Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment

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1.0 Introduction

The Energy Policy and Conservation Act (EPCA) (P.L. 94-163) as amended by the Energy Policy Act of 1992 (EPACT) (P.L. 102-486), establishes a role for the U.S. Department of Energy (DOE) to regulate efficiency levels of certain categories of commercial heating, cooling, and water-heating equipment. Initial minimum efficiency levels for products falling under these equipment categories were established in EPACT (Tables 1.1 and 1.2), based on the requirements contained in *ASHRAE/IES Standard 90.1-1989* (ASHRAE 1989). EPCA[a] requirements state that, if the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) amends efficiency levels prescribed in Standard 90.1-1989, then DOE must establish an amended uniform national manufacturing standard at the minimum level specified in amended Standard 90.1. However, DOE can establish higher efficiency levels if it can show through clear and convincing evidence that a higher efficiency level, that is technologically feasible and economically justified, would produce significant additional energy savings.

On October 29, 1999, ASHRAE approved the amended Standard 90.1,[b] which increases the minimum efficiency levels for some of the commercial heating, cooling, and water-heating equipment covered by EPCA 92. DOE has conducted a screening analysis to determine the energy-savings potential of the efficiency levels listed in Standard 90.1-1999. The analysis estimates the annual national energy consumption and the potential for energy savings that would result if the EPACT-covered products were required to meet these efficiency levels. The analysis also estimates additional energy-savings potential for the EPACT-covered products if they were to exceed the efficiency levels prescribed in Standard 90.1-1999. In addition, a simple life-cycle cost (LCC) analysis was performed for some alternative efficiency levels. This report describes the methodology, data assumptions, and results of the analysis.

Section 2.0 includes a detailed description of the engineering approach used in the analysis, including the data and cost versus efficiency curves. The methodology used for national energy-savings impacts, LCC, and national economic impacts is described in Section 3.0. The energy savings, LCC, and net present value (NPV) results for the various cooling, heating, and water-heating products are also presented in Section 3.0. Section 4.0 is a list of references cited in this report. The details of the building characteristics data used in the BLAST simulations (Building Loads and System Thermodynamics) and for the water-heating analysis for each of the representative building types is presented in Appendix A. Appendix B describes the methodology used to aggregate the engineering results for specific locations (cities) to a national level. Appendix C contains instructions on how to use the analysis spreadsheet

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(a) In this document, EPCA, as amended by EPACT, is often referred to as "EPCA 92."

(b) On June 24, 1999, ASHRAE's Board of Directors provisionally approved revisions to ASHRAE/IES Standard 90.1, subject to a formal appeal process. Four appeals were filed, and an Appeals Hearing was held on October 9, 1999. The Appeals Panel recommended that the appeals be dismissed, and the ASHRAE Board approved the Appeals Panel report in a special meeting on October 29, 1999, thus concluding ASHRAE's process for amending the standard. The commercial HVAC equipment efficiencies contained in ASHRAE/IESNA Standard 90.1-1999 will become effective on October 29, 2001, two years after final ASHRAE approval.

developed for the screening analysis. Appendix D lists one-page summary results for all the products (cooling, heating, and water heating) analyzed in the screening analysis.

Table 1.1. Commercial Equipment Product Categories: Air Conditioners (AC) and Heat Pumps (HP) (EPCA [as amended] Sections 342 (a) (1), (2), and (3))

Equipment Category	**Equipment Subcategory**	**EPCA Section**	**EPCA Date**	**Efficiency Levels**	
				EPCA 92	**90.1-1999**
Small Commercial Packaged Air-Conditioning and Heating Equipment	AC/HP <65 kBtu/h Air-Cooled 3-Phase, Central-Split System	Cooling Eff. 342(a)(1)(A) Heating Eff. 342(a)(1)(D)	1/1/94	SEER 10.0 HSPF 6.8	SEER 10.0 HSPF 6.8
	AC/HP <65 kBtu/h Air-Cooled 3-Phase, Central-Single Package	Cooling Eff. 342(a)(1)(B) Heating Eff. 342(a)(1)(E)	1/1/94	SEER 9.7 HSPF 6.6	SEER 9.7 HSPF 6.6
	AC/HP 65-135 kBtu/h Air-Cooled Central	Cooling Eff. 342(a)(1)(C) Heating Eff. 342(a)(1)(F)	1/1/94	EER 8.9 COP 3.0	EER 10.3 COP 3.2
	AC/HP <65 kBtu/h Water-Cooled Evap. Cooled Water-Source Central	Cooling Eff. 342(a)(1)(G) Heating Eff. Water-Source only 342(a)(1)(I)	1/1/94	EER 9.3 COP 3.8	EER 12.1 COP 4.2
	AC/HP 65-135 kBtu/h Water-Cooled Evap. Cooled Water-Source Central	Cooling Eff. 342(a)(1)(H) Heating Eff. Water-Source only 342(a)(1)(I)	1/1/94	EER 10.5 COP 3.8	EER 11.5 COP 4.2
Large Commercial Packaged Air-Conditioning and Heating Equipment	AC/HP 135-240 kBtu/h Air-Cooled Central	Cooling Eff. 342(a)(2)(A) Heating Eff. 342(a)(2)(B)	1/1/95	EER 8.5 COP 2.9	EER 9.7 COP 3.1
	AC/HP 135-240 kBtu/h Water-Cooled Evap. CooledCentral	Cooling Eff. 342(a)(2)(A) No Heating Eff. Requirement	1/1/95	EER 9.6	EER 11.0
Packaged Terminal Air Conditioners and Heat Pumps	PTAC/PTHP Air-Cooled	Cooling Eff. 342(a)(3)(A) Heating Eff. 342(a)(3)(B)	1/1/94	EER and COP vary by capacity	EER and COP vary by capacity (different formulas)

Table 1.2. Commercial Equipment Product Categories: Furnaces, Boilers, and Storage Water Heaters (EPCA [as amended] Sections 342 (a) (4), and (5))

Equipment Category	Equipment Subcategory	EPCA Section	EPCA Date	Efficiency Levels	
				EPCA 92	90.1-1999
Warm-Air Furnaces	>225 kBtu/h Gas-Fired Oil-Fired	Gas Fired Eff. 342(a)(4)(A) Oil Fired Eff. 342(a)(4)(A)	1/1/94	Thermal Efficiency 80% Gas 81% Oil	Thermal Efficiency 80% Gas 81% Oil
Package Boilers	>300 kBtu/h Gas-Fired Oil-Fired	Gas Fired Eff. 342(a)(4)(C) Oil Fired Eff. 342(a)(4)(D)	1/1/94	Combustion Efficiency 80% Gas 83% Oil	Combustion Efficiency 80% Gas 83% Oil
Storage Water Heaters	Electric	Standby Loss 342(a)(5)(A)	1/1/94	0.3 + 27/Va	$20 + 35\sqrt{V}$
	≤155 kBtu/h and V ≤ 140 gal	Thermal Eff. and Standby Loss 342(a)(5)(B)	1/1/94	Thermal Eff. 78% Standby Loss Varies by Volume	Thermal Eff. 80% Standby Loss Varies by Volume
	>155 kBtu/h and V≤140 gal	Thermal Eff. and Standby Loss 342(a)(5)(C)	1/1/94	Thermal Eff. 78% Standby Loss Varies by Volume	Thermal Eff. 80% Standby Loss Varies by Volume
Instantaneous Water Heaters	V<10 gal Instantaneous	Thermal Eff. 342(a)(5)(D)	1/1/94	Thermal Eff. 80%	Thermal Eff. 80%
	10 gal <V <140 gal Instantaneous	Thermal Eff. and Standby Loss 342(a)(5)(E)	1/1/94	Thermal Eff. 77% Standby Loss Varies by Volume	Thermal Eff. 80% Standby Loss Varies by Volume
Storage Tanks	V >140 gal Unfired	Heat Loss 342(a)(5)(F)	1/1/94	Heat Loss 6.5 $Btu/h{\cdot}ft^2$	Heat Loss 6.5 $Btu/h{\cdot}ft^2$
	Storage Water Heaters and Storage Tanks >140 gal	Prescriptive 342(a)(5)(G)	1/1/94	R-12.5, IID	R-12.5, IID

1.1 Scope of the Analysis

The screening analysis examined the efficiency levels specified in EPCA and Standard 90.1-1999 for the EPACT-covered equipment, as well as more efficient levels, including those associated with the most efficient products available in the market. For each level above the EPCA standard, the following were estimated:

1. the incremental national energy and carbon emission savings that would result from a standard set at that level

2. the NPV that would result from a standard set at that level, as compared with the corresponding Standard 90.1-1999 and EPCA standards.

Table 1.3. Characteristics of Certain Products Analyzed in Screening Analysis

Equipment Type	Size Category	Performance Characteristic Analyzed
3-Phase, Single-Package, Air-Source AC	<65 kBtu/h	
3-Phase, Split-System, Air-Source AC		
3-Phase, Single-Package, Air-Source HP		cooling performance only
3-Phase, Split-System, Air-Source HP		cooling performance only
Central, Air-Source AC	≥65 kBtu/h and <135 kBtu/h	
Central, Air-Source HP		cooling performance only
Central, Water-Source HP		cooling performance only
Central, Water-Cooled AC		
Central, Air-Source AC	≥135 kBtu/h and <240 kBtu/h	
Central, Air-Source HP		cooling performance only
Central, Water-Cooled AC		
Central, Water-Cooled AC	<65 kBtu/h	
Central, Water-Source HP	<17 kBtu/h	cooling performance only
Central, Water-Source HP	≥17 kBtu/h and <65 kBtu/h	cooling performance only
Packaged Terminal Air Conditioners (PTACs)		
Packaged Terminal Heat Pumps (PTHPs)		cooling performance only
Small Gas-Fired Steam Boilers	<2,500 kBtu/h	
Large Gas-Fired Steam Boilers	>2,500 kBtu/h	
Large Gas-Fired Hot Water Boilers	>2,500 kBtu/h	
Gas-Fired Warm-Air Furnaces	>225 kBtu/h	
Gas Storage Water Heaters	>155 kBtu/h	
Gas Storage Water Heaters	≤155 kBtu/h	
Electric Water Heaters	>12kW	
Gas-Fired Tankless Instantaneous Water Heaters		
Gas-Fired Instantaneous Water Heaters with Tanks		

Table 1.4. Characteristics of Certain Products Not Analyzed in Screening Analysis

Equipment Type	Size Category	Performance Characteristic Not Analyzed
3-Phase, Single-Package, Air-Source HP	<65 kBtu/h	heating performance
3-Phase, Split-System, Air-Source HP		heating performance
Central, Air-Source HP	≥135 kBtu/h and <240 kBtu/h	heating performance
Central, Air-Source HP	≥65 kBtu/h and <135 kBtu/h	heating performance
Central, Water-Source HP	<135 kBtu/h	heating performance
PTHP		heating performance
Water-Source HP	≥135 kBtu/h and <240 kBtu/h	
Evaporatively Cooled Products		
Oil-Fired Warm-Air Furnaces	>225 kBtu/h	
Oil-Fired Storage Water Heaters	≤155 kBtu/h	
Oil-Fired Storage Water Heaters	>155 kBtu/h	
Oil-Fired Instantaneous Water Heaters with Tanks		
Oil-Fired Small Boilers	<2,500 kBtu/h	
Oil-Fired Large Boilers	>2,500 kBtu/h	steam and hot water
Tankless Oil-Fired Instantaneous Water Heaters		

These products were excluded because of insufficient data describing baseline energy consumption and cost-efficiency relationships, a small market for the products or lack of product shipment data, or, for heating performance of air-source heat pumps, absence of a suitable methodology to discriminate their heating function from that of supplemental heat sources with which they are often used.

1.2 Methodology Overview

This section provides an overview of the methodology used for the screening analysis (with additional details provided in subsequent sections), which was divided into five steps:

1. Engineering Analysis
2. National Energy Impacts
3. National Economic Impacts
4. Life-Cycle Cost (LCC) Analysis
5. National Emissions Reductions

The energy end-uses for the various cooling, heating, and water-heating equipment categories at several different efficiency levels were estimated using a full-load equivalent operating hour (FLEOH) approach. The details of the engineering analysis are provided in Section 2.0.

The magnitude of heating, ventilating, and air-conditioning (HVAC) and service water-heating (SWH) loads imposed on equipment depends on the physical and operational characteristics of the building in which the equipment is used, as well as the prevailing climatic conditions. To capture this variation of equipment energy use, coil loads for 7 representative building types at 11 climate locations were estimated, based on a whole-building simulation. Details of this process are presented in Section 2.0. The mapping of the building loads to normalized equipment loads (for a particular equipment size) using a FLEOH approach is also addressed.

For each equipment category, the energy usage of a given piece of equipment was estimated based on a characteristic equipment size for each combination of representative building type and climate location. The unit energy use was estimated using FLEOH and adjusted for each nominal equipment efficiency level being considered.

The national energy impacts of higher efficiency equipment were estimated by 1) mapping climate locations onto regions and 2) estimating the fraction of each year's national equipment shipments (by product category) within market segments, as defined by a representative building type within a particular region of the United States. Because detailed statistical information related to where and in what types of buildings the equipment is currently being installed is generally unavailable, an allocation process was developed. The estimated allocation of national shipments to market segments was primarily based on information from the Commercial Building Energy Consumption Survey (CBECS) (EIA 1992, 1995) related to floor space and saturations of generic equipment types for each market segment. National energy consumption for each equipment category was then estimated at each efficiency level by multiplying the annual unit energy use in each market segment with the annual shipments expected for that market segment.

The LCC analysis was conducted at the market segment level with region-specific energy prices; and thus provides some insight on the distribution of LCC cost savings across the building population. National NPV was calculated as a summary metric of the total national economic impact due to any chosen level of efficiency standard. This metric combines the influence of the LCC savings per unit, as well as the projected volume of shipments in each equipment category. This process is explained in more detail in Section 3.0, as well as the national emissions reductions that can be achieved by adopting higher efficiency level.

