65k
Water Cooled w/ FE 65–240 kBtu	WC w/FE 65–240
Water Cooled w/ FE > 240 kBtu	WC w/FE > 240
Glycol Cooled <65 kBtu	GC < 65k
Glycol Cooled 65–240 kBtu	GC 65–240
Glycol Cooled > 240 kBtu	GC >240
Glycol Cooled w/ FE <65 kBtu	GC w/FE < 65k
Glycol Cooled w/ FE 65–240 kBtu	GC w/FE 65–240
Glycol Cooled w/ FE > 240 kBtu	GC w/FE > 240

DOE's LCC analysis typically includes an allowance for equipment prices to change as experience is gained with manufacturing. To derive a price trend for computer room air-conditioners, DOE obtained historical Producer Price Index (PPI) data for all other miscellaneous refrigeration and air-conditioning equipment spanning the time period 1990-2010 from the Bureau of Labor Statistics' (BLS).[b] DOE used PPI data for all other miscellaneous refrigeration and air-conditioning equipment as representative of computer room air-conditioners because PPI data specific to computer room air-conditioners are not available. The PPI data reflect nominal prices, adjusted for product quality changes. An inflation-adjusted (deflated) price index for all other miscellaneous refrigeration and air-conditioning equipment was calculated by dividing the PPI series by the Gross Domestic Product Chained Price Index (see Figure 6.2-1).

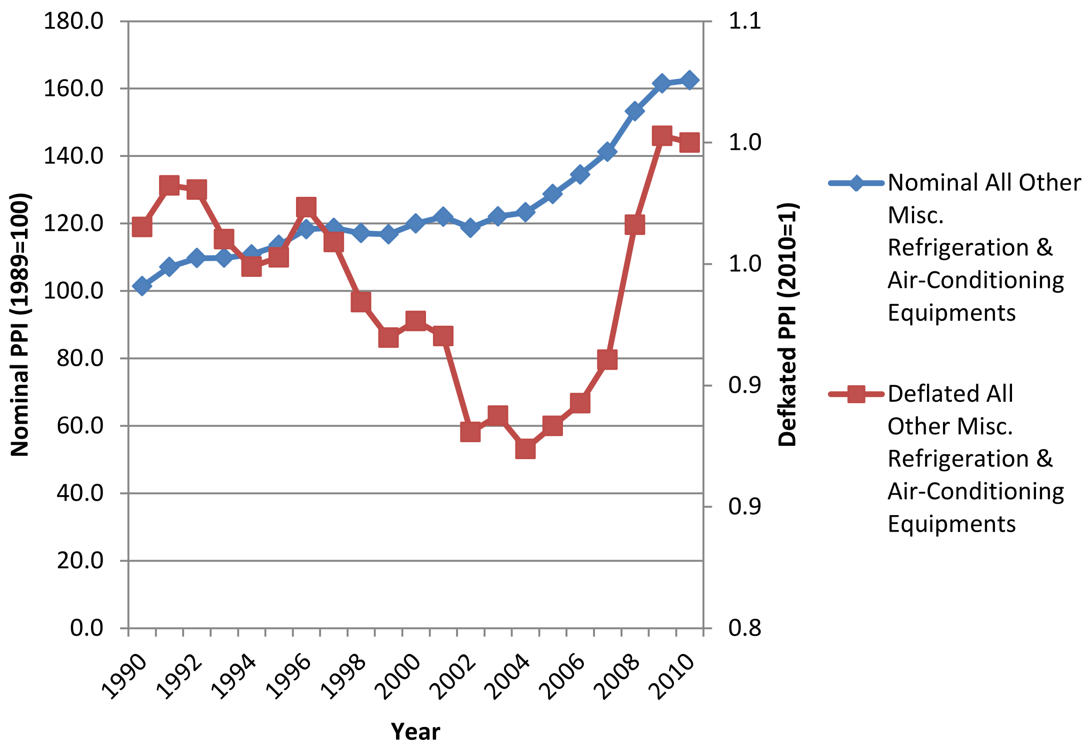

Figure 6.2.1 Historical Nominal and Deflated Producer Price Indexes for Integral Horsepower Motors and Generators Manufacturing

From 1990 to 2004, the deflated price index for all other miscellaneous refrigeration and air-conditioning equipment showed a downward trend. Since then, the index has risen sharply, primarily due to rising prices of copper and steel products that go into computer room air-conditioners (see Figure 6.2-2). The rising prices for copper and steel products were primarily a result of strong demand from China and other emerging economies. Given the slowdown in global economic activity in 2011, DOE believes that the extent to which the trends of the past couple of years will continue is very uncertain. DOE performed an exponential fit on the deflated price index for all other miscellaneous refrigeration and air-conditioning equipment, but the R^2

[b] Series ID PCU3334153334159; http://www.bls.gov/ppi/

parameter, which indicates quality of the fit, was relatively low, indicating a poor fit to the data. DOE also considered the experience curve approach, in which an experience rate parameter is derived using two historical data series on price and cumulative production, but the time series for historical shipments was not available.

Given the above considerations, DOE decided to use a constant price assumption as the default price factor index to project future computer room air conditioner prices in 2017. Thus, prices forecast for the LCC and PBP analysis are equal to the 2011 values for each efficiency level in each equipment class.

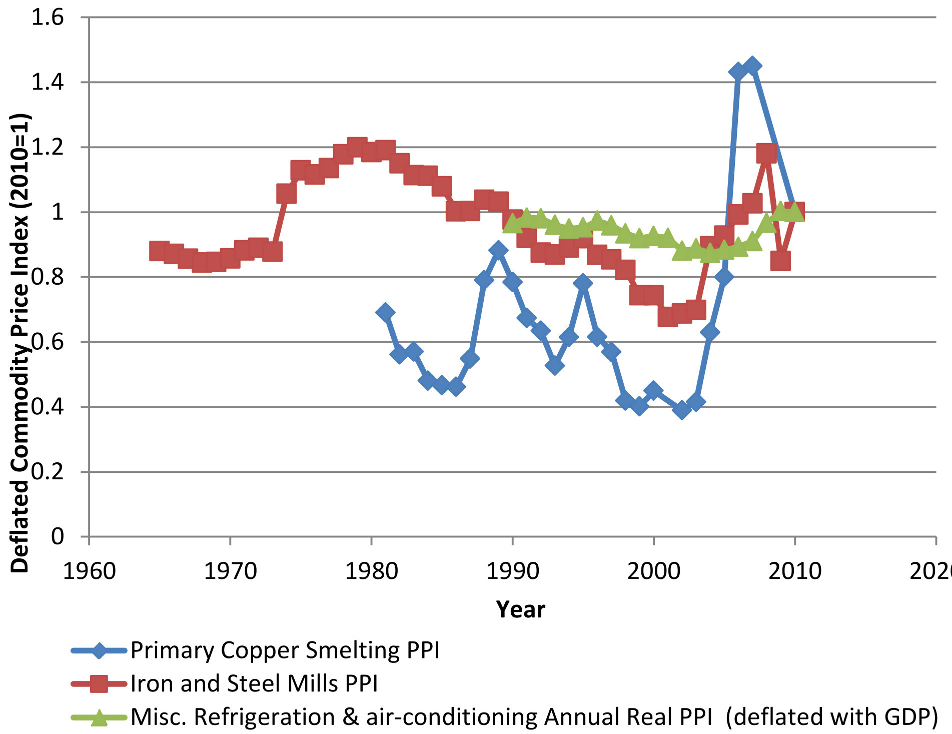

Figure 6.2.2 Historical Deflated Producer Price Indexes for Copper Smelting, Steel Mills Manufacturing and All Other Miscellaneous Refrigeration and Air-Conditioning Equipment

Table 6.2.3 presents the baseline energy consumption values and the baseline MSPs used in the LCC and PBP analysis for the representative sizes for each of the 15 primary equipment classes (see chapter 3). Table 6.2.3 includes the adjustment for cost reduction due to accumulated manufacturing experience, which in the case of CRAC equipment is determined to be zero. Because the analysis in this chapter is designed to help determine whether efficiency levels beyond the ASHRAE standard would be economically justified, the baseline was set at the ASHRAE standard baseline, as explained in section 6.1.2.

Table 6.2.3 Baseline Energy Consumption Levels and MSP Values for the Representative CRAC Equipment Units of All 15 Primary Equipment Classes

Equipment Class	Baseline Energy Consumption *kWh/yr*	Manufacturer Selling Price *2011$*
Air Cooled < 65 kBtu	27,406	6,681
Air Cooled 65–240 kBtu	102,742	22,621
Air Cooled > 240 kBtu	245,964	32,575
Water Cooled < 65 kBtu	24,724	14,233
Water Cooled 65–240 kBtu	92,114	12,883
Water Cooled > 240 kBtu	208,707	24,453
Water Cooled w/ FE <65 kBtu	15,413	15,062
Water Cooled w/ FE 65–240 kBtu	57,426	13,633
Water Cooled w/ FE > 240 kBtu	129,533	25,878
Glycol Cooled <65 kBtu	24,668	14,233
Glycol Cooled 65–240 kBtu	101,829	12,870
Glycol Cooled > 240 kBtu	227,064	24,453
Glycol Cooled w/ FE <65 kBtu	19,786	15,062
Glycol Cooled w/ FE 65–240 kBtu	81,553	13,620
Glycol Cooled w/ FE > 240 kBtu	181,776	25,878

6.2.2.2 Candidate Standard Level Energy Consumption and Manufacturer Selling Price Increases

The candidate standard level MSP increase is the change in MSP associated with producing equipment at higher efficiency levels. Increases in MSP as a function of equipment efficiency were developed for each of the 15 primary equipment classes. The engineering analysis established a series of MSP increases for each standard level. Table 6.2.4 presents the increase in MSP corresponding to all efficiency levels for each primary equipment class, including cost reductions due to accumulated manufacturing experience between 2011 and 2017.

Table 6.2.4 Standard-Level Manufacturer Selling Price Increases (Price Increases Relative to the Price of Baseline Equipment, Including Learning)

Equipment Class	Baseline (ASHRAE) MSP	MSP Increase by Efficiency Level *2011$**			
		Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	6,681	1,172	2,551	4,171	6,075
Air Cooled 65−240 kBtu	22,621	1,762	3,661	5,708	7,914
Air Cooled > 240 kBtu	32,575	2,537	5,272	8,219	11,397
Water Cooled <65 kBtu	14,233	(2,705)	(4,896)	(6,671)	(8,108)
Water Cooled 65–240 kBtu	12,883	4,432	10,389	18,396	29,157
Water Cooled > 240 kBtu	24,453	8,410	19,713	34,903	55,318
Water Cooled w/ FE <65 kBtu	15,062	(2,863)	(5,181)	(7,059)	(8,580)
Water Cooled w/ FE 65–240 kBtu	13,633	4,690	10,995	19,468	30,856
Water Cooled w/ FE > 240 kBtu	25,878	8,900	20,861	36,936	58,540
Glycol Cooled <65 kBtu	14,233	(2,705)	(4,896)	(6,671)	(8,108)
Glycol Cooled 65–240 kBtu	12,870	4,426	10,375	18,370	29,115
Glycol Cooled > 240 kBtu	24,453	8,410	19,713	34,903	55,318
Glycol Cooled w/ FE <65 kBtu	15,062	(2,863)	(5,181)	(7,059)	(8,580)
Glycol Cooled w/ FE 65–240 kBtu	13,620	4,684	10,980	19,440	30,810
Glycol Cooled w/ FE > 240 kBtu	25,878	8,900	20,861	36,936	58,540

*Values in parentheses are negative values.

Table 6.2.5 presents the annual energy consumption of the representative units belonging to each of the 15 primary equipment classes that were selected for the engineering analysis.

Table 6.2.5 Energy Consumption Values for Representative CRAC Equipment Units of the 15 CRAC Equipment Classes and All Efficiency Levels within the Equipment Classes

Product Class	Annual Energy Consumption *kWh/yr*				
	Baseline (ASHRAE)	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	27,406	25,293	23,506	21,973	20,646
Air Cooled 65–240 kBtu	102,742	92,645	84,489	77,764	72,124
Air Cooled > 240 kBtu	245,964	219,349	198,279	181,184	167,037
Water Cooled <65 kBtu	24,724	23,090	21,674	20,435	19,341
Water Cooled 65–240 kBtu	92,114	85,816	80,386	75,657	71,501
Water Cooled > 240 kBtu	208,707	193,842	181,099	170,056	160,394
Water Cooled w/ FE <65 kBtu	15,413	14,576	13,852	13,220	12,664
Water Cooled w/ FE 65–240 kBtu	57,426	54,191	51,410	48,993	46,874
Water Cooled w/ FE > 240 kBtu	129,533	121,882	115,344	109,693	104,759
Glycol Cooled <65 kBtu	24,668	22,989	21,542	20,282	19,174
Glycol Cooled 65–240 kBtu	101,829	93,813	87,055	81,280	76,288
Glycol Cooled > 240 kBtu	227,064	208,770	193,404	180,314	169,029
Glycol Cooled w/ FE <65 kBtu	19,786	18,536	17,462	16,529	15,710
Glycol Cooled w/ FE 65–240 kBtu	81,553	75,540	70,490	66,188	62,479
Glycol Cooled w/ FE > 240 kBtu	181,776	168,036	156,540	146,779	138,388

6.2.2.3 Overall Markup

As discussed in chapter 5, Markups for Equipment Price Determination, DOE calculated overall markups to calculate the equipment purchase price to customers from the equipment MSP. DOE calculated baseline markups to convert baseline MSP to baseline customer purchase price and incremental markups to convert the increments in MSP into increments in customer purchase price. DOE used these markup values in the LCC-PBP analysis for calculation of baseline and higher efficiency equipment price to customers.

6.2.2.4 Installation Cost

Although much CRAC equipment is not installed in standard configurations, which complicates estimating the cost of installation, some standardized estimates do exist. The estimated installation cost is designed to represent a one-time fixed cost, to incorporate the labor and materials required to fully install CRAC equipment of various capacities to serve a computer room. DOE utilized RS Means installation cost data from RS Means CostWorks 2011[2] to derive installation cost curves by size of unit for the base efficiency unit. Installation cost was also derived as a percentage of equipment cost at each of several unit sizes for each equipment class, and this percentage was used to estimate installation cost increase for more efficient equipment.

The installation cost functions by size for the three CRAC equipment cooling methods are as follows:

$$INST_{Air} = 690.13 \times Cap^{0.6538}$$

$$INST_{Glycol} = 1017.8 \times Cap^{0.5407}$$

$$INST_{Water} = 702.45 \times Cap^{0.5161}$$

Where capacity is measured in tons (multiples of 12 kBtu/hr).

For the notice of proposed rulemaking (NOPR) analysis, DOE is assuming that the engineering design options do not significantly affect installation labor within an equipment class, and therefore, within a given equipment class the installation cost will not vary with efficiency levels, though installation cost may still vary from one equipment class to another. If installation costs do not vary with efficiency levels, they do not impact the LCC, PBP, or national impact analysis results. The installation costs in the NOPR analysis are estimated very simply as a fixed value for each equipment class. To allow for the possibility that installation cost could increase as a function of increased efficiency within an equipment class, installation cost was also derived as a percentage of equipment cost at each of several unit sizes for each equipment class using the RS Means CostWorks 2011 data and the average percentage in each case (9.4, 9.2, and 7.7 percent for air-cooled, water-cooled, and glycol-cooled units, respectively) was recorded. The percentages are available to estimate installation cost as a function of equipment efficiency. DOE designed the LCC spreadsheet such that installation costs can be varied by efficiency level, but has modeled installation cost as constant across efficiency levels for the NOPR analysis.

Table 6.2.6 shows installation cost indices for installations in each of the 50 states, the District of Columbia, and weighted-average for the entire United States, which are used to adjust the nationally representative installation costs for each state. To arrive at an average index for each state, DOE first weighted the city indices in each state by their population within the state. DOE used state-level population weights for 2010 from the U.S. Census Bureau[3] to calculate a weighted-average index for each state from the RS Means data.

6.2.2.5 Weighted-Average Total Installed Cost

As presented in Eq. 6.2, the total installed cost is the sum of the equipment price and the installation cost. DOE derived the customer equipment price for any given standard level by multiplying the baseline MSP by the baseline markup and adding to it the product of the incremental MSP and the incremental markup. Because MSPs, markups, and the sales tax all can take on a variety of values, depending on location, the resulting total installed cost for a particular standard level will not be a single-point value, but rather a distribution of values.

DOE used the baseline and incremental markups, the sales tax, and installation costs to convert the MSPs into total installed costs for a case where the incremental installation costs are held flat. Table 6.2.7 summarizes the weighted average or mean costs and markups necessary for determining the weighted-average baseline and standard-level total installed costs for office buildings as an example.