2.0 Engineering Analysis

This section describes the engineering approach used in the screening analysis. A discussion on how the space-heating, space-cooling, and water-heating loads were generated is presented. The method for selecting representative building types and climate locations used for the analysis and the basis for their selection are then described, followed by the approach used to estimate the equipment loads and annual energy use. Finally, the cost data, including the first cost and equipment cost versus efficiency for each of the products analyzed and the sources of the information, are provided.

2.1 Engineering Approach

The annual load and energy use for the various EPACT-covered heating, cooling, and water-heating products at different efficiency levels were estimated for the analysis using a FLEOH approach. The FLEOH is effectively the number of hours that a system would have to run at full capacity to serve a total load equal to the annual load on the equipment. FLEOH is calculated as:

$$\text{FLEOH} = \frac{\text{Annual Load}}{\text{Equipment Capacity}} \tag{2.1}$$

FLEOH is strictly defined as being related to the equipment capacity, not the peak load on the system. Because FLEOH is used to generate annual heating and cooling loads irrespective of equipment size, an assumption is required on how the equipment is typically sized that must be used consistently. For this analysis, the assumption was that the equipment is sized based on the design-day peak equipment load with no explicit oversizing:

$$\text{Equipment Capacity} = \text{Design Day Peak Load} \tag{2.2}$$

Substituting Equation (2.1) into Equation (2.2) yields:

$$\text{FLEOH} = \frac{\text{Annual Load}}{\text{Design Day Peak Load}} \tag{2.3}$$

The FLEOH for a piece of equipment is a function of the relative annual load to the peak building load. In general, this ratio will vary depending on building construction, building internal loads, building schedules, and orientation and exposure of the zone that the equipment serves. It was assumed that for any given building type, the internal-load characteristics and building schedules are constant across the building.

The FLEOH represents a simplified approach for estimating energy use. The efficiency level analysis is based on the rated efficiency at the rated conditions [e.g., the energy efficiency ratio (EER) rating for commercial packaged cooling equipment] as a proxy for equipment efficiency. For example, improvements in rated EER can come from several design modifications, including more efficient compressor designs, better heat transfer characteristics of the coils, improved refrigerants, or reduced fan energy requirements. The EER may not reflect efficiency improvements from some design options or control strategies used to enhance the part-load or off-design performance, such as a multiple-compressor system designed to improve part-load performance.

The design changes that enhance full-load performance will generally improve part-load efficiency; thus, improvements in full-load efficiency ratings can be used in estimating a minimum improvement in average annual efficiency for a product.

Three general caveats should be noted with regard to the FLEOH approach. First, the approach does not directly address the off-design performance. Second, accuracy decreases when assessing equipment energy uses that do not scale with the load on the equipment; e.g., the supply fan energy use in packaged cooling equipment, or the standby loss inherent in a water heater or a boiler. Third, the approach does not address cycling losses in equipment.

For cooling equipment, the condenser performance (COP) generally increases at off-design performance. However, this fact is mitigated by the cycling losses that tend to occur in actual use and by the fact the fan energy use is relatively constant.

A review of package system annual average EER data from simulations of actual cooling systems by Barwig et al. (1996) showed no consistent pattern as to whether the annual efficiency of packaged air-conditioning equipment in a typical building application was over- or under-represented. Annual average EER variations of –14% to +12% of the nominal EER rating were seen across the building types and locations modeled.

For boilers and furnaces, the FLEOH approach may somewhat underestimate the annual energy used in the equipment. For furnaces, the effect is small because the losses during the off-cycle periods are small, and much of the heat remaining in the heat exchanger during the off-cycle will be picked up in the building air stream, at least during periods of occupancy.

For boilers, the total annual standby loss is largely a function of the period available for operation (hot standby period). Because this is an operation issue and is not specific to equipment design and climate location, the standby loss cannot be accurately captured in a simplified analysis. For this analysis, the boiler FLEOHs are adjusted by calculating a standby loss factor to account for the standby losses (as described in Appendix A).

The analysis of SWH equipment was similar to the boiler analysis. The total standby loss of energy for SWH equipment is a function of the standby loss rating for the equipment being examined, as well as the number of hours the system is on standby (generally 8760 hours minus actual firing hours). Unlike the boiler analysis, where the FLEOHs were adjusted to reflect standby losses, the standby losses for water heaters were explicitly specified.

2.2 Annual Building and Equipment Space-Heating and -Cooling Loads

The first step in the process to create the building-level weighted FLEOH was to use a generic three-story, 15-zone prototype building, with characteristics that represent a particular building type to estimate the coil loads. The generic building coil loads are estimated for each building type and at each climate location. In addition to the variation in building characteristics, the use of airside economizers and setback (setup) schedules can significantly affect the space loads. To account for these variations, four sets of the generic building coil loads were estimated: 1) with economizer and setbacks; 2) with economizer and without setbacks; 3) without economizer with setbacks; and 4) without economizers and setbacks. The generic coil loads for each simulation (308 total runs, corresponding to 7 building types, 11 climate locations, and 4 combinations) were scaled to represent an average building (see Appendix A for details of the building size and shape selections). The four sets of FLEOH for the cooling products and two sets of FLEOH for the heating products (economizer runs do not apply to heating products) are tabulated in Appendix A, as well as the weights associated with the fraction of the buildings having economizers and setbacks/setups. These weights were derived from the CBECS (EIA 1995a).

From the scaled results, FLEOH were generated for heating and cooling equipment for each representative building. Because multiple building zones exist in the scaled building, the FLEOHs from each zone are weighted by the design loads in the zone to determine an average weighted FLEOH for that building. The weights account for higher influence by zones having larger peak loads and a corresponding larger number of units serving the zone. This aggregation results in a single FLEOH for a particular building type and climate location. FLEOH are calculated for each class of equipment (heating and cooling) and for each representative building type and climate location simulated. The process for estimating the weighted FLEOH by building type and climate location is illustrated in Figure 2.1.

The annual load on HVAC or SWH equipment can be estimated by multiplying the FLEOH for that representative building type, equipment use (heating, cooling or water heating), and climate, by the output capacity (i.e., kBtu/h) of the equipment. For this analysis, the assumption was that the equipment is sized to meet the design-day peak load, consistent with the chosen sizing algorithm.

2.3 Translation of Annual Loads to Annual Energy Use

Equipment efficiency is used to translate annual equipment loads to energy use as shown in Equation (2.4). For simplicity, the equipment efficiency rating was used in the analysis seasonal energy efficiency ratio (SEER)/EER for cooling equipment, thermal efficiency for heating and water-heating equipment) because it is readily available for comparison across equipment categories; hence, for commercial cooling equipment:

$$\text{Annual Energy Use} = \frac{\text{FLEOH x Equipment Capacity}}{\text{Efficiency}} \tag{2.4}$$

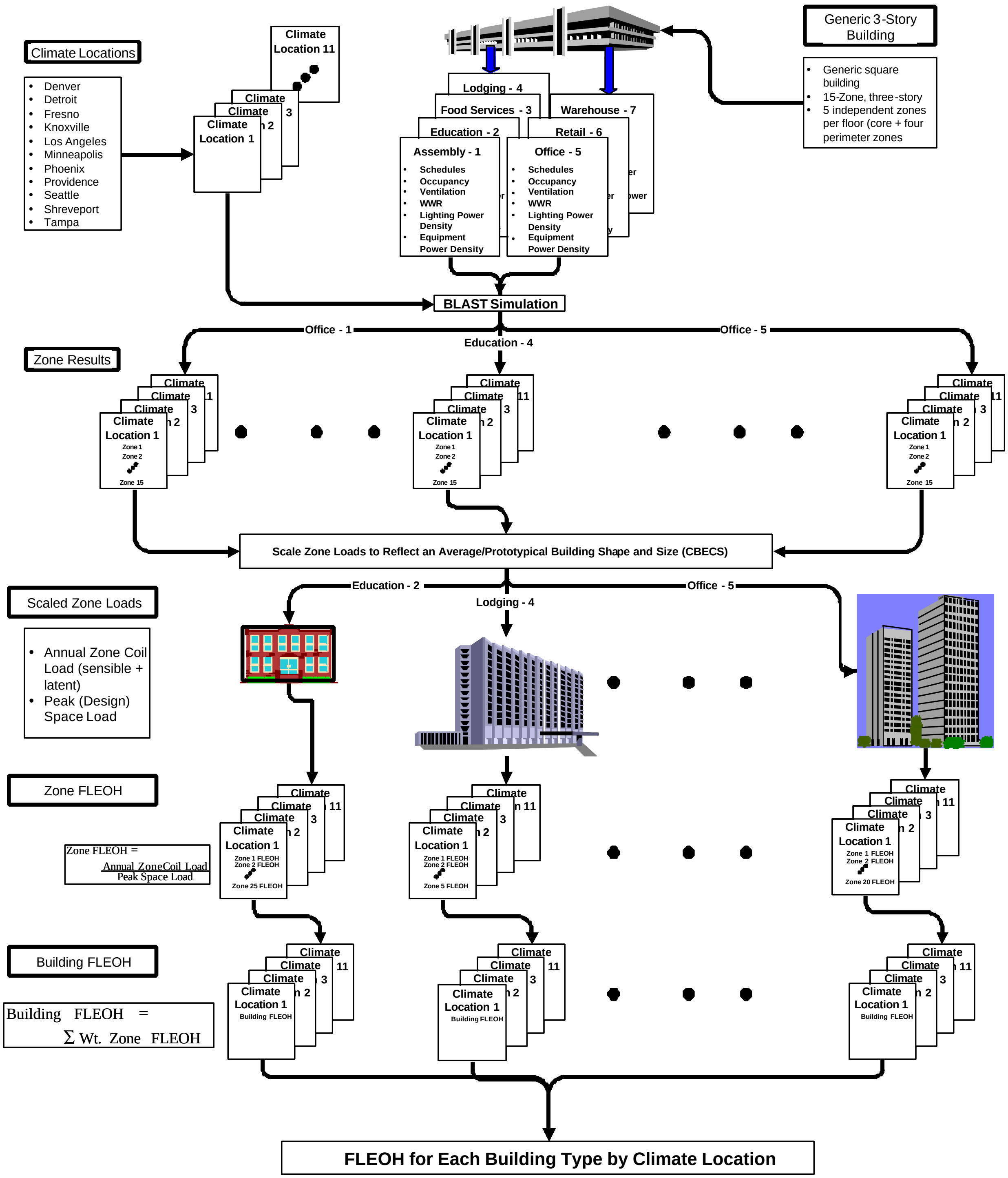

Figure 2.1. Proposed Process for Estimating the Weighted FLEOH by Building Type and Climate Location

For packaged boilers and water-heating equipment, the FLEOH were adjusted to account for jacket losses and standby losses, respectively. Therefore, the calculated annual energy use is the gross consumption, including any losses associated with the products.

2.4 Representative Building Types

Because the scope of the analysis was to screen the products showing significant additional energy savings over the Standard 90.1-1999 efficiency levels, the building types to be used in the analysis were selected to account for at least 75% of the total commercial building energy consumption.

Based on the annual energy use of principal building types from the CBECS (EIA 1995), a ranking of the building types was developed as shown in Table 2.1. Seven of the top eight building types (in terms of the magnitude of annual energy use) were used in a previous analysis of efficiency levels for selected commercial equipment (Barwig et al. 1996). The 7 building types also represent 78.4% of the cumulative total energy consumption of all commercial buildings. Because they account for more than three-quarters of the total commercial building energy consumption, the 7 building types were selected as the representative building types that were simulated using the BLAST software for the present analysis (BLAST 1991).

Although the health care building type accounts for a significant fraction (10%) of the total commercial building energy use, it was not chosen for this analysis because comprehensive and accurate building characteristics were not available. However, the outpatient care/doctor's office segment of the health care building type was accounted for by using the office building model to represent space-cooling, space-heating, and water-heating loads. This addition brought the percentage of the energy consumption captured in the screening analysis up to over 80%.

Table 2.1. Energy Consumption by Principal Building Activity

Principal Building Activity	Annual Energy Use (trillion Btu)	Percent of Total	Cumulative Percent
Office	**1,019**	**19.1**	**19.1**
Mercantile and Service	**973**	**18.3**	**37.4**
Education	**614**	**11.5**	**49.0**
Health Care	561	10.5	59.5
Lodging	**461**	**8.7**	**68.2**
Public Assembly	**449**	**8.4**	**76.6**
Food Service	**332**	**6.2**	**82.8**
Warehouse and Storage	**325**	**6.1**	**88.9**
Other	173	3.3	92.2
Food Sales	137	2.6	94.8
Public Order and Safety	124	2.3	97.1
Religious Worship	104	2.0	99.0
Vacant	51	1.0	100.0
Total	5,323	100.0	

Source: CBECS (EIA 1995).
The building activities in bold were used in the screening analysis.

2.5 Climate Locations for the BLAST Simulation

The national climate variations for the BLAST simulation were represented by the same 11 climate locations used in the Standard 90.1-1999 analysis, as well as the earlier equipment standards analysis (Barwig et al. 1996). The 11 climate locations are Providence, Rhode Island; Detroit, Michigan; Minneapolis, Minnesota; Knoxville, Tennessee; Shreveport, Louisiana; Tampa, Florida;[(a)] Denver, Colorado; Phoenix, Arizona; Seattle, Washington; Fresno, California; and Los Angeles, California.

Climate locations (see Figure 2.2) were selected to represent their influence on energy use in commercial buildings. The selection process used climate-based criteria to determine the most representative climates. Work performed in developing Standard 90.1-1989 identified 11 climate-based criteria that were determined to have significant influence on energy use in commercial buildings (ASHRAE 1989). Further details on the selection criteria can be found in Appendix D of Barwig et al. (1996).

2.6 Building Heating, Cooling, and Water-Heating Loads

For heating and cooling equipment, the annual energy use is a function of the heating or cooling loads the equipment must meet. For a single equipment application, these loads can vary by hour of the day,

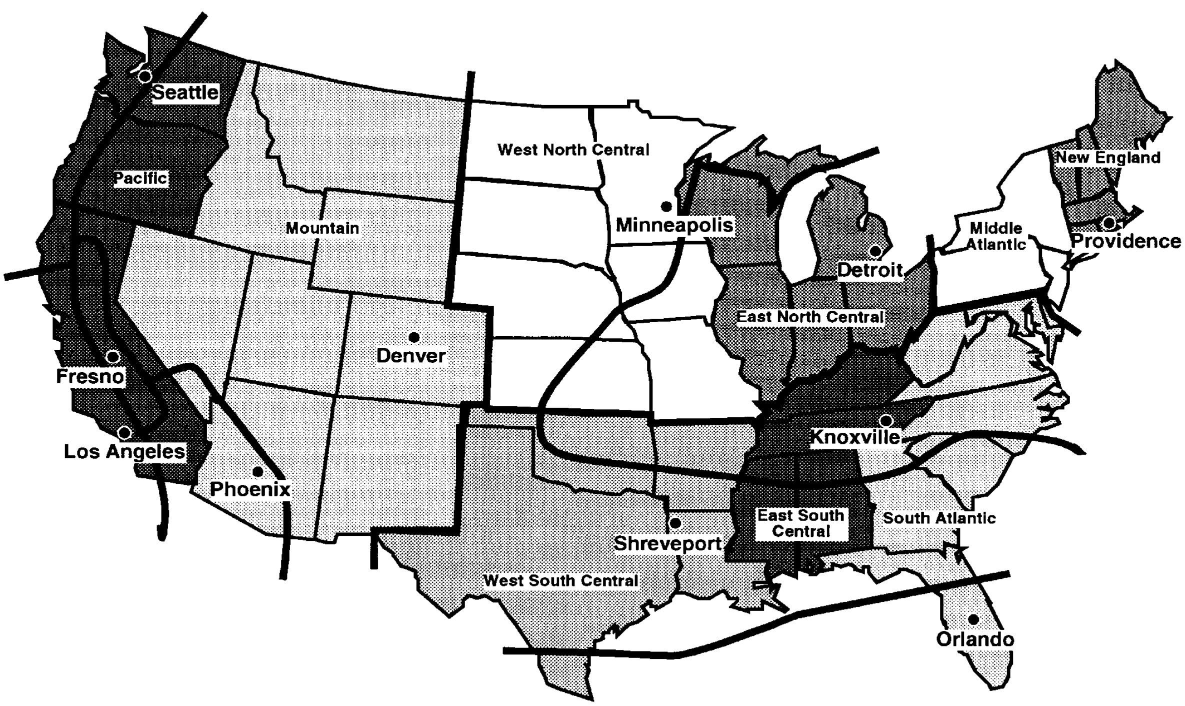

Figure 2.2. U.S. Map Showing 11 Climate Locations (cities) and Corresponding Climate Regions (dark boundaries), and 9 Census Divisions (shaded area)

(a) We replaced Orlando, Florida with Tampa, Florida because TMY2 weather data used for this analysis were not available for Orlando.

day of the week, and time of the year. The variations are driven by factors such as the type of building in which the equipment is installed; the activities and internal loads (lighting, occupant, and receptacle loads) in the building; and the buildings' internal and external environmental conditions, ventilation rates, and HVAC control strategy. Building type is a convenient descriptor for categorizing the nature of loads the HVAC equipment must meet. For water-heating equipment, annual energy consumption depends on the demand for hot water. This demand can be also be linked to building type by the activities that create the demand.

2.6.1 Building Space-Heating and Space-Cooling Loads

The BLAST detailed hourly simulation program was used to calculate the building (zone) loads (BLAST 1991). Modeling the commercial buildings using the BLAST simulation tool required several important input assumptions about the buildings' internal loads; key envelope characteristics; occupancy/activity characteristics; ventilation rates and strategies; equipment control schedules; and HVAC. Most of these inputs are based on the review of CBECS data (EIA 1992, 1995), and utility metering studies of real buildings. Appendix A provides a detailed discussion of building load data that were used in estimating the loads for the representative buildings types selected for the screening analysis.

This screening analysis used a generic three-story, 15-zone prototype building to estimate the coil loads for all building types. Because of the extreme diversity in building size, shape, and other characteristics, even within a particular building-type category, it is difficult to identify a single prototype building that adequately represents the stock of buildings being analyzed. Any specific building plan selected to represent an office building, for example, will have features that are not appropriate to apply to all office buildings; e.g., the interdependence of a building's aspect ratio (length versus width) and window orientation. Few buildings are exactly square or have the same amount of glass on each face. To address this issue and others, including the economy of BLAST input file development and maintenance, a single generic building prototype for all building types was used.

The generic prototype[a] was a square, 15-zone, three-story building with five independent controlled zones on each floor–a single "core" zone and four "perimeter" zones facing each of the four cardinal directions. For each building type actually modeled (e.g., office buildings), the internal loads, load and operation schedules, and building envelope were modified to represent the particular characteristics of the building type. The coil loads from BLAST are used as generic estimates of loads in the zones (core versus perimeter, ground versus roof) of the different building types.

The generic zone coil load estimates for various building types and climate locations were scaled to represent the coil loads for an average building of that type. The details of the scaling process are described in the Appendix B of Barwig et al. (1996). The representative building size and shape (or average building) for each building type were developed based on CBECS data (EIA 1992, 1995). The details are provided in Appendix A of this report.

(a) Justification for using a three-story, 15-zone building and scaling loads from the generic building to a specific building type is described in Barwig et al. (1996); additional details on the 15-zone building prototype are also described in Friedrich and Messinger (1995).

2.6.2 SWH Loads and Equipment Sizing

2.6.2.1 Loads

Average and peak hourly loads are based on data provided in Chapter 45, Table 7, of the ASHRAE *Handbook of HVAC Applications* (ASHRAE 1995). However, the loads are given in terms of service units, which were converted to loads per sq ft for this analysis. These conversions were developed for each building type (see Appendix A, Section A.11).

2.6.2.2 Sizing

Knowing the peak hourly load is not sufficient to properly size water-heating equipment. The volume-to-recovery ratio for most commercial storage water heaters is considerably less than one hour, and commercial buildings with built-up systems often provide storage much greater than one hour. Chapter 45 of ASHRAE (1995) provides curves that characterize the trade-off between water heater recovery capacity and usable storage capacity for each building type. For this analysis, the ASHRAE curves were normalized by expressing storage capacity in terms of storage *time* rather than storage *volume*. With the normalized curves, presented in Appendix A, Section A.11, the ratio of a given water heater's peak-load capacity to steady-state capacity in a given application can be obtained from the water heater's storage time:

$$\text{Storage Time (hours)} = \frac{\text{Storage Volume}}{\text{Recovery Capacity}} \tag{2.5}$$

where storage volume is the actual storage volume in gallons and recovery capacity is the rated recovery capacity in gallons per hour.

The analysis was further simplified by finding the slope and intercept for each sizing curve in the small region (Storage Time <1 hour) where all EPACT-covered equipment lies. The slopes and intercepts, and service unit conversions from Appendix A; the average and peak hourly loads from Chapter 45 of ASHRAE (1995), Table 7; and other essential parameters (sources noted) are summarized by building type in Table 2.2.

2.7 Mapping EPCA Equipment Categories to ASHRAE/Industry Equipment Categories

EPCA, Section 342, as modified by EPACT, includes minimum-efficiency standards for small and large commercial packaged air-conditioning and heating equipment, packaged terminal air conditioners and heat pumps, warm-air furnaces, packaged boilers, storage water heaters, instantaneous water heaters, and unfired hot water storage tanks. Each of these general classes of equipment is broken down by size and design into categories, for each of which a minimum efficiency standard is prescribed in EPCA. Most of these original categories are from Standard 90.1-1989.

Table 2.2. Building Service Water Heater Load Parameters by Building Type

	Assembly	Education	Restaurant	Lodging	Office	Retail	Warehouse	Source
Average Loads (gph/su)	0.042	0.050	0.100	0.583	0.042	0.042	0.042	ASHRAE 1995
Peak Load (gph/su)	0.4	0.8	1.5	5	0.4	0.4	0.4	ASHRAE 1995
Service Unit	Occupant	Student	Meal	Room	Occupant	Occupant	Occupant	ASHRAE 1995
Occupancy (people/1,000 ft^2)	16	10.7	11	3.3	3.3	2.2	0.3	Barwig et al. 1996
Service Unit (su/1,000 ft^2) Density	16	10	19	3.3	3.3	2.2	0.3	Appendix A, Section A.11
Average Load (agph/1,000 ft^2)	0.67	0.50	1.90	1.93	0.14	0.09	0.013	Calculated
Peak Load (xgph/1,000ft^2)	6.40	8.00	28.50	16.50	1.32	0.88	0.120	Calculated
Slope	-2.5	-6.7	-3.3	-2.7	-2.5	-2.5	-2.5	Appendix A, Section A.11
Intercept (xgph/agph)	9.6	18.2	15.0	8.3	9.6	9.6	9.6	Appendix A, Section A.11
Set Point (°F)	120	120	160	140	120	120	140	Barwig et al. 1996
Set Point (°F)	120	120	140	120	120	120	120	ASHRAE 1995
Operation (day/yr)	365.25	205	365.25	365.25	365.25	365.25	365.25	ASHRAE 1995

su = service units; gph = gal per hour; agph = average hourly load and peak hourly load in gal per hour; xgph = peak gal per hour.

To update the EPCA 92 minimum-efficiency requirements to be based on those in Standard 90.1-1999, and to obtain cost data for the appropriate equipment categories, the Standard 90.1-1999 equipment categories were mapped to those in EPCA. Generally, a one-to-one correspondence existed between the categories in Standard 90.1-1999 and EPCA. However, in the following instances, EPCA does not delineate categories of equipment in the same manner as Standard 90.1-1999:

1. where Standard 90.1-1999 splits the EPCA size category into multiple-size categories such as the EPCA category for water-source heat pumps <65 kBtu/h

2. where EPCA provides a single efficiency level for “water-cooled, evaporatively cooled, and water-source central air conditioners and central air-conditioning heat pumps;” in each of several size categories identified. Standard 90.1-1999 provides a separate standard for three product categories: water-cooled air conditioners, evaporatively cooled air conditioners, and water-source heat pumps.

3. where Standard 90.1-1999 has broken both the PTAC and PTHP categories into “new construction” and replacement market categories

4. where EPCA has two boiler categories–one for natural gas and one for oil–Standard 90.1-1999 has broken these two boiler categories into several separate categories based on size range (300 to <2,500 kBtu/h and >2,500 kBtu/h), fuel type (gas-fired, oil-fired, oil-fired [residual]), and either hot water or steam output.

2.8 Lifetime, Shipment, Baseline Cost, and Relative Cost Data

This section presents the engineering data that were gathered and used for the screening analysis.

2.8.1 Distribution Chain and Pricing for HVAC/SWH Equipment

To understand cost information on HVAC and SWH equipment, we had to know the distribution chain and the point in the chain from which a cost was collected. Original equipment manufacturers (OEMs) have design, development, materials, labor, and overhead costs to produce mechanical equipment. Based on these costs and other factors, they determine selling prices for various markets and circumstances. As a product moves through distributors, agents, and dealers/contractors, expenses and margins are added to the selling price. For any group of costs, we must know the source of each cost and its level within the distribution chain (see Figure 2.3).

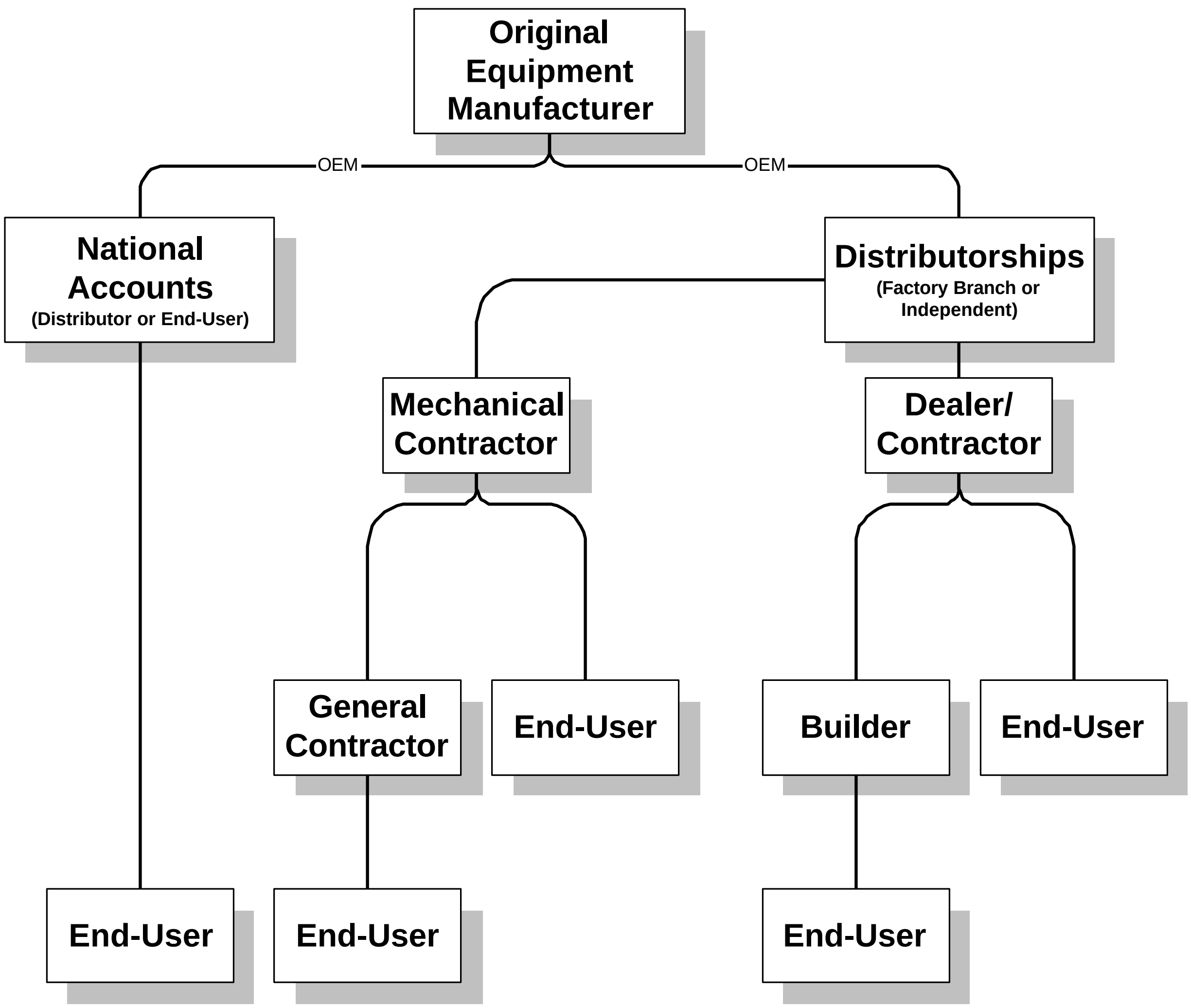

Figure 2.3. Equipment Distribution Chain

While the structure of the distribution chain may vary among manufacturers, several basic levels can be identified. OEMs traditionally market their products in two ways–through national accounts and distribution systems. National accounts may be end-users or function as secondary distribution systems. Distribution systems may be multiple combinations of factory-owned distribution branches, independently owned distributorships, and manufacturer's agents.