Table 6.2.6 Installation Cost Indices (National Value = 100.0)

State	Index	State	Index	State	Index
Alabama	58.7	Kentucky	81.4	North Dakota	57.9
Alaska	113.9	Louisiana	65.7	Ohio	96.9
Arizona	86.6	Maine	68.4	Oklahoma	58.8
Arkansas	62.2	Maryland	92.7	Oregon	106.8
California	131.0	Massachusetts	128.2	Pennsylvania	128.2
Colorado	83.9	Michigan	109.4	Rhode Island	116.8
Connecticut	122.0	Minnesota	126.3	South Carolina	40.2
Delaware	125.6	Mississippi	61.1	South Dakota	46.4
Dist. of Columbia	102.6	Missouri	105.4	Tennessee	76.9
Florida	73.5	Montana	78.0	Texas	63.6
Georgia	72.2	Nebraska	86.3	Utah	75.9
Hawaii	117.5	Nevada	108.4	Vermont	68.7
Idaho	72.4	New Hampshire	90.5	Virginia	73.9
Illinois	142.8	New Jersey	137.4	Washington	110.9
Indiana	87.5	New Mexico	75.5	West Virginia	92.2
Iowa	88.7	New York	170.1	Wisconsin	106.4
Kansas	77.4	North Carolina	40.3	Wyoming	60.4

Table 6.2.7 Costs and Markups for Determination of Weighted-Average Total Installed Costs, Air Cooled <65 kBtu Equipment Class*

Variable	Weighted Average or Mean Value
Baseline MSP	$6,681
Standard-Level MSP Increase (Efficiency Level 4)	$6,075
Overall Markup Factor–Baseline	1.572
Overall Markup Factor–Incremental	1.263
Installation Cost–Baseline	$1,415
Installation Cost Factor, for U.S. Average	1.000

*Installation costs apply to the baseline unit, with no incremental installation costs.

To illustrate the derivation of the weighted-average total installed cost based on the data shown in Table 6.2.7, DOE presents Eq. 6.3 for the baseline (ASHRAE standard level) and for a higher efficiency level (Level 4) Air Cooled <65 kBtu equipment class. For the baseline product, the calculation of the total installed cost at national average conditions is as follows:[c]

[c] Note that the numbers shown in Eq. 6.3 have been rounded and do not exactly match the numbers in the analysis.

$$IC_{BASEAC<65} = EQP_{BASE\ AC<65} + INST_{BASE\ AC<65} \times ISTINDEX$$

$$= MFG_{BASE\ AC<65} \times Price\ Learning\ Coef_{Analysis\ Year} \times MU_{BASE\ AC<65} \times Sales\ Tax_{State} + INST_{BASE\ AC<65} \times ISTINDEX$$

$$= \$6{,}681 \times 1.000 \times (1.4743 \times (1.0726) + \$1{,}415 \times (1.00)$$

$$= \$10{,}565 + \$1{,}415$$

$$\times (1.000)$$

$$= \$11{,}980$$

Eq. 6.3

Where:

$IC_{BASE}\ AC < 65_{-B}$ = total installed cost of $AC < 65$ equipment at baseline efficiency level ($),
$EQP_{BASE}\ AC < 65_{-B}$ = equipment purchase price of $AC < 65$ equipment at baseline efficiency level ($),
$INST_{BASE}\ AC < 65$ = installation cost of $AC < 65$ equipment at baseline efficiency level ($),
$MFG_{BASE}\ AC < 65_{B}$ = MSP of $AC < 65$-B equipment at baseline efficiency level ($),
$MU_{BASE}\ AC < 65_{B}$ = overall baseline markup for equipment class $AC < 65$,
ISTINDEX = location dependent multiplier on installation costs; approximately 1.0 at a national average, and
$Price\ Learning\ Coef_{Analysis\ Year}$ = price learning coefficient value for the year in which the unit is being purchased (=1.0 in 2011)

The calculation of the higher Efficiency Level 4 total installed cost includes the use of an MSP increment. DOE uses an incremental markup factor that applies to incremental increases in MSP. The Level 4 price is equal to the baseline price calculated above, plus the MSP increment for a higher efficiency level multiplied by the incremental markup.

As an example, DOE calculated the national average Level 4 total installed cost ($IC_{IMH\text{-}A\text{-}Small\text{-}B LEVEL4}$) as follows:[d]

$$IC_{AC<65-B\ LEVEL4} = EQP_{AC<65\ LEVEL4} + INST_{AC<65\ LEVEL4} \times ISTINDEX$$

$$= MFG_{BASE\ AC<65} \times Price\ Learning\ Coef_{Analysis\ Year} \times MU_{BASE\ AC<65} + \Delta MFG_{AC<65\ LEVEL4} \times Price\ Learning\ Coef_{Analysis\ Year} \times MU_{IMH-A-Small-B\ LEVEL4} \times Sales\ Tax_{State} + INST_{AC<65LEVEL4} \times ISTINDEX$$

$$= \$6{,}681 \times 1.000 \times (1.4743) \times 1.0726 + \$6{,}075 \times 1.000 \times (1.1844) \times 1.0726 + \$1{,}415 \times (1.000)$$

$$= \$19{,}698$$

Eq. 6.4

Where:

$IC_{AC<65\ LEVEL4}$ = total installed cost of $AC < 65$ equipment at Efficiency Level 4($),
$EQP_{AC<65LEVEL4}$ = equipment price of $AC < 65$ equipment at Efficiency Level 4 ($),
$INST_{AC<65LEVEL4}$ = installation cost of AC<65 equipment at Efficiency Level 4 ($),
$\Delta MFG_{AC<65LEVEL4}$ = incremental increase in MSP of AC<65 equipment at Efficiency Level 4 compared to equipment at baseline efficiency level ($), and
$MU_{IMH\text{-}A\text{-}Small\text{-}BLEVEL4}$ = incremental markup for equipment class AC<65.

Table 6.2.8 presents the weighted-average equipment price, installation costs, and total installed costs for the Air Cooled <65 kBtu equipment classes at the baseline level and each higher efficiency level examined.

Table 6.2.8 Weighted-Average Equipment Price, Installation Cost, and Total Installed Costs for Air Cooled <65 kBtu at U.S. Average Conditions (2011$)[e]

Efficiency Level	Equipment Price (MSP)	Installation Cost	Total Installed Cost
Baseline (ASHRAE)	10,565	1,415	11,980
Level 1	12,055	1,415	13,470
Level 2	13,805	1,415	15,221
Level 3	15,863	1,415	17,279
Level 4	18,283	1,415	19,698

[d] Note that the numbers shown in Eq. 6.4 have been rounded and do not exactly match the numbers in the analysis.
[e] Figures shown in the table were taken straight from the LCC analyses, and thus can differ from those shown above in the text due to the rounding issue mentioned in footnotes b and c.

6.2.3 Operating Cost Inputs

DOE defines the operating cost as the sum of energy cost, repair cost, and maintenance cost, as shown in the following equation:

$$OC = EC + RC + MC$$

Eq. 6.5

Where:

OC = operating cost ($),
EC = energy cost ($),
RC = repair cost ($), and
MC = maintenance cost ($).

The remainder of this section provides information about the variables that DOE used to calculate the operating cost for commercial refrigeration equipment. Table 6.2.9 shows the inputs for the determination of operating costs.

Table 6.2.9 Inputs for Operating Costs

Electricity price (cents/kWh)
Electricity price trends
Repair cost ($)
Maintenance cost ($)
Lifetime (years)
Discount rate (%)
Effective date of standard
Baseline electricity consumption (kWh/yr)
Standard case electricity consumption (kWh/yr)

6.2.3.1 Electricity Price Analysis

This section describes the electricity price (cents/kWh) analysis used to develop the energy portion of the annual operating costs (price multiplied by electricity consumption) for commercial refrigeration equipment used in different commercial building types.

Subdivision of the Country. Because of the wide variation in electricity consumption patterns, wholesale costs, and retail rates across the country, it is important to consider regional differences in electricity prices. For this reason, DOE divided the United States into the 50 states and the District of Columbia. DOE used reported average effective commercial electricity prices at the state level from the EIA publication *Form EIA-826 Database Monthly Electric Utility Sales and Revenue Data*.[4] The latest available prices from this source are for the calendar year 2010. These were adjusted to represent 2011$ prices using the gross domestic product price deflator from *AEO2011*.[5] Table 6.2.10 provides data on the adjusted electricity prices.