Factory-owned distribution branches and independently owned distributorships usually operate within designated or franchised territories. Regardless of whether the distributorship is factory- or independently owned, it represents the OEM in the area and is responsible for delivering the market share considered appropriate by the OEM.

Manufacturer's agents function similar to independent distributorships. They are the OEM's distribution representatives within a franchised sales territory responsible for delivering market share. Agents do not customarily stock products but rather arrange product shipments from the OEM.

National accounts are usually high-volume purchasers developed and serviced by the OEM at the national level. They tend to cut across sales territory lines and are usually excluded from franchised distribution agreements. Products are shipped directly from factories to clients at either individual job sites or warehousing facilities. Some national accounts are end-users while others resell the product for installation. Manufactured and modular home producers are traditional national account markets because the ultimate destination of the OEM's product may cross sales territory lines.

Distribution systems primarily serve two groups of contractors–heating and air-conditioning or plumbing dealers/contractors and mechanical contractors. The heating and air-conditioning or plumbing dealer/contractor traditionally purchases mechanical equipment from the distributorship and contracts with end-users to provide and install the equipment. The dealer/contractor is usually a local company that sells and services one or two equipment brands. In exchange for loyalty to a distributor's brand, the company may be given a somewhat exclusive right to market that brand in a given area. When quoting equipment and installation costs, the contract price is usually presented as one figure and does not separate equipment from other costs. Issues such as system design, installation, start-up, and warranty make the sale of "equipment only" impractical and unlikely.

Mechanical contractors generally bid to general contractors on construction projects designed by architects and engineers. The bid must be based on specified or listed equipment approved as equivalent for each job. The distributorship or manufacturer's agent furnishes quotes on the specified equipment (or approved alternatives) for each construction project to all mechanical contractors planning to bid on the project and for other equipment upon request. The mechanical contractor exhibits no brand loyalty and has no protected sales territory. Equipment sales to mechanical contractors are from the distributorship or manufacturer's agent and do not go through the dealer/contractor. The mechanical contractor's bid is incorporated into the general contractor's bid and increased by some percentage as a part of the general contractor's fee for managing the project. The cost of the equipment is not separated from other costs. For design-build and other negotiated work, the mechanical contractor may contract directly with the end-user. Even in these situations, the contract price seldom separates equipment from other costs.

2.8.2 Efficiency and Cost Data – Cooling Equipment

This section presents the lifetime, shipments, baseline cost, and relative cost for higher efficiency levels for the cooling equipment.

2.8.2.1 Service Life

Estimates of service life for equipment are based on data in ASHRAE (1995). A 15-year service life was used for all air-cooled products. A 19-year service life was used for all evaporatively cooled and water-cooled products.

2.8.2.2 Shipment Data and Characteristic Equipment Size

In 1994, during the development of Standard 90.1-1999, the Air-Conditioning and Refrigeration Institute (ARI) provided annual shipment data[(a)] on most of the cooling equipment categories covered in this analysis. In November 1999, ARI provided updated 1999 shipment estimates for most of the cooling product categories in the screening analysis.[(b)] In addition, ARI updated a list of characteristic equipment sizes for each product category to best reflect current industry standards. Table 2.3 shows the 1999 shipment data provided by ARI[(b)] and representative equipment sizes used in the screening analysis.

In the 1999 data, ARI recommended that the PTAC and PTHP equipment categories be broken into four capacity ranges. It is necessary to examine multiple capacities for PTAC and PTHP equipment because both the existing EPCA and Standard 90.1-1999 efficiency requirements are stated as a function of cooling capacity.

Separate shipment estimates for evaporatively cooled air-conditioning equipment were not available because ARI statistics combine the shipments of evaporatively cooled products with water-cooled air conditioners. ARI believes that over 90% of these combined evaporative and water-cooled shipments are water-cooled products.

Shipment estimates for the following five additional categories of equipment were not provided:

1. 3-phase, single-package air conditioners <65 kBtu/h
2. 3-phase, split-system air conditioners <65 kBtu/h
3. 3-phase, single-package heat pumps <65 kBtu/h

(a) ARI provided 1994 shipment data to the ASHRAE Mechanical Subcommittee during Standard 90.1-1999 development.
(b) 1999 commercial cooling equipment shipment data and supporting letter provided by ARI to DOE, December 1, 1999.

4. 3-phase, split-system heat pumps <65 kBtu/h

5. water-source heat pumps >135 kBtu/h cooling capacity.

Table 2.3. Cooling Equipment Annual Shipment Data Used in the Screening Analysis

Category Description	Characteristic Capacity (kBtu/h)	Estimated Shipments	Source
3-Phase, Single-Package, Air-Source AC, <65 kBtu/h	60	213,728	ADL, PNNL
3-Phase, Single-Package, Air-Source HP, <65 kBtu/h	60	27,773	ADL, PNNL
3-Phase, Split-system, Air-Source AC, <65 kBtu/h	60	91,598	ADL, PNNL
3-Phase, Split-system, Air-Source HP, <65 kBtu/h	60	11,903	ADL, PNNL
Central, Air-Source AC, ≥65 and <135 kBtu/h	90	165,000	ARI 1999
Central, Air-Source HP, ≥65 and <135 kBtu/h	90	17,000	ARI 1999
Central, Water-Cooled AC, <65 kBtu/h	60	700	ARI 1999
Central, Evaporatively Cooled AC, <65 kBtu/h	36	N/A	ARI 1999
Central, Water-Source HP, <17 kBtu/h	12 (or pick a reasonable size)	41,000	ARI 1999
Central, Water-Source HP, >17 and <65 kBtu/h	36	86,000	ARI 1999
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	90	800	ARI 1999
Central, Evaporatively Cooled AC, ≥65 and <135 kBtu/h	90	Included with water-cooled for same size category	
Central, Water-Source HP, ≥65 and <135 kBtu/h	90	5,000	ARI 1999
Central, Air-Source AC, ≥135 and <240 kBtu/h	180	65,000	ARI 1999
Central, Air-Source HP, ≥135 and <240 kBtu/h	180	2,900	ARI 1999
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	180	600	ARI 1999
Central, Evaporatively Cooled AC, ≥135 and <240 kBtu/h	180	Included with water-cooled for same size category	
Central, Water-Source HP, ≥135 and <240 kBtu/h	180	Not Available	
Package Terminal AC, <7 kBtu/h	7	18,000	ARI 1999
Package Terminal AC, 7-10 kBtu/h	9	93,000	ARI 1999
Package Terminal AC, 10-13 kBtu/h	12	97,000	ARI 1999
Package Terminal AC, >13 kBtu/h	14	44,000	ARI 1999
Package Terminal HP, <7 kBtu/h	7	16,000	ARI 1999
Package Terminal HP, 7-10 kBtu/h	9	89,000	ARI 1999
Package Terminal HP, 10-13 kBtu/h	12	74,000	ARI 1999
Package Terminal HP, >13 kBtu/h	14	37,000	ARI 1999

2.8.2.3 3-Phase, <65 kBtu/h Unitary Cooling Equipment Shipment Estimates

According to the Copeland Corporation, unitary residential shipments (condensing units) were roughly 5,639,000.[a] Shipments of commercial 3-phase equipment were 625,000 units, for a total of 6,264,000 units shipped (ARI 1998b). ARI reports shipments by equipment capacity so that out of the total ARI shipment, 280,134 units were listed as ≥65 kBtu/h in capacity. It is assumed that virtually all of the units >65 kBtu/h use 3-phase motors. If we use the Copeland estimate of 625,000 3-phase condensing units and subtract the 280,134 unitary equipment shipments >65 kBtu/h capacity, we arrive at 344,860 3-phase units <65 kBtu/h capacity.

(a) Data provided by Mark Kendal of Arthur D. Little (ADL) in e-mail communication in December 1999. Original data published in *Air Conditioning, Heating and Refrigeration News*, December 14, 1998.

It was necessary to develop the shipments of single package versus split systems for both air conditioner and heat pump units. ADL suggests that in 1994, single-package equipment made up approximately 14% of all 3-phase and single-phase unitary shipments <65 kBtu/h. However, information from commercial contractors suggests that a much larger fraction (probably the majority) of the commercial systems in this size range is single-package rooftops as opposed to split systems. For this analysis, it was assumed that 70% of the 3-phase systems in this size range are single-package equipment.

2.8.2.4 Baseline Cost Data

Baseline costs for cooling equipment were developed based on data collected through mechanical contractors and equipment distributors in 1999.[a] Collected cost data represented the minimum efficiency products available from a given distributor. The number of data points collected varied from 1 to 7 for each product analyzed. When more than three data points were collected, the high- and low-cost data points were removed and the remaining cost data were averaged to reduce the effects of high- and low-cost outliers. In addition, the rated efficiency (EER or SEER) data were collected for as many of the equipment categories as available.

In all cases, the average EER was higher than the minimum specified by EPCA 92. Thus, the average of the cost and efficiency data are referred to as the market baseline cost and efficiency. When possible, the available relative cost versus efficiency data for each product were used to back out the cost for an EPCA 92 baseline product from the market baseline cost and efficiency data. This was done using relative cost versus efficiency curves discussed in the following section.

Table 2.4 shows the number of data points collected; the high, low, and average cost without high- and low-cost outliers; and the corresponding average efficiency figure for each product. The relative cost for the higher efficiency level (EER), as compared with the EPCA 92 baseline, is also shown, as well as the final estimate for the baseline EPCA 92 contractor cost.

2.8.2.5 Relative Cost for Higher Efficiency Levels

In 1994, ARI provided the ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1) with relative cost versus efficiency curves for product efficiencies above the EPCA 92 baseline. These curves were based on data collected by member industries and represented costs for which 90% of the industries surveyed believed they could manufacture the equipment (relative to EPCA 92 baseline efficiency level). The data were collected in this manner to preserve sensitive cost information among manufacturers.

Updated relative cost curves based on the average relative cost figures provided by manufacturers, were unavailable for the present analysis. Thus, the 1994 relative cost curves, in conjunction with the baseline costs discussed previously, were used as the basis for developing costs for higher efficiency equipment, except for the 3-phase, <65 kBtu/h single-package and split-unitary systems.

(a) Baseline commercial equipment cost data collected by a) DuPont Dobbs Engineers, LLC, in 1999 under contract to DOE and b) Pacific Northwest National Laboratory staff.

Table 2.4. Cooling Equipment Baseline Cost Data

Product	1994 Estimated Cost for ASHRAE Analysis ($)	1999 Cost Data							
		No. of Data Points	High Cost ($)	Low Cost ($)	Average Cost ($)[a]	Average EER[a]	Relative Cost[b]	Relative Cost Curve	EPCA Baseline Contractor Cost ($)
3-Phase, Single-Package, Air-Source AC, <65 kBtu/h[c]	N/A	7	3,760	1,770	2,234	10.04	1.05	ARI Data for CAC Rule	2,128
3-Phase, Single-Package, Air-Source HP, <65 kBtu/h[c]	N/A	6	4,640	2,100	2,613	10.07	1.04	ARI Data for CAC Rule	2,513
3-Phase, Split-system, Air-Source AC, <65 kBtu/h[c]	N/A	4	2,800	1,750	2,200	10.15	1.015	ARI Data for CAC Rule	2,167
3-Phase, Split-system, Air-Source HP, <65 kBtu/h[c]	N/A	5	3,280	2,080	2,395	11.20	1.128	ARI Data for CAC Rule	2,123
Central, Air-Source AC, ≥65 and <135 kBtu/h	3,452	7	7,196	2,587	3,613	9.70	1.131	UAC1	3,194
Central, Air-Source HP, ≥65 and <135 kBtu/h	3,636	6	8,560	3,200	4,115	8.93	1.006	UHP1	4,090
Central, Water-Cooled AC, <65 kBtu/h	2,550	4	4,000	2,650	3,536	12.00	1.305	UAC5	2,709
Central, Water-Source HP, <17 kBtu/h	N/A	5	835	632	700	11.03	1.141	UHP3	613
Central, Water-Source HP, ≥17 and <65 kBtu/h	1,655	5	1,200	960	1,127	12.20	1.31	UHP3	860
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	5,468	5	6,800	3,000	4,141	13.07	1.424	UAC6	2,908
Central, Evaporatively[c] Cooled AC, ≥65 and <135 kBtu/h	N/A	1	3,475	3,475	3,475	13.70	1.558		2,230
Central, Water-Source HP, ≥65 and <135 kBtu/h	N/A	6	4,490	3,200	3,557	12.07	1.285	UHP3	2,768
Central, Air-Source AC, ≥135 and <240 kBtu/h	5,967	6	9,560	5,163	7,273	9.20	1.07	UHP1	6,797
Central, Air-Source HP, ≥135 and <240 kBtu/h	7,911	5	11,520	6,644	9,526	9.48	1.14	UHP21	8,356
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	11,079	5	9,600	5,800	7,830	12.33	1.15	UAC4	6,808
Central, Evaporatively[d] Cooled AC, ≥135 and <240 kBtu/h	11,079	2	6,400	5,800	NA	NA	NA	UAC4	NA
Central, Water-Source[e] HP, ≥135 and <240 kBtu/h	N/A	7	9,078	5,800	7,372	NA	NA	NA	NA
Package Terminal AC, <7 kBtu/h	N/A	5	748	640	710	11.45	1.214	NA	585
Package Terminal AC, 7-10 kBtu/h	808	6	774	660	726	10.62	1.134	pt1	640
Package Terminal AC, 10-13 kBtu/h	834	6	800	680	753	10.62	1.334	pt2	564
Package Terminal AC, >13 kBtu/h	891	6	840	720	802	9.36	1.119	pt3	716
Package Terminal HP, <7 kBtu/h	N/A	5	832	710	781	11.53	1.204	NA	649
Package Terminal HP, 7-10 kBtu/h	905	6	1,054	730	817	10.84	1.157	pt4	706
Package Terminal HP, 10-13 kBtu/h	936	6	1,076	760	842	10.36	1.344	pt5	626
Package Terminal HP, >13 kBtu/h	1,009	6	1,160	780	886	9.20	1.159	pt6	764

(a) After removing high- and low-cost outliers.
(b) Relative cost estimate of market baseline above EPCA baseline.
(c) SEER Rating
(d) Evaporatively cooled products were not analyzed independently from water-cooled products.
(e) Water-source HP >135 kBtu/h were not analyzed.

For this equipment, relative cost curves were based on ARI data for single-phase, single-package, and split-system air conditioners and heat pumps.

For PTHP and PTAC products, the 1994 ARI relative cost versus efficiency curves were for three equipment capacities–9, 12, and 14 kBtu/h. Relative costs for efficiency levels for the <7 kBtu/h categories were determined from an average relative-cost increase for the other three size categories for the same relative increase in efficiency.

2.8.2.6 For central water-source heat pumps ≥65 kBtu/h and <135 kBtu/h, the relative cost versus efficiency data for the <65 kBtu/h water-source heat pump was used.

2.8.2.7 Product Efficiencies Analyzed

The range of efficiencies available on the market were determined by reviewing several data sources, including the California Energy Commission Cooling Equipment Database (CEC 1999) and the ARI unitary and applied equipment databases (ARI 1998a). From this list of available products, a highest efficiency level was chosen to represent the highest efficiency products available on the market. The highest efficiency level was not always the highest single point available on the market because, in some cases, efficiency level may be available only for a single capacity in an otherwise wide-capacity range. More often, the high-efficiency product analyzed represented the upper 5% of efficiencies available for that product category and size range.

The analysis also required several intermediate efficiency levels between the EPCA 92 baseline and the highest efficiency level analyzed level. No single method was used to choose these data points for all cooling products. However, intermediate efficiency levels were based on several sources, including

- Standard 90.1-1999 Tier 2 efficiency levels
- recommended 2005 efficiency levels provided as comment to Standard 90.1-1999 by the ASHRAE 90.1-1999 upgrade committee
- the end points of the ARI relative cost curves, which should represent high-efficiency levels that could be met by 90% of equipment manufacturers.

In other instances, points were chosen only to provide a range of possible efficiency levels for the analysis based on the available data (e.g., single package and split systems <65 kBtu/h capacity). For some products, the endpoints of the ARI relative cost curves or the recommended Tier 2 efficiency levels exceeded the efficiencies available on the market, and these points became new highest-efficiency levels for the screening analysis. For the PTHP and PTAC categories, Standard 90.1-1999 provides a required efficiency for new construction and a lower required efficiency requirement for replacement market. A maximum of six efficiency levels were analyzed for any given product.

Costs for each of the chosen efficiency levels were generated using the EPCA baseline cost estimates and the relative cost versus efficiency curves. Table 2.5 shows the estimated contractor cost for each efficiency level used in the cooling equipment analysis.

Table 2.5. 1999 Contractor Cost Data for Cooling Products by Efficiency Level

		Level 1 (EPCA 92)		Level 2		Level 3		Level 4		Level 5		Level 6	
Product Description	**Capacity Analyzed (kBtu/h)**	**EER**	**Cost ($)**	**EER**	**Cost ($)**	**EER**	**Cost ($)**	**EER**	**Cost ($)**	**EER**	**Cost ($)**	**EER**	**Cost ($)**
3-Phase, Single-Package, Air-Source AC, <65 kBtu/h(a)	60	9.7	2,128	9.7	2,128	11.0	2,532	12.0	2,766	13.0	3,468	15.0	4,745
3-Phase, Single-Package, Air-Source HP, <65 kBtu/h(a)	60	9.7	2,513	9.7	2,513	11.0	2,865	12.0	3,216	13.0	4,021	15.0	5,353
3-Phase, Split-system, Air-Source AC, <65 kBtu/h(a)	60	10.0	2,167	10.0	2,167	11.0	2,514	12.0	2,947	13.0	3,533	15.0	5,201
3-Phase, Split-system, Air-Source HP, <65 kBtu/h(a)	60	10.0	2,123	10.0	2,123	11.0	2,335	12.0	2,632	13.0	3,057	15.0	4,437
Central, Air-Source AC, ≥65 and <135 kBtu/h	90	8.9	3,194	10.3	3,932	10.5	4,101	10.8	4,392	11.0	4,648	12.5	8,823
Central, Air-Source HP, ≥65 and <135 kBtu/h	90	8.9	4,090	10.1	4,957	10.5	5,485	10.6	5,636	11.0	6,524	11.7	9,219
Central, Water-Cooled AC, <65 kBtu/h	60	9.3	2,709	12.1	3,573	12.5	3,752	13.1	4,080	14.0	4,798	12.5	3,752
Central, Water-Source HP, <17 kBtu/h	12	9.3	614	11.2	711	12.5	843	13.1	946	14.0	1,165	15.8	NA
Central, Water-Source HP, ≥17 and <65 kBtu/h	36	9.3	861	12.0	1,094	12.5	1,182	13.1	1,327	14.0	1,634	15.2	NA
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	90	10.5	2,908	11.5	3,347	12.0	3,562	12.4	3,760	14.0	4,714	NA	NA
Central, Water-Source HP, ≥65 and <135 kBtu/h	90	10.5	2,768	12.0	3,239	12.5	3,502	13.0	3,848	14.0	4,839	NA	NA
Central, Air-Source AC, ≥135 and <240 kBtu/h	180	8.5	6,797	9.7	7,613	10.2	7,885	10.4	8,089	10.8	NA	11.5	NA
Central, Air-Source HP, ≥135 and <240 kBtu/h	180	8.5	8,356	9.3	9,259	9.8	9,919	10.4	10,713	10.8	NA	10.5	NA
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	180	9.6	6,808	11.0	7,830	11.1	7,830	11.2	7,945	11.3	7,993	11.5	8,081
Package Terminal AC, <7 kBtu/h	6	8.88	585	9.41	597	11.01	686	11.24	713	0.00	776	11.60	NA
Package Terminal AC, 7-10 kBtu/h	8.5	8.56	640	8.98	656	10.58	725	10.83	741	NA	NA	11.50	831
Package Terminal AC, 10-13 kBtu/h	11.5	8.08	564	8.34	582	9.94	703	10.20	725	10.50	753	10.70	NA
Package Terminal AC, >13 kBtu/h	14	7.76	716.	7.92	721	9.52	819	9.79	871	10.00	967	10.00	967
Package Terminal HP, <7 kBtu/h	6	8.88	649	9.31	658	10.81	745	11.04	776	0.00	865	11.60	NA
Package Terminal HP, 7-10 kBtu/h	8.5	8.56	706	8.88	727	10.38	791	10.63	802	11.40	882	11.50	NA
Package Terminal HP, 10-13 kBtu/h	11.5	8.08	626	8.24	631	9.74	719	10.00	762	10.50	877	10.70	NA
Package Terminal HP, >13 kBtu/h	14	7.76	764	7.82	766	9.32	899	9.59	943	NA	NA	10.00	1,032
(a) SEER rating.													

2.8.3 Efficiency and Cost Data – Packaged Boilers

This section presents the lifetime, shipments, baseline cost, and relative cost for higher efficiency data for packaged boilers based on 1999 estimates.

2.8.3.1 Service Life

Estimates of service life for equipment are based on data in ASHRAE (1995). A 30-year service life was used for all boilers.

2.8.3.2 Shipment Data and Characteristic Equipment Size

Boilers represent a large and diverse category of heating equipment, both in terms of the range of sizes available, fuel types used, output (steam or hot water), or designs. During the development of Standard 90.1-1999, steam and hot water boilers were analyzed separately (since the performance and sometimes design varies with the type of output), using four different sizes of gas-fired packaged boilers. Oil-fired boilers were not explicitly analyzed but were assumed to have thermal and combustion efficiencies three percentage points higher than that finally established for gas-fired boilers. These same four sizes were used for the screening analysis as well.

In November 1999, the Gas Appliance Manufacturers' Association (GAMA) provided historical shipment estimates for gas-fired and oil-fired package boilers by fuel type.[a] The data provided was insufficient to establish shipments for commercial boilers by size and fuel type as needed for the screening analysis. Shipments by size and fuel type were were based on data provided by the Hydronics Institute in 1996, which included shipments for 1994 and projected shipments to 2000.[b] The projected shipments suggested a 45% growth in boiler shipments between 1994 and 2000. The historical data provided by GAMA in 1999 did not suggest any growth trend in total boiler shipments over the period from 1989 to 1998. Thus, the commercial shipments in 1994 were assumed to be an acceptable estimate for future annual shipments.

The Hydronics Institute data were by size category and fuel, as well as by hot water and steam output for cast iron construction. For steel boiler construction, steam, or hot water output were not indicated so shipments of steel boilers were split between gas and oil categories.

The size categories in the Hydronics Institute data do not align with those specified for the screening analysis. Shipments in several of the Hydronics Institute size categories were split according to the fraction of the category range that belonged within the size ranges used in the screening analysis. The resulting shipment estimates for gas-fired boilers are shown in Table 2.6.

(a) Gas-fired space-conditioning and service water-heating equipment shipment data and supporting letter provided to Cyrus Nasseri of DOE, December 7, 1999.
(b) Detailed boiler shipment data provided in a fax from the Hydronics Institute to Pacific Northwest National Laboratory, 1996.

Table 2.6. Estimated Annual Shipments for Gas-Fired Boilers Used in the Analysis

Product Description	Typical Capacity (kBtu/h)	Estimated Shipments	
		Gas-Fired	**Oil-Fired**
Hot Water Boilers, 300-400 kBtu/h	400	2,821	2,389
Hot Water Boilers, 400-1,000 kBtu/h	800	3,077	2,641
Hot Water Boilers, 1,000-2,500 kBtu/h	1,500	540	1,337
Hot Water Boilers, 2,500+ kBtu/h	3,000	178	627
Steam Boilers, 300-400 kBtu/h	400	1,268	987
Steam Boilers, 400-1,000 kBtu/h	800	1,731	1,213
Steam Boilers, 1,000-2,500 kBtu/h	1,500	424	850
Steam Boilers, 2,500+ kBtu/h	3,000	135	374

2.8.3.3 Baseline Cost Data

Baseline costs for boilers were developed from data provided primarily by mechanical contractors or equipment distributors. The data identified boiler costs by characteristic boiler size, hot water or steam output, and gas or oil fuel input. The number of data points available varied from 3 to 7 for each product analyzed. When more than three data points were available, the high- and low-cost data points were removed from the set and the remaining cost data were averaged to reduce the effects of high- and low-cost outliers.

In all cases, the average combustion efficiency was higher than the minimum specified by EPCA. Thus, the average of the cost and efficiency data are referred to as the market baseline cost and efficiency. When possible, available relative cost versus efficiency data for each product were used to back out the cost for an EPCA baseline product from the market baseline cost and efficiency data. The relative cost versus efficiency data used was based on combustion efficiency relative cost curves supplied by GAMA in 1994 to the SSPC. When the efficiency for a particular product was not provided, 80% combustion efficiency was assumed. Note that the averaged market combustion efficiency was generally close to the EPCA baseline (within two percentage points in all but one instance), and the impact on the final cost estimate was a 5% to 13.5% reduction in cost from the market baseline to the EPCA baseline, depending on product. Table 2.7 shows the baseline cost data for boilers.

2.8.3.4 Relative Cost for Higher Efficiency Levels

In 1994, GAMA provided tables to the ASHRAE Mechanical Subcommittee during Standard 90.1-1999 development showing relative costs for specific combustion efficiency and thermal efficiency improvements above the efficiency levels required by Standard 90.1-1989 (same as the EPCA levels). These data were developed based on GAMA surveys of member industries and represented the average manufacturer cost increases needed to reach specific efficiency levels. In some instances, the given efficiency level represented a range of efficiencies that could be achieved at essentially the same relative cost. The SSPC 90.1 performed its analysis using thermal efficiency as the metric of choice and thus recommended thermal efficiency as the metric for the Standard 90.1-1999 requirements covering all boiler sizes except for boiler capacities >2,500 kBtu/h. Because thermal efficiency can be directly

Table 2.7. Boiler Baseline Cost Data

Product	1994 Estimated Cost for ASHRAE Analysis ($)	No. of Data Points	Average Cost[a] ($)	Average Comb EFF (%)	Relative Cost [b] (%)	EPCA Baseline Contractor Cost ($)
Package Boilers, Gas-Fired, 400, HW	5,015	7	4,389	80.7	111	3,972
Package Boilers, Gas-Fired, 800, HW	6,621	7	6,220	80.7	111	5,629
Package Boilers, Gas-Fired, 1,500, HW	9,258	7	9,649	80.9	114	8,501
Package Boilers, Gas-Fired, 3,000, HW	14,969	7	15,161	81.4	110	13,733
Package Boilers, Gas-Fired, 400, Steam	5,015	4	5,460	80.0	100	5,460
Package Boilers, Gas-Fired, 800, Steam	6,621	4	7,248	80.0	100	7,248
Package Boilers, Gas-Fired, 1,500, Steam	9,258	5	13,813	81.0	110	12,580
Package Boilers, Gas-Fired, 3,000, Steam	14,969	5	18,746	82.0	104	18,025

(a) After removing high- and low-cost outliers.
(b) Based on 1995 ARI relative cost versus combustion efficiency data.

correlated with energy use, the screening analysis also uses thermal efficiency as the metric for efficiency improvements. For boilers >2,500-kBtu/h input rating, the Standard 90.1-1999 efficiency level is a combustion efficiency rating primarily because of difficulties in testing the thermal efficiency of larger boilers.