Table 6.2.10 Commercial Electricity Prices by State (2011 cents/kWh)

State	Commercial Electricity Price *cents/kWh*	State	Commercial Electricity Price *cents/kWh*	State	Commercial Electricity Price *cents/kWh*
Alabama	10.27	Kentucky	7.80	North Dakota	6.96
Alaska	14.78	Louisiana	7.86	Ohio	9.86
Arizona	9.55	Maine	12.82	Oklahoma	6.91
Arkansas	7.73	Maryland	12.23	Oregon	7.65
California	13.71	Massachusetts	15.71	Pennsylvania	9.75
Colorado	8.33	Michigan	9.44	Rhode Island	13.97
Connecticut	17.23	Minnesota	8.09	South Carolina	8.93
Delaware	12.24	Mississippi	9.71	South Dakota	7.30
Dist. of Col.	13.24	Missouri	7.11	Tennessee	9.82
Florida	11.01	Montana	8.50	Texas	9.87
Georgia	9.14	Nebraska	7.49	Utah	7.11
Hawaii	22.34	Nevada	10.87	Vermont	13.21
Idaho	6.63	New Hampshire	14.87	Virginia	8.24
Illinois	11.56	New Jersey	14.13	Washington	7.11
Indiana	8.50	New Mexico	8.58	West Virginia	6.92
Iowa	7.72	New York	15.85	Wisconsin	9.78
Kansas	8.04	North Carolina	8.15	Wyoming	7.44

DOE recognized that different kinds of businesses typically use electricity in different amounts at different times of the day, week, and year, and therefore face different effective prices. To make this adjustment, DOE used the 2003 Commercial Buildings Energy Consumption Survey (CBECS)[6] data set to identify the average prices paid by the three kinds of businesses in this analysis compared with the average prices paid by all commercial customers. Eq. 6.6 shows the ratios of prices paid by the three types of businesses were used to increase or decrease the average commercial prices.

$$EPRICE_{COM\ BLDGTYPE\ STATE\ 2010} = EPRICE_{COM\ STATE\ 2010} \times \left(\frac{EPRICE_{BLDGTYPE\ US\ 2003}}{EPRICE_{COM\ US\ 2003}}\right)$$

Eq. 6.6

Where:

$EPRICE_{COM\ BLDGTYPE\ STATE\ 2010}$ = average commercial sector electricity price in a specific building type (such as health care, education, and office) in a specific state in 2010,
$EPRICE_{COM\ STATE\ 2010}$ = average commercial sector electricity price in a specific state in 2010,
$EPRICE_{BLDGTYPE\ US\ 2003}$ = national average commercial sector electricity price in a specific building type in 2003 CBECS, and
$EPRICE_{COM\ US\ 2003}$ = national average commercial sector electricity price in 2003 CBECS.

Table 6.2.11 shows the derivation of the EPRICE ratios from CBECS.

Table 6.2.11 Derived Average Commercial Electricity Price by Business Type

Business Type	Electricity Price *cents/kWh*	Ratio of Electricity Price to Average Price for All Commercial Buildings
HealthCare	0.07222	0.910
Education	0.07962	1.003
Office	0.07664	0.966
All commercial buildings	0.07936	1.000

Source: CBECS 2003

The derived ratio of commercial electricity prices by building type to the overall average commercial building price was then combined with state-by-state commercial rates to derive a series of prices for each state and for each building type. Future prices are forecasted as described in section 6.2.3.2. To obtain a weighted-average national price, DOE weighted the prices paid by each business in each state by the 2010 population in each state.

6.2.3.2 Electricity Price Trend

The electricity price trend provides the relative change in electricity prices for future years out to the year 2045. Estimating future electricity prices is difficult, especially considering that there are efforts in many states throughout the country to restructure the electricity supply industry.

DOE applied a projected trend in national average electricity prices to each customer's energy prices based on the *AEO2011* price scenarios. The discussion in this chapter refers to the 2011 reference price scenario. In the LCC analysis, the following four scenarios can be analyzed:

1. constant (real) energy prices at 2011 values (*i.e.*, a constant index of 1.0 in Figure 6.2.3)
2. *AEO2011*, High Economic Growth ("AEO2011 High Growth" in Figure 6.2.3)
3. *AEO2011*, Reference Case ("AEO2011 Reference" in Figure 6.2.3)
4. *AEO2011*, Low Economic Growth ("AEO2011 Low Growth" in Figure 6.2.3)

Figure 6.2.3 shows the trends for the three *AEO2011* price projections where prices are assumed to change. DOE extrapolated the values in later years (*i.e.*, after 2035—the last year of the *AEO2011* forecast). To arrive at values for these later years, DOE used the price trend from 2025 to 2035 of each forecast scenario to establish prices for the years 2036 to 2045.

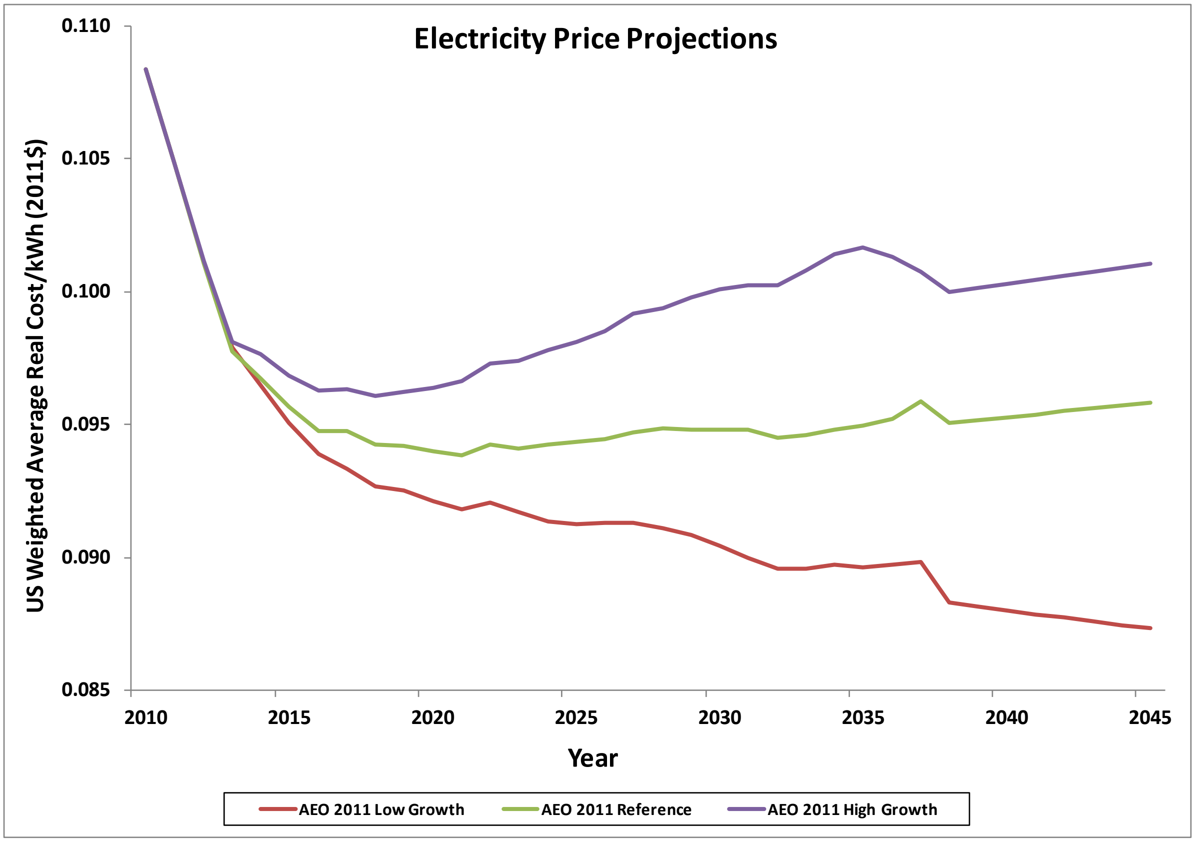

Figure 6.2.3 Electricity Price Trends for Commercial Rates to 2045

The default electricity price trend scenarios used in the LCC analysis are the trends at the Census division level from the *AEO2011* Reference Case, the national average of which is shown in Figure 6.2.3. Spreadsheets used in calculating the LCC have the capability to analyze the other electricity price trend scenarios, namely, the *AEO2011* High Growth and the *AEO2011* Low Growth price trends and constant energy prices.

6.2.3.3 Repair Cost

The repair cost is the average annual cost to the consumer for replacing or repairing components in the CRAC equipment that have failed. Available data from chapter 3 as well as data on repair costs from RS Means suggest that replacement parts used in repair increase as the size and the efficiency of CRAC units increases.

$$RC_{BASE} = K_{CAP} \times (EQP_{OEM})/LIFE$$

Eq. 6.7

Where:

RC_{BASE} = annual repair cost for a baseline efficiency unit (including labor, overhead and profit) (\$),
K_{CAP}=*percentage* of original equipment price from manufacturer for a given equipment capacity
EQP_{OEM} = estimate of raw original equipment price for one major repair (\$), and
LIFE = average lifetime of the equipment in years, assumed to be 15 years.

$$K_{CAP} = 0.0373 \times Cap + 0.0749$$

Eq. 6.8

K_{CAP} increases according to equation 6.8 through capacities of 15 tons capacity (*Cap*), and is constant thereafter for larger sizes. This is in recognition of the observation that repair labor costs in the RS Means database are essentially constant for large capacities and the main increases occur as a result of equipment costs.