In 1994, GAMA provided relative cost versus efficiency data to the SSPC 90.1. Applying these relative cost data to the baseline costs results in costs that do not reflect current prices for high-efficiency Equipment.[a] Therefore, using boiler cost data from Freeman (1995), a functional relationship was developed between the contractor cost data and boiler performance characteristics as shown below:

$$\text{ContractorCost}(\$96) = 3.23 \text{ x input} + 2.64 \text{ x } (Ec)^2 + 1{,}009 \text{ x burner} - 15{,}755 \qquad (2.6)$$

where input = the gas fuel input in kBtu/h
E_c = rated combustion efficiency as a two-digit integer (80 = 80% E_c)
burner = a bimodal variable to represent the presence of a power burner (burner =1) or atmospheric burner (burner = 0).

Equation (2.6) was used to generate the relative cost for targeted efficiency levels above the EPCA minimum for hot water boilers with capacities up to 2,500 kBtu/h. Power burners were assumed for boiler efficiencies greater than 82%, which was characteristic of the collected data. The data used to generate Equation (2.6) incorporated few boilers above 2,500 kBtu/h. For boilers greater than 2,500 kBtu/h, estimates of cost for higher efficiency levels were based on data supplied by an industry consultant.[b]

(a) Personal communications with Dirk Granberg; Chris Jostel of Mechanical Sales Inc., in 1999.
(b) Personal communications with Dirk Granberg in 1999.

Equation (2.6) provides the relative cost as a function of input rating. However, a contractor purchases a boiler based on output capacity to ensure it can meet the building load. Output capacity is a function of the input rating as well as the thermal efficiency. Using a higher efficiency allows the input rating to be reduced, reducing the boiler cost as calculated by the equation.

For low-pressure steam boilers, where the boiler design may be essentially the same as that for a hot water boiler except for controls, the combustion efficiency is somewhat lower due to the change in temperature of the working fluid from 180°F to 212°F (0 psig steam) as specified in the proposed test procedure). The gap between the combustion and thermal efficiency is also larger for steam boilers due to the higher operating temperature increasing the shell losses from a steam boiler. The effect or shell losses depends on boiler volume, boiler input rating, and insulation level. Relative cost curves for steam boilers were also developed assuming a typical 2% point difference between hot water and steam thermal efficiencies for the two smaller size categories (400-800 kBtu/h boilers) analyzed, and a 1% point difference for the next-larger (1,500 Btu/h) size category. For the largest size category, costs were based directly on relative cost estimates supplied by consultants.[a]

Relative cost versus efficiency data for oil-fired boilers were not collected during the analysis, nor were these data provided for the analysis of these products during the development of Standard 90.1-1999. Data provided by industry consultant[a] and other manufacturer's representatives indicate that a combustion efficiency of 83% to 84% is typically the maximum for oil-fired designs due to difficulties in designing for condensation in oil-fired equipment and associated flue systems.

2.8.3.5 Efficiency Levels Analyzed

An EPCA minimum, a Standard 90.1-1999 minimum, and the highest thermal efficiency level were used for all gas-fired boliers. The combustion efficiency specified in EPCA was translated to thermal efficiency based on the information provided by GAMA, which is 75% thermal efficiency for hot water boilers and 72% thermal efficiency for steam boilers. The highest thermal efficiencies analyzed were 88% for hot water boilers and between 81% and 82% for steam boilers, depending on size and available data. Efficiency levels between the EPCA minimum and the highest efficiency levels were used based on the availability of data points from the GAMA relative cost data. Table 2.8 shows the efficiency levels analyzed and the corresponding relative costs above the EPCA minimum. Table 2.9 shows cost estimates for boilers at each efficiency level that were obtained by applying the relative costs (from Table 2.8) to the first-cost data.

2.8.4 Efficiency and Cost Data – Warm-Air Furnaces

This section presents the lifetime, shipments, baseline cost, and relative cost for higher efficiency levels for warm-air furnaces.

(a) Provided by Dirk Granberg in December 1999.

Table 2.8. Gas-Fired Boiler Efficiencies Analyzed (with relative cost above baseline)

Product Description	Typical Capacity (kBtu/h)	Level 1 (EPCA 92) Thermal Efficiency (%)	Level 1 (EPCA 92) Relative Cost (%)	Level 2 (90.1-1999) Thermal Efficiency (%)	Level 2 (90.1-1999) Relative Cost (%)	Level 3 Thermal Efficiency (%)	Level 3 Relative Cost (%)	Level 4 Thermal Efficiency (%)	Level 4 Relative Cost (%)	Level 5 Thermal Efficiency (%)	Level 5 Relative Cost (%)	Level 6 Thermal Efficiency (%)	Level 6 Relative Cost (%)
Hot Water Boilers, 300-400 kBtu/h output	400	75	100	75	100	78	115	79	132	81	209	88	318
Hot Water Boilers, 400-1,000 kBtu/h output	800	75	100	75	100	76	110	78	120	79	158	88	237
Hot Water Boilers, 1,000-2500 kBtu/h output	1,500	75	100	75	100	77	105	78	111	79	134	88	180
Hot Water Boilers, 2,500+ kBtu/h output	3,000	75	100	72	100	78	110	79	120	80	122	88	160
Steam Boilers, 300-400 kBtu/h output	400	72	100	75	110	76	115	77	132	79	209	82	244
Steam Boilers, 400-1,000 kBtu/h output	800	72	100	75	115	76	120	78	158	79	163	82	225
Steam Boilers, 1,000-2,500 kBtu/h output	1,500	72	100	75	105	77	123	78	134	79	141	81	152
Steam Boilers, 2,500+ kBtu/h output	3,000	72	100	72	100	78	130	79	135	80	138	82	156

Table 2.9. Cost Estimates for Gas-Fired Boilers

Product Description	Typical Capacity (kBtu/h)	Level 1 (EPCA 92) Thermal Efficiency (%)	Level 1 (EPCA 92) Cost ($)	Level 2 (90.1-1999) Thermal Efficiency (%)	Level 2 (90.1-1999) Cost ($)	Level 3 Thermal Efficiency (%)	Level 3 Cost ($)	Level 4 Thermal Efficiency (%)	Level 4 Cost ($)	Level 5 Thermal Efficiency (%)	Level 5 Cost ($)	Level 6 (highest efficiency level) Thermal Efficiency (%)	Level 6 (highest efficiency level) Cost ($)
Hot Water Boilers, 300-400 kBtu/h output	400	75	3,972	75	3,972	78	4,585	79	5,262	81	8,291	88	12,636
Hot Water Boilers, 400-1,000 kBtu/h output	800	75	5,629	75	5,629	76	6,220	78	6,772	79	8,908	88	13,360
Hot Water Boilers, 1,000-2,500 kBtu/h output	1,500	75	8,502	75	8,502	77	8,927	78	9,452	79	11,420	88	15,293
Hot Water Boilers, 2,500+ kBtu/h output	3,000	75	13,733	75	13,733	78	15,107	79	16,480	80	16,755	88	21,973
Steam Boilers, 300-400 kBtu/h output	400	72	5,460	75	6,006	76	6,279	77	7,207	79	11,411	82	13,322
Steam Boilers, 400-1,000 kBtu/h output	800	72	7,248	75	8,335	76	8,698	78	11,452	79	11,814	82	16,308
Steam Boilers, 1,000-2,500 kBtu/h output	1,500	72	12,580	75	13,209	77	15,443	78	16,899	79	17,704	81	19,136
Steam Boilers, 2,500+ kBtu/h output	3,000	72	18,026	72	18,026	78	23,433	79	24,335	80	24,875	82	28,120

2.8.4.1 Service Life

Most commercial furnaces covered under EPCA are installed as an integral part of a combined packaged cooling and heating unit, typically rooftop mounted. A 15-year service life was used for all furnaces based on equipment life data published in the ASHRAE (1995) for packaged cooling equipment. Life expectancies for stand-alone furnaces are expected to be slightly longer based on the same data source.

2.8.4.2 Shipment Data and Characteristic Equipment Size

Total annual shipments of commercial furnaces are estimated to be 181,384, based on 1994 GAMA data showing shipments of 164,300 commercial furnaces adjusted for a 15% increase in total furnace shipments (residential and commercial) between 1994 and 1998.[(a)]

Two furnace sizes were analyzed in the screening analysis−250 and 400 kBtu/h. These two sizes were chosen based on the availability of relative cost versus efficiency data supplied by GAMA during the development of Standard 90.1-1999. In addition, the relative cost versus efficiency data supplied by GAMA suggested strong differences between the 250 and 400-kBtu/h furnace costs relative to baseline efficiency models.

Shipment weights for furnaces were estimated based on the fraction of total unitary equipment shipments having furnaces corresponding to the 250-kBtu/h category or to the larger 400-kBtu/h furnace design. It was assumed that larger furnaces would have relative costs versus efficiency profiles similar to those for the 400-kBtu/h category. The 1998 ARI statistical releases (ARI 1998b) provide the following equipment shipment data as shown in Table 2.10.

All of the 135 through 184.9-kBtu/h cooling equipment and 50% of the 185 through 249.9-kBtu/h cooling equipment were assumed to use furnaces around the 250-kBtu/h size. The remainder of the cooling equipment was assumed to use furnaces at or around the 400-kBtu/h sizes. Thus, the relative weights applied to these two furnace categories are 61% for 250-kBtu/h and 39% for 400-kBtu/h and above furnaces. The estimated annual shipment was 110,644 small furnaces (represented by the 250-kBtu/h size) and 70,740 large furnaces (represented by the 400-kBtu/h size).

2.8.4.3 Baseline Cost Data

The Standard 90.1-1999 furnace analysis was based on cost data provided by GAMA in 1994 to the SSPC 90.1. The data were provided as a multiplier on the entire cost of a package heating and cooling system. An assumption was made that the 250-kBtu/h capacity furnace was appropriately sized to a 10-ton system and a 400-kBtu/h furnace was appropriately sized to a 15-ton cooling system. The screening analysis used the relative cost information for higher efficiency furnaces that was tied to the total package system price.

(a) Gas-fired space-conditioning and service water-heating equipment shipment data and supporting letter provided to Cyrus Nasseri of DOE, December 7, 1999.

Table 2.10. ARI 1998 Statistical Profile for Year Round Units

Cooling Capacity (kBtu/h)	1998 Shipments
135 - 184.9	46,030
185 - 249.9	22,224
250 - 319.9	10,788
320 - 379.9	4,207
380 - 539.9	4,013
540 - 639.9	2,292
640 & Over	4,377

In 1994, the ASHRAE 90.1 mechanical subcommittee assumed the 250-kBtu/h capacity furnaces would be used on a 10-ton system, and a 400-kBtu/h furnace would be used on a 15-ton system. A review of available products from Carrier, Trane, and Bryant suggested this match was uncommon (Barwig et al. 1996). Furnaces are typically available in both low-heat and high-heat configurations for most commercial packaged equipment. A more typical matching for the high-heat configuration would be to use a 250-kBtu/h furnace on a 10 to 12.5-ton system, and a 400-kBtu/h furnace would be considered the high-heat option for a 15 to 20-ton system and the low-heat option on a 25-ton air-conditioning system. For any piece of equipment, the low-heat furnace options are typically about two-thirds the input rate of the high-input furnaces, and may actually represent the more commonly purchased option. Using the combination analyzed by the SSPC 90.1 minimized the cost increases for higher efficiency furnaces; therefore, the same combination (250 kBtu/h to 10 ton and 400 kBtu/h to 15 ton) was also used for the present analysis.

The base cost data for packaged systems with furnaces was based on 1994 data used by the Standard 90.1 Mechanical Subcommittee in the furnace analysis. These furnace costs provided to the subcommittee included a 25% markup. For this analysis, these costs were brought forward to 1999 using a 2% per year gross domestic product inflator. After removing the 25% markup, the first costs used in the screening analysis were $4,602 for a 250-kBtu/h furnace combined with a 10-ton packaged cooling system, and $6,349 for a 400-kBtu/h furnace on a 15-ton packaged cooling system.

2.8.4.4 Relative Cost for Higher Efficiency Levels

The relative cost versus design options data provided to the Standard 90.1-1999 committee included costs for reducing casing losses, as well as adopting power burners and Intermittent Ignition Devices (IIDs) in furnaces. Twelve separate design options were considered (as shown in Table 2.11). Because the basic EPCA 92 specifies only a combustion efficiency (Ec) rating of 80%, Case 2 (as shown in Table 2.11) was used as the EPCA 92 baseline. This baseline furnace has a casing loss of 1.5% based on rated test conditions. The test condition casing loss was then multiplied by a factor of 3.3 to represent losses in outdoor conditions (10 CFR Part 430 Subpart B, Appendix N). Table 2.11 shows the relative cost and thermal efficiency data for each design option.

The lowest-cost product suggested by GAMA was Case 1, which, at 78% efficiency, is not allowed under EPCA. The next lowest-cost product was for Case 2, which is assumed to represent the EPCA baseline rooftop furnace product (1.5% casing loss, atmospheric burner, IID, 80% combustion efficiency).