For repair costs at higher efficiency levels as a result of standards, the materials component of repair costs is assumed to increase proportionately with the cost of the more efficient equipment, while labor component is assumed involve approximately the same activity at each level of efficiency and is held constant as efficiency increases:

$$RC_{STD} = RC_{MATERIAL\ BASE} \times \frac{EQP_{OEM\ STD}}{EQP_{OEM\ BASE}} + RC_{LABOR\ BASE}$$

Eq. 6.9

As the components used for higher efficiency equipment have a higher original equipment manufacturer cost, the above equation yields an increasing repair costs scenario for higher efficiency equipment.

There are other parts of the units that typically require repair, such as water distribution components, control modules, fan motors or water pumps for air- or water-cooled units respectively, or evaporator components. However, these parts are assumed to be the same for all efficiency levels, so the repair costs for these parts remain constant for all efficiency levels. Therefore, these additional repair costs were not taken into consideration for the analysis.

6.2.3.4 Maintenance Cost

The maintenance cost is the cost to the consumer of maintaining equipment operation. The maintenance cost is not the cost associated with the replacement or repair of components that have failed (as discussed above). Rather, it is the cost associated with general maintenance (*e.g.*, checking and maintaining refrigerant levels, replacing filters, checking coolant distribution lines for leaks, cleaning, sanitizing, and descaling).

DOE estimated annualized preventative maintenance costs for CRAC equipment as a percentage of the total MSP for each equipment class from data in the RS Means Costworks data. RS Means provides estimates on the person-hours, labor rates, and materials required to maintain commercial refrigeration equipment. RS Means specifies preventative maintenance activities for CRAC equipment expected to occur on an annual basis as including the following actions: cleaning evaporator coils, lubricating motors, cleaning condenser coils, checking refrigerant pressures as necessary, and similar activities. DOE did not break out these activities into separate line-item maintenance activities. Instead, DOE used a single figure of $83.98 per year (2011$) for preventative maintenance activities for all CRAC equipment classes between 3 tons and 24 tons capacity and $102.10 per year (2011$) for CRAC equipment classes of larger capacity.

Data were not available to indicate how maintenance costs vary with equipment efficiency level. In addition, although preventative maintenance activities may vary by size of the unit, they are about the same regardless of efficiency level. Therefore, DOE decided to use preventative maintenance costs that remain constant as equipment efficiency is increased.

Table 6.2.12 Annualized Maintenance Costs by Equipment Class for Each Efficiency Level

Equipment Class	Annualized Maintenance Costs for LCC by Efficiency Level *$/yr*				
	Baseline (ASHRAE)	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	84	84	84	84	84
Air Cooled 65–240 kBtu	84	84	84	84	84
Air Cooled > 240 kBtu	102	102	102	102	102
Water Cooled <65 kBtu	84	84	84	84	84
Water Cooled 65–240 kBtu	84	84	84	84	84
Water Cooled > 240 kBtu	102	102	102	102	102
Water Cooled w/ FE <65 kBtu	84	84	84	84	84
Water Cooled w/ FE 65–240 kBtu	84	84	84	84	84
Water Cooled w/ FE > 240 kBtu	102	102	102	102	102
Glycol Cooled <65 kBtu	84	84	84	84	84
Glycol Cooled 65–240 kBtu	84	84	84	84	84
Glycol Cooled > 240 kBtu	102	102	102	102	102
Glycol Cooled w/ FE <65 kBtu	84	84	84	84	84
Glycol Cooled w/ FE 65–240 kBtu	84	84	84	84	84
Glycol Cooled w/ FE > 240 kBtu	102	102	102	102	102

6.2.3.5 Lifetime

DOE defines lifetime as the age at which CRAC equipment is retired from service. DOE based equipment lifetime on review of available online literature and studies and concluded that a typical lifetime of between 10 and 25 years with an average of 15 years is appropriate for most CRAC equipment. While references to service life were found in online CRAC equipment literature, most documents found appeared to reference ASHRAE generally, and cited equipment life estimates of 15 years,[7] 15-25 years,[8,9] or 10–25 years.[10] ASHRAE publishes service life estimates for a variety of equipment in the ASHRAE Handbook,[11] but appears to have little data specific to CRAC equipment. A 2005 ASHRAE study on equipment service life found a median age for 92 CRAC units still in operation at 12 years, with the oldest at 20 years, but did not have end of life information.[12] An Australian study estimated the life at 10 years.[13] Based on the range of service life information available, DOE established the 10–25 year range and 15-year average service life estimates for this analysis.

6.2.3.6 Discount Rate

The discount rate is the rate at which future expenditures are discounted to establish their present value. DOE derived the discount rates for the CRAC equipment analysis by estimating the cost of capital for companies that purchase CRAC equipment. The cost of capital is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the company of equity and debt financing.

DOE estimated the cost of equity financing by using the Capital Asset Pricing Model (CAPM).[14] The CAPM, among the most widely used models to estimate the cost of equity financing, assumes that the cost of equity is proportional to the amount of systematic risk associated with a company. The cost of equity financing tends to be high when a company faces a large degree of systematic risk and it tends to be low when the company faces a small degree of systematic risk.

DOE determined the cost of equity financing by using several variables, including the risk coefficient of a company, β (beta), the expected return on "risk free" assets (R_f), and the additional return expected on assets facing average market risk, also known as the equity risk premium or *ERP*. The risk coefficient of a company, β, indicates the degree of risk associated with a given firm relative to the level of risk (or price variability) in the overall stock market. Risk coefficients usually vary between 0.5 and 2.0. A company with a risk coefficient of 0.5 faces half the risk of other stocks in the market; a company with a risk coefficient of 2.0 faces twice the overall stock market risk.

Eq. 6.10 gives the cost of equity financing for a particular company:

$$k_e = R_f + (\beta \times ERP)$$

Eq. 6.10

Where:

k_e = the cost of equity for a company (%),
R_f = the expected return of the risk free asset (%),
β = the risk coefficient, and
ERP = the expected equity risk premium (%).

DOE defined the risk-free rate as the 40-year geometric average yield on long-term government bonds. The risk free rate was calculated using Federal Reserve data for the period 1971 to 2010,[15] with a resulting rate of 6.74 percent. DOE used a 3.23-percent estimate for the *ERP* based on data from Damodaran Online.[16]

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate.

$$k_d = R_f + R_a \, ,$$

Eq. 6.11

Where:

k_d = the cost of debt financing for each firm (%),
R_f = the expected return on risk-free assets (%), and
R_a = the risk adjustment factor to risk-free rate for each firm (%).

The risk adjustment factor depends on the variability of stock returns represented by standard deviations in stock prices and was taken from Damodaran Online individual company cost of capital worksheets.[17] The weighted-average cost of capital (WACC) of a company is the weighted-average cost of debt and equity financing:

$$k = k_e \times w_e + k_d \times w_d$$

Eq. 6.12

Where:

k = the (nominal) cost of capital (%),
k_e = the expected rate of return on equity (%),
k_d = the expected rate of return on debt (%),
w_e = the proportion of equity financing in total annual financing, and
w_d = the proportion of debt financing in total annual financing.

The cost of capital is a nominal rate, because it includes anticipated future inflation in the expected returns from stocks and bonds. The real discount rate or WACC deducts expected inflation (r) from the nominal rate. DOE calculated expected inflation (3.83 percent) over the 1971–2010 historical period used for the other data calculations.

To estimate the WACC of CRAC equipment purchasers, DOE used a sample of companies involved in each of the three building types being analyzed, drawn from a database of U.S. companies given on the Damodaran Online individual company worksheet cited earlier. The Damodaran database includes most of the publicly traded companies in the United States.

DOE divided the companies into categories according to their type of activity. DOE used financial information for all of the firms in the Damodaran database in the three classes of buildings likely to use CRAC equipment. Three occupant categories were also used in the analysis: private companies, state and local government (including K-12 schools, colleges, and universities), and Federal government.

Table 6.2.13 outlines the building type and ownership categories as well as the number of companies used for determining real discount rates.

Table 6.2.13 Derivation of Real Discount Rates by Business Type

Business Type Description	Private		Federal Government*		State and Local Government*		Wtd	No. Obs.*
	WACC	Percent of Stock	Federal Risk-Free Rate	Percent of Stock	Muni Bond Rate	Percent of Stock	Discount Rate	
Health Care	4.10%	100%	2.80%	0%	2.05%	0%	4.10%	5
Education	4.26%	25%	2.80%	0%	2.05%	75%	2.68%	20
Office	4.96%	83%	2.80%	5%	2.05%	12%	4.51%	913

Source: Pacific Northwest National Laboratory (PNNL) WACC calculations applied to firms sampled from the Damodaran Online website. Assumptions for weighting factors in offices are based on civilian employment in office and administrative occupations and reflect lack of reliable data sources on the distribution of computer rooms.
*No Damodaran observations available for governments.

Data in the Damodaran database was representative of the privately operated schools, but lacked data on cost of capital for public schools. Data from representative 10-year AA municipal bonds were used as a proxy for the Damodaran data for public schools. There are both Federal government agencies and state and local government agencies with computer rooms outfitted with CRAC equipment in the offices category. The Federal risk-free rate was used for the discount rate for Federal offices; the same average AA municipal bond rate was used for state offices as for public education.

6.2.3.7 Compliance Date of Standard

As discussed in section 6.1.2, DOE assumed that the final rule would be issued in 2013 and, therefore, that the new standards would take effect in 2017. For the LCC analysis, the year of equipment purchase is 2017. However, all dollar values are expressed in 2011$.

6.3 PAYBACK PERIOD INPUTS

6.3.1 Definition

PBP is the amount of time it takes the consumer to recover the higher purchase cost of more energy efficient equipment as a result of lower operating costs. Numerically, the PBP is the ratio of the increase in purchase cost to the decrease in annual operating expenditures. This type of calculation is known as a “simple” PBP because it does not take into account changes in operating cost over time or the time value of money, that is, the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \Delta IC / \Delta OC$$

Eq. 6.13

Where:

PBP = payback period in years,
ΔIC = difference in the total installed cost between the more efficient standard level and the baseline equipment, and
ΔOC = difference in annual operating costs.

PBPs are expressed in years. PBPs greater than the life of the product mean that the increased total installed cost of the more efficient equipment is not recovered in reduced operating costs over the life of the equipment. Negative paybacks were observed for certain equipment classes. Some of these negative paybacks occurred because the available data indicated that higher efficiency equipment had a lower initial cost than less efficient equipment just meeting the ASHRAE standard. DOE regards this as likely to be a data quality issue rather than reflective of real first cost savings due to higher standards. A smaller group of negative paybacks occurred because the increase in annualized repair and maintenance cost at higher efficiencies was greater than the energy cost savings, resulting in negative operating gains going from ASHRAE to the higher standard, and thus negative paybacks. Although technically possible, this outcome would also mean LCC losses. An efficiency level with LCC losses would not be chosen as an efficiency standard.

6.3.2 Inputs

The data inputs to PBP are the total installed cost of the equipment to the customer for each efficiency level and the annual (first year) operating costs for each efficiency level. The inputs to the total installed cost are the consumer's final equipment price and the installation cost. The inputs to the operating costs are the annual energy cost, the annual repair cost, and the annual maintenance cost. The PBP calculation uses the same inputs as the LCC analysis described in section 6.2, except that electricity price trends and discount rates are not required because the PBP is a "simple" (undiscounted) payback and the required electricity price is only for the year in which a new efficiency standard is to take effect—in this case, the year 2017. The electricity price used in the PBP calculation of electricity cost was the price projected for 2017, expressed in 2011$. Discount rates are not used in the PBP calculation.

6.4 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

The results of the LCC and PBP analysis are presented in this section. Mean values of LCC savings and PBP are presented along with a summary of the distribution of these values.

6.4.1 Life-Cycle Cost Results

Figure 6.4.1 shows the change in LCC over the ASHRAE baseline and the four higher efficiency levels for the Air Cooled <65 kBtu equipment class. The LCC values on this chart are mean values obtained from the LCC analysis. This curve is presented here as an example to illustrate the typical relationship between installation cost and LCC values over all the efficiency levels in an equipment class. The installed costs increase steadily from the baseline to the highest possible efficiency level and the life-cycle costs decrease from ASHRAE standard level (baseline) to the highest possible efficiency level (Level 4).

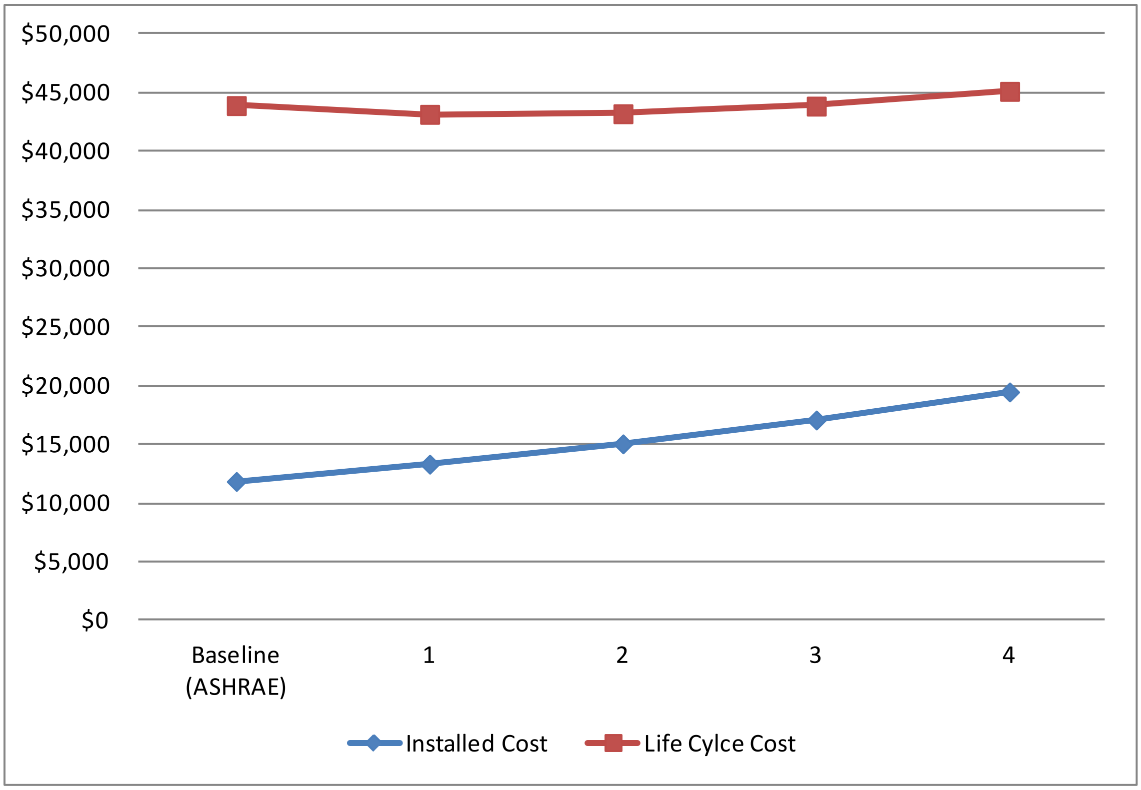

Figure 6.4.1 LCC and Installed Cost Variation over Efficiency Levels for Air Cooled <65 kBtu Equipment Class

As stated earlier, the LCC savings output obtained from the LCC analysis are in the form of distributions. LCC savings distributions are illustrated here with the example of Air Cooled <65 kBtu equipment class as shown in Figure 6.4.2. Similar plots of LCC savings distribution are presented in appendix 6B for all equipment classes analyzed. Table 6.4.1 presents the numerical values associated with the plot in Figure 6.4.2. Figure 6.4.2 illustrates the mean and median values on the plot with the help of red and blue markers, respectively. The elongated large rectangular box is used to represent the 25th and 75th percentile values. The lower edge of the elongated rectangle represents 25th percentile, which means that 25 percent of the customers will experience LCC savings of $49 or less if the standard were to be set at Level 1, minus $ 471 or below in LCC savings if the standards were set at Level 2, and so on. The median value of LCC savings is equal to the 50th percentile. The upper edge of the elongated rectangle represents the 75th percentile. The two ends of the vertical black line for each efficiency level represent the 5th percentile (lower end) and 95th percentile (upper end).

Mean and median LCC savings for all equipment classes analyzed are summarized in Table 6.4.2 and Table 6.4.3, respectively.