Table 2.11. Standard 90.1 Furnace Design Options

Furnace Designs	Costs Relative To EPCA Baseline		Combustion Efficiency (%)	Casing Loss (%)	Thermal Efficiency (%)
	250 kBtu/h	400 kBtu/h			
Case 1, Atmospheric Burner, Ec = 78%, 600-Btu/h Pilot, 1.5% Casing Loss	1.000	1.000	78	1.50	73.05
Case 2, Atmospheric Burner, Ec = 80%, IID, 1.5% Casing Loss	1.015	1.015	80	1.50	75.05
Case 3, Atmospheric Burner, Vent Cap, Ec = 80%, IID, 1.5% Casing Loss	1.035	1.035	80	1.50	75.05
Case 4, Power Burner, Ec = 80%, IID, 1.5% Casing Loss	1.060	1.060	80	1.50	75.05
Case 5, Power Burner, Ec = 82%, IID, 1.5% Casing Loss	1.070	1.060	82	1.50	77.05
Case 6, Power Burner, Ec = 88%, IID, 1.5% Casing Loss	1.500	1.510	88	1.50	83.05
Case 7, Atmospheric Burner, Ec = 78%, 600-Btu/h Pilot, 0.75% Casing Loss	1.050	1.010	78	0.75	75.53
Case 8, Atmospheric Burner, Ec = 80%, IID, 0.75% Casing Loss	1.065	1.025	80	0.75	77.53
Case 9, Atmospheric Burner, Vent Cap, Ec = 80%, IID, 0.75% Casing Loss	1.085	1.045	80	0.75	77.53
Case 10, Power Burner, Ec = 80%, IID, 0.75% Casing Loss	1.110	1.070	80	0.75	77.53
Case 11, Power Burner, Ec = 82%, IID, 0.75% Casing Loss	1.120	1.070	82	0.75	79.53
Case 12, Power Furnace, Ec = 88%, IID, 0.75% Casing Loss	1.550	1.520	88	0.75	85.53

In addition to the EPCA baseline product features, the Standard 90.1-1999 efficiency level has mandated a 0.75% casing loss, represented by Case 8.

The next higher combustion efficiency level (82%) is met by applying a power burner to Case 8, represented by Case 11.

The highest efficiency level analyzed corresponds to Case 12, a condensing furnace. However, no condensing rooftop furnaces were found from available literature.

Because a large number of existing furnace products have combustion efficiency levels near 81%, an 81% efficiency level was added (for the analysis) at 50% of the cost to reach the 82% level. Table 2.12 shows costs normalized to the EPCA baseline (Case 2).

Incorporating the first-cost information and the relative costs for higher efficiency levels results in the cost estimates for each efficiency level shown in Table 2.13.

Table 2.12. Relative Cost and Efficiency Data for Furnace Screening Analysis

Furnace Designs	Costs Relative to EPCA Baseline 250 kBtu/h	Costs Relative to EPCA Baseline 400 kBtu/h	Combustion Efficiency (%)	Casing Loss (%)	Thermal Efficiency (%)
Case 2, Atmospheric Burner, Ecomb = 80%, IID, 1.5% Casing Loss	1.000	1.000	80	1.50	75.05
Case 8, Atmospheric Burner, Ec = 80%, IID, 0.75% Casing Loss	1.049	1.010	80	0.75	77.53
Case 11, Power Burner, Ec = 81%, IID, 0.75% Casing Loss	1.044	1.020	81	0.75	78.53
Case 11, Power Burner, Ec = 82%, IID, 0.75% Casing Loss	1.103	1.054	82	0.75	79.53
Case 12, Power Furnace, Ec = 88%, IID, 0.75% Casing Loss	1.527	1.498	88	0.75	85.53

Table 2.13. Contractor Costs for Furnace Efficiency Levels Analyzed

Gas-Furnace Product	Level 1 (EPCA 92) Thermal Efficiency (%)	Level 1 (EPCA 92) Cost ($)	Level2 (90.1-1999) Thermal Efficiency (%)	Level2 (90.1-1999) Cost ($)	Level 3 Thermal Efficiency (%)	Level 3 Cost ($)	Level 4 Thermal Efficiency (%)	Level 4 Cost ($)	Level 5 Thermal Efficiency (%)	Level 5 Cost ($)	Level 6 Thermal Efficiency (%)	Level 6 Cost ($)
Warm-Air Furnaces, Gas-Fired, 250 kBtu/h	75.1	4,602	77.5	4,827	78.5	4,952	79.5	5,076	NA	NA	85.5	7,027
Warm-Air Furnaces, Gas-Fired, 400 kBtu/h	75.1	6,349	77.5	6,412	78.5	6,552	79.5	6,692	NA	NA	85.5	9,511

2.8.5 Efficiency and Cost Data – Service Water Heaters

This section presents the lifetime, shipments, baseline cost, and relative cost for higher efficiency levels for service water heaters.

2.8.5.1 Service Life

Commercial storage water heaters covered under EPCA were analyzed assuming a 7-year service life and a 15-year life for instantaneous water heaters, based on data developed in the SSPC 90.1 analysis.

2.8.5.2 Shipment Data and Characteristic Equipment Size

GAMA provided annual shipments of gas commercial water heaters and electric commercial water heaters from 1989 to 1998.[a] GAMA data breaking down the shipments into product categories were not

(a) Gas-fired space-conditioning and service water-heating equipment shipment data and supporting letter provided to Cyrus Nasseri of DOE, December 7, 1999.

available. In addition, the gas water heater shipments did not include copper tube or coil-type water heaters. The GAMA data through 1996 separates residential from commercial (EPACT-covered) water heaters. However, the data beginning in 1997 separates residential and commercial water heater shipments, based on the manufacturer's marketing of the product, which modifies the shipment data for both gas-fired and electric products.

For this analysis, the shipments over the 5-year period from 1992 to 1996 were averaged to provide an estimate for total shipments of gas storage and electric commercial water heaters. The resulting estimated shipments are 107,646 units per year for commercial gas water heaters and 23,387 for electric water heaters (see Table 2.14). GAMA does not track shipments of oil water heaters at either the residential or the commercial level.

Table 2.14. Total Gas and Electric Commercial Water Heater Shipments

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997(a,b)	1998(a,b)	5-yr avg.(c)
Gas Water Heaters	106,401	98,872	91,143	103,386	118,923	91,027	96,913	127,978	96,501	94,577	107,646
Electric Water Heaters	19,768	20,121	19,768	22,646	21,142	22,288	23,905	26,954	30,339	35,586	23,387

(a) Does not include coppertube or coil-type commercial water heaters.
(b) Definitions for residential and commercial water heaters modified (see text).
(c) Represents data from 1992 through 1996.

Estimates were made of the relative proportions of commercial water heater shipments in 10 product categories. These estimates were primarily based on data from an industry consultant[(a)] and are shown in Table 2.15. These estimates, in conjunction with GAMA shipment data, were used to develop shipments data for the current analysis. It was assumed that shipments of commercial electric water heaters are correctly represented by the GAMA data. It was assumed that the GAMA data for gas water heaters essentially represented all shipments of gas storage water heaters, as well as instantaneous water heaters ≥10-gal capacity. Hence, the total GAMA shipments were allocated to these four categories in the proportions indicated in Table 2.15. Shipments for the remaining <10-gal instantaneous gas water heaters were assumed to be in the relative proportion to gas storage water heater shipments shown in Table 2.15. Estimated annual shipments for all gas and electric water heater categories are shown in the rightmost column of Table 2.15. ADL has estimated shipments of commercial oil-fired water heaters at less than 1,000 units annually.[(b)] Because of the low volume of shipments and uncertainty in the number of shipments, no further analysis of oil-fired water heaters was done.

(a) Personal communication with Max Minnear on January 8, 2000, regarding annual water heater shipments by model category.
(b) Personal communication with Ed Barbour from ADL in November 1999.

2.8.5.3 Baseline Cost Data and Characteristic Sizes

Characteristic sizes for gas storage and instantaneous water heaters were based on sizes and input ratings used in the Standard 90.1-1999 analysis for each category of commercial gas water heaters listed under EPCA. Two sizes of tankless instantaneous water heaters (400 and 1,000 kBtu/h) and a single size instantaneous, integral tank water heater design were analyzed (500 kBtu/h, 100 gal). A single size commercial electric storage water heater with a 120-gal storage volume and 30-kW input rate was chosen for the analysis.

Table 2.15. Commercial Water Heater Shipment Proportions and Estimated Shipments

Type	Fuel	Input Rating (kBtu/h)	Volume Rating (gal)	Original Estimated Proportion of Shipment: Individual Elements (%)			Original Estimated Proportion of Shipment: Total (%)	Final Estimated Annual Shipments
Storage	Electric	All	None	100	20		15.00	23,387[(a)]
Storage	Gas	>75, ≤155	None	20			11.25	21,083
Storage	Gas	>155, ≤250	None	40			22.50	42,166
Storage	Gas	>250	None	40	75	75	22.50	42,166
Instantaneous	Gas	>210	<10	95			22.56	42,279
Instantaneous	Gas	>210	≥10	5	95	25	1.19	2,230

(a) Reflects supplied GAMA data for electric water heaters and not the original shipment fraction estimates.
(b) Totals appear to overestimate actual shipments.

Baseline cost data for storage water heaters were developed based on contractor cost data collected by industry consultants in 1999.[(a)] Cost data for instantaneous water heaters was based on data collected in 1995 (Freeman 1995), which was used to develop equations relating contractor cost to water heater input capacity and combustion efficiency. For tankless water heaters, this equation simplifies to

$$\text{COST} = 2.35 \times \text{INPUT} - 7{,}872 \times Ec + 49.5 \times Ec^2 + 314{,}743 \quad (2.7)$$

where COST = the contractor cost in 1996$
INPUT = the input rating in kBtu/h
E_c = the combustion efficiency.

For instantaneous water heaters with integral tank, the difference between a high-input storage water heater and the instantaneous water heater with tank is somewhat irrelevant and immaterial in terms of design, with units falling just above and just below the 4,000-Btu/h·gal threshold level. Equation (2.8) gives the cost for a water heater with integral tank above 155 kBtu/h and between 10- and 140-gal capacity, regardless of whether the water heater is classified as an instantaneous design or a storage water heater under EPCA.

(a) Baseline commercial equipment cost data collected by DuPont Dobbs Engineers, LLC, in 1999.

$$COST = 5.80 \text{ x } INPUT + 129 \text{ x } WARRANTY + 486 \text{ x } TANK + 910 \text{ x } BURNER + 468 \quad (2.8)$$

where COST = the contractor cost in 1996$
INPUT = the input rating in kBtu/h
WARRANTY = the length of the warranty in years
TANK = an indicator of tank construction (ASME tank =1, else 0)
BURNER = an indicator of type of burner (power burner = 1, atmospheric = 0).

For the screening analysis, a 3-year warranty was assumed. For these high-input instantaneous water heater designs, a power burner and ASME-rated tank were assumed.

In all cases, costs for gas instantaneous water heaters calculated using Equations (2.7) and (2.8) were adjusted to 1999 costs using a 2% GDP inflator. The 1999 cost estimates for the products analyzed are shown in Table 2.16.

Table 2.16. Baseline Gas Storage Water Heater Costs

Equipment Category	Input Category (kBtu/h)	Size Category (gal)	Typical Volume (gal)	Typical Input Rating (kBtu/h)	ASHRAE Cost (1994$)	No. Data Points Collected (1999)	Average Cost w/o Hi and Lo (1999$)
Gas-Fired Storage Water Heaters	>75, ≤155	Any	75	120	3,665	3	1,775
Gas-Fired Storage Water Heaters	>155	Any	100	199	4,291	4	2,213
			100	360	5,720	4	3,784
Storage Tanks	N/A	V <140 gal	120	N/A	1,980	4	1,609
		V ≥140 gal	200		3,294	3	2,375
			500		8,274	3	5,022
			1,000		13,550	3	8,900

Costs for the baseline electric storage water heater were estimated using data collected by Freeman (1995). These data are very extensive for electric water heaters, representing approximately 1,000 records for electric storage water heaters from nine companies, with tank volumes from 50 to 1,000 gal and input ratings from 13.5 to 480 kW. Three separate cost models were developed from the data, representing costs for common tank volumes of 50, 80, and 120 gal. Each cost model was a function of the type of thermostat used (surface or immersion), tank construction (ASME or standard), warranty, and one of three input rating classes. The cost model for a 120-gal electric water heater is shown as:

$$COST = 877 + 485 \text{ x } THERM + 371 \text{ x } TANK + 162 \text{ x } WARRANTY + 392 \text{ x } C2 + 1002 \text{ x } C3 \quad (2.9)$$

where COST = the contractor cost in 1996$
THERM = thermostat type (surface = 0, immersion = 1)
TANK = tank construction (Standard = 0, ASME =1)
WARRANTY = the warranty in years.

C2 and C3 are variables representing input class (C2 = 1 if input between 20 and 40 kW, otherwise 0. C3 = 1 if input greater than 40 kW, otherwise 0)

For the design analyzed, a surface-mount thermostat with a standard-tank construction, a 3-year warranty, and a 30-kW element was chosen to represent the baseline model.

Table 2.17 provides the costs used in the Standard 90.1-1999 analysis for instantaneous water heater products, as well as the estimated cost based on the data collected in 1999 that were used in the screening analysis.

Table 2.17. Baseline Gas Instantaneous and Electric Water Heater Costs

Equipment Category	Input Category (kBtu/h)	Size Category (gal)	Typical Volume (gal)	Typical Input Rating	ASHRAE Cost (1994$)	Estimated Cost (1999$)
Gas-Fired Instantaneous Water Heaters – Tankless	>200	V <10	N/A	400 kBtu/h	3,477	2,794
			N/A	1,000 kBtu/h	5,460	4,294
Gas-Fired Instantaneous Water Heaters – Integral Tank	>200	V ≥10	100	500 kBtu/h	8,824	5,466
Electric Water Heaters	N/A	V ≥100	120	30 kW	NA	1862

2.8.5.4 Costs for Higher Efficiency Levels

Storage Water Heaters - Five combinations of thermal efficiency and standby loss levels were analyzed for gas storage water heaters. These levels represented:

1. EPCA baseline
2. Standard 90.1-1999 requirements for thermal efficiency and standby loss
3. 82% thermal efficiency with Standard 90.1-1999 standby loss levels
4. 82% thermal efficiency with Standard 90.1-1999 standby loss levels reduced by an additional inch of insulation on the tank
5. a high-efficiency (86% thermal) water heater with approximately two-thirds of the standby loss of the EPCA baseline
6. 94% thermal efficiency, fully condensing commercial water heater with two-thirds of the standby loss of the EPCA baseline.