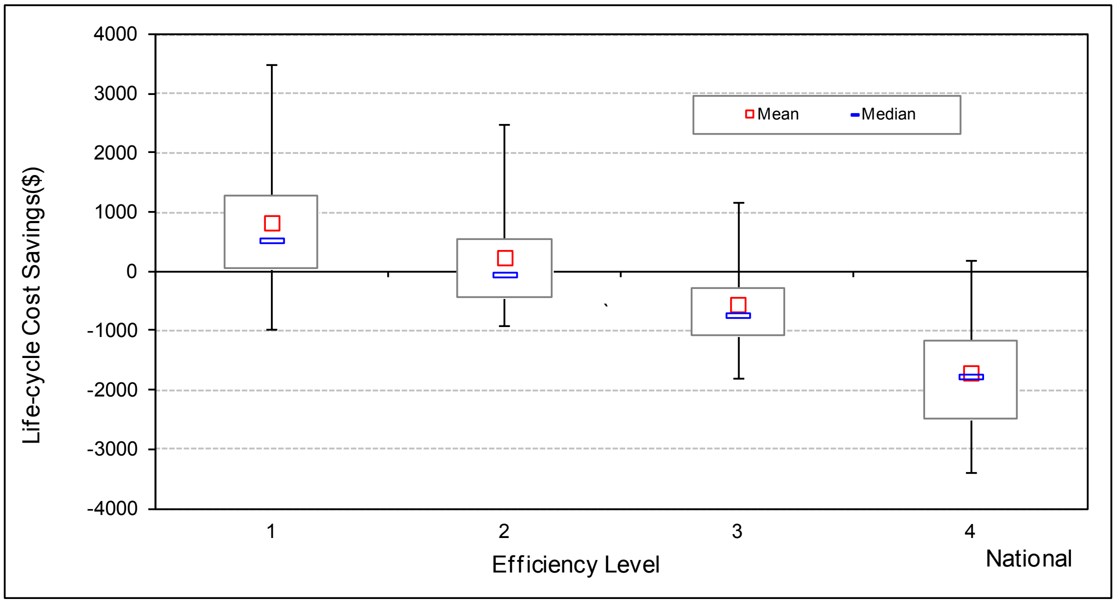

Figure 6.4.2 LCC Savings Distribution for All the Efficiency Levels for the Equipment Class Air Cooled <65 kBtu

Table 6.4.1 LCC Savings Distribution Results for Equipment Class Air Cooled <65 kBtu (2011$)

	Efficiency Level	1	2	3	4
LCC Savings* ***2011$***	**Mean**	809	212	(587)	(1,761)
	Median (50th Percentile)	513	(67)	(757)	(1,821)
	5th Percentile	(991)	(939)	(1,850)	(3,456)
	25th Percentile	49	(471)	(1,099)	(2,542)
	75th Percentile	1,255	522	(300)	(1,216)
	95th Percentile	3,493	2,443	1,118	137

* Values in parenthesis are negative numbers. These are efficiency levels for which the installed cost increases cannot be recovered through savings in operating costs.

Table 6.4.2 Mean LCC Savings for All Equipment Classes and Efficiency Levels

Product Class	Mean LCC Savings *2011$**			
	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	809	212	(587)	(1,761)
Air Cooled 65–240 kBtu	9,334	6,406	5,895	6,437
Air Cooled > 240 kBtu	27,198	19,713	19,071	22,152
Water Cooled <65 kBtu	5,455	7,389	8,003	10,213
Water Cooled 65–240 kBtu	(672)	(5,118)	(12,844)	(25,278)
Water Cooled > 240 kBtu	2,133	(5,292)	(18,696)	(40,964)
Water Cooled w/ FE <65 kBtu	4,759	6,459	6,960	8,832
Water Cooled w/ FE 65–240 kBtu	(4,439)	(10,105)	(19,437)	(33,672)
Water Cooled w/ FE > 240 kBtu	(6,568)	(16,717)	(33,664)	(59,831)
Glycol Cooled <65 kBtu	5,540	7,501	8,117	10,350
Glycol Cooled 65–240 kBtu	594	(3,901)	(11,921)	(25,047)
Glycol Cooled > 240 kBtu	4,429	(3,308)	(17,633)	(41,761)
Glycol Cooled w/ FE <65 kBtu	5,295	7,159	7,717	9,808
Glycol Cooled w/ FE 65–240 kBtu	(1,802)	(7,200)	(16,388)	(30,857)
Glycol Cooled w/ FE > 240 kBtu	(891)	(10,569)	(27,375)	(54,306)

*Values in parentheses are negative values.

Table 6.4.3 Median LCC Savings for All Equipment Classes and Efficiency Levels

Product Class	Median LCC Savings *2011$**			
	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	513	(67)	(757)	(1,821)
Air Cooled 65–240 kBtu	7,360	5,326	4,501	4,755
Air Cooled > 240 kBtu	21,711	16,697	14,952	17,644
Water Cooled <65 kBtu	5,185	8,045	7,505	9,659
Water Cooled 65–240 kBtu	(1,471)	(5,372)	(12,960)	(25,805)
Water Cooled > 240 kBtu	199	(6,824)	(18,417)	(42,143)
Water Cooled w/ FE <65 kBtu	4,545	7,488	6,592	8,459
Water Cooled w/ FE 65–240 kBtu	(5,277)	(8,904)	(20,107)	(35,165)
Water Cooled w/ FE > 240 kBtu	(8,478)	(15,610)	(34,827)	(61,505)
Glycol Cooled <65 kBtu	5,268	8,192	7,608	9,792
Glycol Cooled 65–240 kBtu	(324)	(4,589)	(11,596)	(25,577)
Glycol Cooled > 240 kBtu	2,404	(5,538)	(18,020)	(43,148)
Glycol Cooled w/ FE <65 kBtu	4,957	8,061	7,174	9,218
Glycol Cooled w/ FE 65–240 kBtu	(3,117)	(7,788)	(17,301)	(32,251)
Glycol Cooled w/ FE > 240 kBtu	(3,950)	(12,720)	(28,790)	(57,297)

*Values in parentheses are negative values.

6.4.2 Payback Period Results

Figure 6.4.3 presents the distribution of the PBP results for Efficiency Level 1 to Efficiency Level 4 of the equipment class Air Cooled <65 kBtu. The numerical values associated with this plot are presented in Table 6.4.4. The red marker represents the mean and the blue marker represents the median PBP for each efficiency level. The lower edge of the elongated rectangular box represents the 25th percentile, which means that 25 percent of the customers will experience a PBP of 6.7 years or lower if the energy conservation standard were to be set at the ASHRAE standard (Level 1), 7.9 years or lower if the energy conservation standard were to be set at Level 2, and so on. The upper edge of the rectangular box represents the 75th percentile. The two ends of the vertical line represent the 5th percentile (lower end) and 95th percentile (upper end). Table 6.4.5 and Table 6.4.6 summarize the mean and median PBPs, respectively, for all efficiency levels for all the analyzed equipment classes.

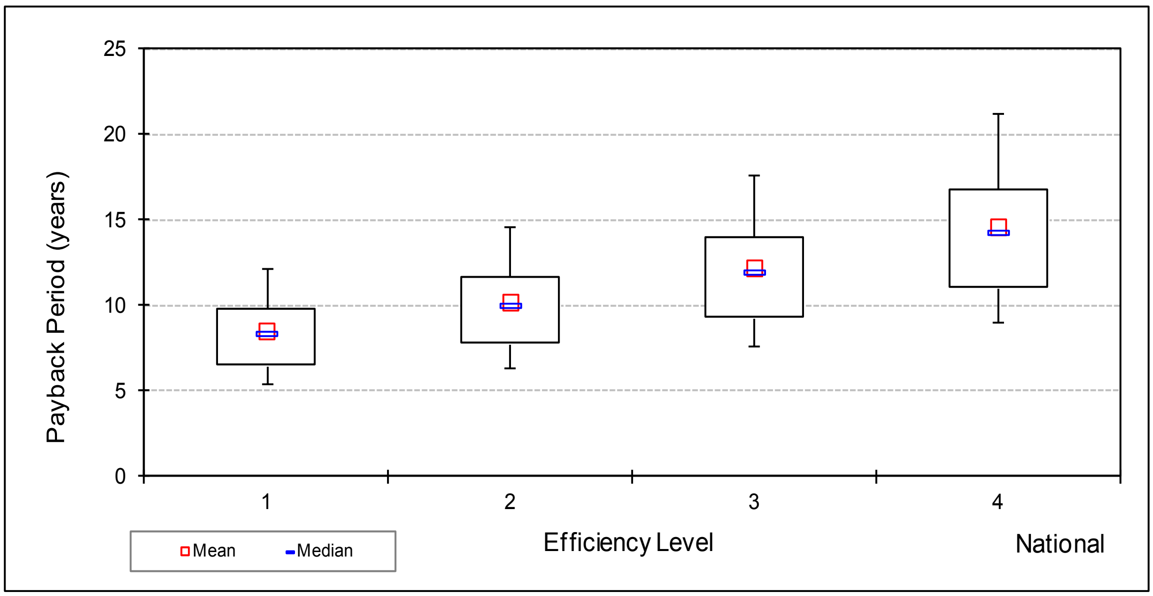

Figure 6.4.3 Mean Payback Period for All Efficiency Levels for the Equipment Class Air Cooled <65 kBtu

Table 6.4.4 Payback Period Distribution Results for Air Cooled <65 kBtu

	Efficiency Level	**Level 1**	**Level 2**	**Level 3**	**Level 4**
Payback period *years*	Mean	8.6	10.3	12.4	14.8
	Median (50th Percentile)	8.5	10.2	12.1	14.5
	5th Percentile	5.5	6.5	7.7	9.1
	25th Percentile	6.7	7.9	9.5	11.2
	75th Percentile	9.9	11.9	14.2	17.0
	95th Percentile	12.3	14.8	17.8	21.5

Table 6.4.5 Mean Payback Period for All Equipment Classes and Efficiency Levels

Product Class	Mean Payback Period* *years*			
	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	8.6	10.3	12.4	14.8
Air Cooled 65–240 kBtu	2.6	3.1	3.5	4.0
Air Cooled > 240 kBtu	1.4	1.7	1.9	2.2
Water Cooled <65 kBtu	(21.3)	(20.7)	(20.1)	(19.5)
Water Cooled 65–240 kBtu	16.4	25.3	45.6	105.8
Water Cooled > 240 kBtu	11.5	16.4	25.1	43.2
Water Cooled w/ FE <65 kBtu	(43.6)	(42.6)	(41.6)	(40.6)
Water Cooled w/ FE 65–240 kBtu	68.9	73.0	(153.4)	(84.2)
Water Cooled w/ FE > 240 kBtu	(565.1)	522.0	(37.8)	12.3
Glycol Cooled <65 kBtu	(20.3)	(19.8)	(19.3)	(18.8)
Glycol Cooled 65–240 kBtu	12.9	20.3	40.4	252.8
Glycol Cooled > 240 kBtu	9.7	14.4	24.0	(9.4)
Glycol Cooled w/ FE <65 kBtu	(28.9)	(28.3)	(27.6)	(26.9)
Glycol Cooled w/ FE 65–240 kBtu	30.0	56.4	198.0	(38.9)
Glycol Cooled w/ FE > 240 kBtu	21.0	32.6	(119.4)	6.4

* Values in parentheses are negative values. Either there are savings in installed costs or repair and maintenance cost increases outweigh energy savings as efficiency levels are compared with the baseline (ASHRAE) standard level.

Table 6.4.6 Median Payback Period for All Equipment Classes and Efficiency Levels

Product Class	Median Payback Period* *years*			
	Level 1	Level 2	Level 3	Level 4
Air Cooled <65 kBtu	8.5	10.2	12.1	14.5
Air Cooled 65–240 kBtu	2.6	3.0	3.5	4.0
Air Cooled > 240 kBtu	1.4	1.7	1.9	2.2
Water Cooled <65 kBtu	(21.5)	(20.9)	(20.3)	(19.7)
Water Cooled 65–240 kBtu	15.4	22.4	35.9	64.6
Water Cooled > 240 kBtu	11.1	15.4	22.4	36.0
Water Cooled w/ FE <65 kBtu	(40.3)	(39.3)	(38.3)	(37.3)
Water Cooled w/ FE 65–240 kBtu	41.5	34.1	(66.1)	(75.0)
Water Cooled w/ FE > 240 kBtu	30.5	40.7	43.1	(57.8)
Glycol Cooled <65 kBtu	(20.2)	(19.7)	(19.2)	(18.6)
Glycol Cooled 65–240 kBtu	11.9	17.8	29.1	50.4
Glycol Cooled > 240 kBtu	9.2	13.2	20.2	35.1
Glycol Cooled w/ FE <65 kBtu	(28.2)	(27.6)	(26.9)	(26.3)
Glycol Cooled w/ FE 65–240 kBtu	21.0	33.4	40.8	22.4
Glycol Cooled w/ FE > 240 kBtu	15.4	23.3	32.3	34.8

* Values in parentheses are negative values. Either there are savings in installed costs or repair and maintenance cost increases outweigh energy savings as efficiency levels are compared with the baseline (ASHRAE) standard level.

6.4.3 Rebuttable Presumption Payback Period

Sections 325(o)(2)(B)(iii) and 345(e)(1)(A) of EPCA (42 U.S.C. 6295(o)(2)(B)(iii) and 42 U.S.C. 6316(e)(1)(A)) establish a rebuttable presumption for CRAC equipment. The rebuttable presumption states that a standard is economically justified if the Secretary finds that "the additional cost to the consumer of purchasing a product complying with an energy conservation standard level will be less than three times the value of the energy savings during the first year that the consumer will receive as a result of the standard, as calculated under the applicable test procedure …" This rebuttable presumption test is an alternative path to establishing economic justification.

To evaluate the rebuttable presumption, DOE estimated the additional cost of purchasing more efficient, standards-compliant equipment, and compared this cost to the value of the energy saved during the first year of operation of the equipment. DOE interprets that the increased cost of purchasing standard-compliant equipment includes the cost of installing the equipment for use by the purchaser. DOE calculated the rebuttable presumption payback period (RPBP), or the ratio of the value of the increased installed price above the baseline efficiency level to the first year's energy cost savings. When RPBP is less than 3 years, the rebuttable presumption is satisfied; when RPBP is equal to or more than 3 years, the rebuttable presumption is not satisfied. Note that this PBP calculation does not include other components to the annual operating cost of the equipment (*i.e.*, maintenance costs and repair costs). The RPBPs calculated can thus be different from the PBPs calculated in section 6.4.2.

DOE calculated the RPBPs for the distribution of installed costs and energy prices discussed in sections 6.4.1 and 6.4.2, which are representative of the same three building types and all 50 states plus the District of Columbia. The RPBP was calculated for each higher efficiency level within each equipment class.

Table 6.4.7 shows the nationally averaged median RPBPs calculated for all equipment classes and efficiency levels.

Table 6.4.7 Rebuttable Presumption Payback Periods by Efficiency Level and Equipment Class

Product Class	Rebuttable Payback Period* *years*			
	Level 1	**Level 2**	**Level 3**	**Level 4**
Air Cooled <65 kBtu	7.6	8.9	10.4	12.2
Air Cooled 65–240 kBtu	2.4	2.7	3.1	3.5
Air Cooled > 240 kBtu	1.3	1.5	1.7	2.0
Water Cooled <65 kBtu	(22.5)	(21.8)	(21.2)	(20.5)
Water Cooled 65–240 kBtu	9.6	12.1	15.2	19.3
Water Cooled > 240 kBtu	7.7	9.7	12.3	15.6
Water Cooled w/ FE <65 kBtu	(46.5)	(45.2)	(43.8)	(42.5)
Water Cooled w/ FE 65–240 kBtu	19.7	24.9	31.4	39.8
Water Cooled w/ FE > 240 kBtu	15.8	20.0	25.3	32.2
Glycol Cooled <65 kBtu	(21.9)	(21.3)	(20.7)	(20.1)
Glycol Cooled 65–240 kBtu	7.5	9.6	12.2	15.5
Glycol Cooled > 240 kBtu	6.3	8.0	10.2	13.0
Glycol Cooled w/ FE <65 kBtu	(31.2)	(30.3)	(29.5)	(28.7)
Glycol Cooled w/ FE 65–240 kBtu	10.6	13.5	17.2	22.0
Glycol Cooled w/ FE > 240 kBtu	8.8	11.3	14.4	18.4

* Values in parentheses are negative values. Either there are savings in installed costs as efficiency levels are compared with the baseline (ASHRAE) standard level..

6.5 DETAILED RESULTS

DOE presents detailed results from the LCC analysis in appendix 6B. Plots similar to Figure 6.4.2 and Figure 6.4.3 are presented in the appendix for all equipment classes. In addition, summary tables with all the necessary data in one table for each equipment class are presented. Table 6.5.1 is a reproduction of the summary table for Air Cooled <65 kBtu equipment class. This table presents the mean values of installed costs, annual operating costs, LCC, LCC savings, and median PBP values for all the efficiency levels. It also presents the percentage of customers who experience net cost, no impact, and net benefit. The average LCC savings and the percentage of customers experiencing a net benefit or cost are based on a distribution of efficiency choices. In the base case, not all customers are assumed to be buying equipment at the baseline efficiency. Some are assumed to be buying at higher efficiency levels. The LCC savings is an average of the savings achieved by customers who, in the base case, were buying less efficient equipment than the efficiency level examined. Customers with no impact were assumed in the base case to be already buying more efficient equipment, so the efficiency level in question would not affect them.

Table 6.5.1 Summary of Results of LCC and PBP Analysis for Air Cooled <65 kBtu Equipment Class

Efficiency Level Number	**Life-Cycle Cost, All Customers**			**Life-Cycle Cost Savings**				**Payback Period, Median** *years*
					% of Customers that Experience			
	Installed Cost *2011$*	**Total Discounted Operating Cost** *2011$*	**LCC, All Customers** *2011$*	**Affected Customers' Average Savings** *2011$*	**Net Cost** *%*	**No Impact** *%*	**Net Benefit** *%*	
Baseline (ASHRAE)	11,982	32,039	44,021	—	—	—	—	—
1	13,471	29,822	43,294	809	3	89	8	8.5
2	15,222	28,140	43,362	212	17	68	14	10.2
3	17,281	26,756	44,037	(587)	65	23	12	12.1
4	19,700	25,623	45,323	(1,761)	90	5	6	14.5

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