Relative costs above the EPCA 92 baseline were established for levels 2 through 6 above as follows: cost information for changes in efficiencies from 78% to 82% were based on regressions of product cost and efficiency outlined in Freeman (1995) for the <155 kBtu/h gas storage water heater category and brought up to present value using a 2% cost inflator. For storage water heaters >155 kBtu/h, cost increases were scaled by input rate. Note that the resulting cost increase in all three cases was consistently below the GAMA relative cost data provided for the Standard 90.1-1999 analysis.

Typical commercial gas water heaters use 2 in. of insulation.[a] An estimate of standby loss reduction by adding 1 in. of insulation (R-7.5) was made for a 100-gal tank. No corresponding improvement in efficiency was assumed because the thermal efficiency standard is separately regulated in both ASHRAE and EPCA requirements. Manufacturer costs were estimated to increase $20 for the 100-gal water heaters examined based on data supplied by industry consultants.[a] The manufacturing cost for adding 1 in. of insulation to the 75-gal water heater design was $17.17, based on the relative area to be covered on the top and sides of two typical water heater designs (each with tank height of 55 in., and either 20 or 23 in. in diameter for 75 and 100-gal water heaters, respectively). A 60% markup from manufacturing to contractor costs was assumed.

An 86% thermal efficiency rating (partial condensing) with approximately two-thirds of the EPCA 92 standby loss was also analyzed based on GAMA relative cost data provided for the Standard 90.1 analysis.

Finally, the fully condensing water heater (highest efficiency level) design was analyzed, assuming a first-cost at 200% of the last noncondensing water heater design (82% efficiency, 3 in. of insulation).

2.8.5.5 Instantaneous Water Heaters

Five levels of thermal efficiency were examined for the gas-fired instantaneous water heaters with <10-gal storage capacity. Estimates for the higher efficiency costs were obtained from Freeman (1995). The costs estimated for a baseline in this report are similar to those used in the Standard 90.1 analysis. The relative cost increases for higher efficiency levels are typically less than those supplied by GAMA to ASHRAE for the 83% and 86% efficiency levels analyzed. A fully condensing thermal efficiency level of 94% was assumed to cost 200% of the cost of the 83% (noncondensing) level.

Six combinations of thermal efficiency and standby loss requirements were examined for instantaneous gas-fired water heaters with volume >10 gal. These cost estimates were based on the same data as for the storage water heaters.

2.8.5.6 Electric Water Heaters

Only one size of an electric storage water heater was examined (18 kW, 120 gal). Information from industry consultant[a], as well as a review of the products in the commercial equipment cost survey (Freeman 1995), suggested that most electric water heaters have 3 in. of insulation and standby loss levels below those required by EPCA 92. Some products may meet the EPCA requirements with 2 to 2.5 in. of insulation. For this analysis, we have assumed that the baseline model would have 3 in. of insulation.

(a) Personal communication with Max Minnear in 1999.

Standard 90.1-1999 allows an increase in standby loss, which occurs across all sizes of electric water heaters. An analysis was done to estimate the impact of going from the EPCA levels to the requirements in Standard 90.1-1999. No requirement exists under EPCA for a minimum thermal efficiency of electric water heaters; however, to be consistent with the other water heater analysis, we estimated the thermal efficiency as:

$$\text{Thermal Efficiency} = 1 - \text{Standby loss/input rating} \qquad (2.10)$$

where standby loss is the allowed standby loss requirement in Standard 90.1-1999 and input is based on the 30 kW assumed for this water heater design. Both variables were converted to consistent heat units (Btu/h) for use in Equation (2.9), assuming a 100% conversion of electrical power input to heat.

For the screening analysis, 2 in. of foam insulation was assumed to meet the Standard 90.1-1999 standby loss level. The standby loss impact of an additional inch of insulation (R-7.5) on the tank walls and roof (estimated at 35.6 ft^2 for the 120-gal electric water heater design analyzed) was calculated. The difference between hot water and ambient air temperature was assumed to be 70^{o}F for the above calculation.

The cost to add this third inch of insulation was estimated assuming a manufacturing cost increase of approximately $23, based on a $20 manufacturer's cost increase for a 100-gal tank.[a] A further 60% markup was used to go from manufacturer's cost increase to a contractor cost increase of $37. No further reduction in standby loss requirement was analyzed for electric water heater designs.

No relative cost information was collected for commercial oil-fired water heaters in the screening analysis. Because of the low volume of shipments and lack of cost data for higher efficiency levels, no further analysis of oil-fired water heaters was attempted in the screening analysis.

Table 2.18 outlines the water heater thermal efficiency levels, standby loss requirements, and associated product cost. Efficiency levels corresponding to Test Level 2 for instantaneous gas water heaters (<10-gal capacity) and Test Levels 2, 3, and 4 for electric water heaters were not developed for the screening analysis and hence are marked "NA" in Table 2.18.

(a) Personal communication with Max Minnear in 1999.

Table 2.18. Water Heater Efficiency Levels and Contractor Costs Used in Screening Analysis

Product	EPCA 1992			Standard 90.1-1999			Test Level 1			Test Level 2			Test Level 3			Test Level 4		
	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)	Eff. (E_t) (%)	Standby Loss (Btu/h)	First Cost ($)
Storage Water Heater, Gas-Fired, 120 kBtu/h	78	1,193	1,775	80	1,103	1,822	82	1,103	1,869	82	1,053	1,897	86	804	2,787	94	804	3,739
Storage Water Heater, Gas-Fired, 199 kBtu/h	78	1,262	2,213	80	1,349	2,291	82	1,349	2,369	82	1,291	2,401	86	934	3,696	94	934	4,739
Storage Water Heater, Gas-Fired, 360 kBtu/h	78	1,262	3,784	80	1,550	3,924	82	1,550	4,067	82	1,492	4,099	86	934	6,319	94	934	8,134
Instantaneous Water Heater, Gas-Fired, 400 kBtu/h	80	NA	2,794	80	NA	2,794	83	NA	3,420	NA	NA	NA	86	NA	4,991	94	NA	6,839
Instantaneous Water Heater, Gas-Fired, 1,000 kBtu/h	80	NA	4,294	80	NA	4,294	83	NA	4,920	NA	NA	NA	86	NA	6,491	94	NA	9,839
Instantaneous Water Heater, Gas-Fired, with integral tank, 500 kBtu/h	77	1,649	5,466	80	1,725	5,747	82	1,725	6,027	82	1,667	6,059	86	1,110	9,730	94	1,110	12,055
Electric (120 gal)	99.4	343	1,862	99.3	403	1,862	99.4	348	1,900	NA	NA	NA	NA	NA	NA	NA	NA	NA

3.0 Energy Savings and Economic Impact Analysis

This section describes the methodology and key data inputs to estimate energy savings and economic impacts of alternative efficiency levels for products addressed in the screening analysis. Section 3.1 provides an overview of the energy savings and economic analysis methodology. Section 3.2 discusses the key data sources and assumptions used in the economic analysis–energy prices, the conversion of delivered-to-primary energy, the discount rate, the shipment projections, and product cost markups. The methodology and the resulting estimates of national energy savings and national net present value (NPV) are included in Section 3.3. Section 3.4 presents the detailed methodology used to generate life-cycle cost (LCC) estimates by building type and region and to aggregate them to national impacts. Section 3.5 discusses the expected reduction in carbon emissions associated with the national energy savings. Finally, Section 3.6 presents the aggregated summary results for national energy savings, carbon emission savings, and NPV for all products considered in the screening analysis. A one-page summary of the energy and economic results for each product is provided. A more detailed discussion of the results for selected products using this one-page summary is contained in Appendix C (Section C.4).

3.1 Overview of Methodology

Figure 3.1 presents an overview of the energy savings and economic impact analysis conducted as part of the screening analysis. The figure is divided into three columns. The left column shows the inputs from the engineering analysis. The center column shows the key inputs and outputs that are estimated for each of the 77 market segments (product of 7 building types and 11 subcensus divisions) that were used in the overall analysis. The right column shows the aggregation of both energy savings and economic results to national values.

With respect to the engineering analysis, the top left box shows the estimated FLEOH (generated for each of the market segments) that serve as the primary input to estimating unit energy consumption. Of course, the unit consumption also depends upon the capacity of the equipment and the efficiency level. To estimate national energy consumption, unit energy consumption was multiplied by an estimate of product shipments to each market segment and then summed to a national total. Lacking direct information on regional shipments of equipment, the approach in the screening analysis was to use information on the distribution of commercial building floor space and the percentage of floor space served by generic types of equipment to generate estimates of distributions of shipments by market segment. These distributions were applied to projections of total national shipments to yield projections of shipments by market segment. (The methodology and data sources to generate these distributions are described in Appendix B.) National energy savings estimates were calculated as the difference in national energy consumption between two assumed levels (a baseline standard and a potentially higher standard) of energy efficiency for the product being analyzed.

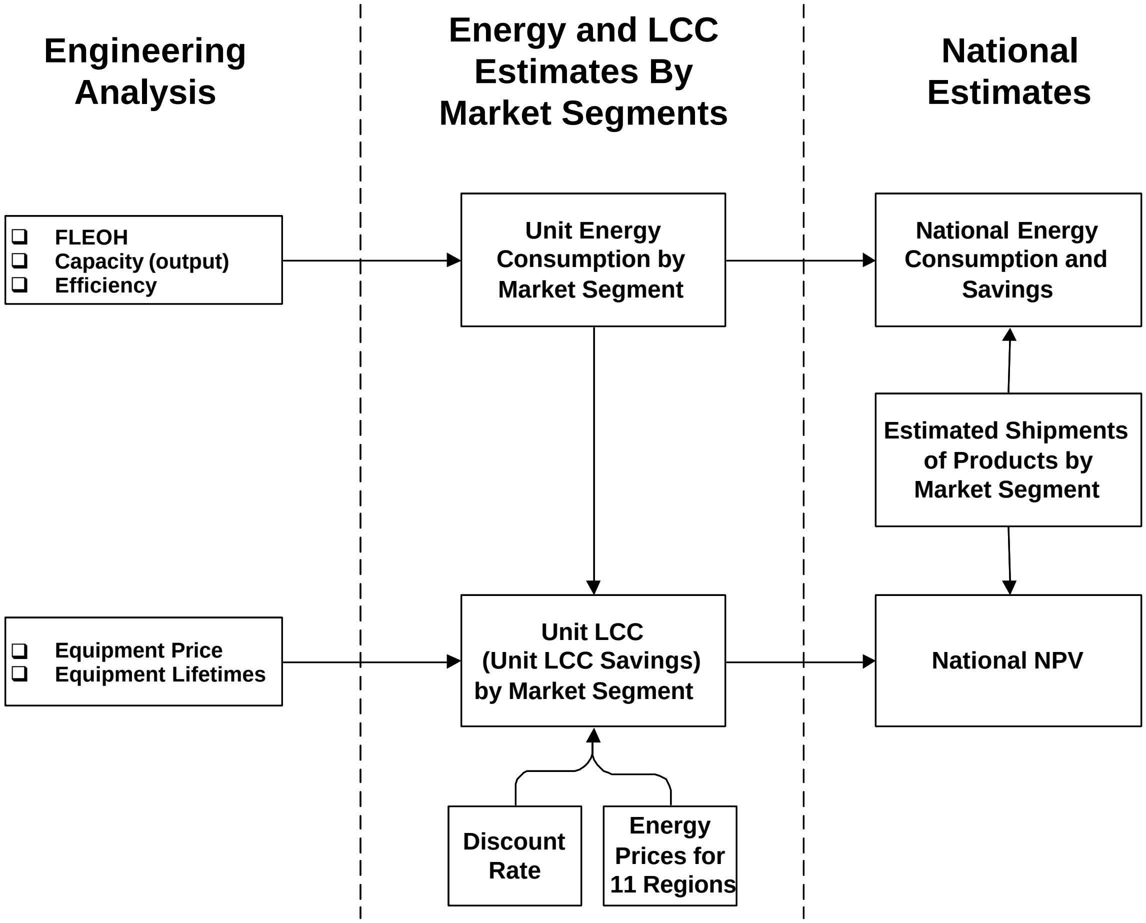

Figure 3.1. Overview of the Energy Savings and Economic Analysis Methodology

The LCC analysis was also conducted at the market segment level. Among other inputs, for a single unit of equipment, the LCC analysis requires estimates of the price (first cost) of the equipment as well as annual energy consumption. The equipment price information and estimated lifetime of the equipment are also inputs to the analysis. Unit energy consumption feeds directly into the LCC analysis as shown in the middle column. The two boxes at the bottom of the middle column illustrate the two remaining inputs to generate LCC—discount rate and energy prices. Energy prices were determined for the subcensus divisions (modified census divisions) used in the market segment analysis, and were assumed constant for all representative building types within a given division.

National NPV was based upon an aggregation of the LCC estimates for each market segment, again using the estimated distribution of shipments by market segment.

3.2 Data and Key Assumptions

LCC measures are functions of the unit energy consumption, equipment prices, energy prices, and the discount rate. The approach for determining the unit energy consumption and equipment prices is discussed in Section 2.0. This section documents the approach used to generate energy prices for the economic analysis, as well as the discount rate chosen. In addition, conversion factors are needed to convert delivered energy to a primary basis.

3.2.1 Energy Prices

The Energy Information Administration (EIA) *Annual Energy Outlook* (AEO) provided the projected energy prices used in the screening analysis (EIA 1999b). The AEO projects energy prices by census division for all major fuels for each sector (residential, commercial, industrial, and transportation). The AEO extends to only 2020, whereas the screening analysis used a time horizon extending to 2030. The energy prices beyond 2020 were fixed at the AEO 2020 levels.

As described in Appendix B, the Mountain and Pacific census divisions were split into “north” and “south” regions. The projected energy prices for these subcensus divisions were estimated using adjustment factors applied to the AEO energy price projections. This process is explained in Appendix B.

We had to consider how to account for the (electricity) demand charges that may affect the economics of higher-efficiency cooling equipment. *A priori*, the impact of demand charges is expected to result in a marginal price of electricity that exceeds the average price because the contribution of lower cooling energy consumption is expected to have a greater proportional effect on peak load than on the total energy consumption. A rough analysis of the effect of demand charges on the marginal electricity price showed that adding perhaps 1 to 1.5 cents per kWh to the average electricity price would adequately account for this effect.[a]

For the screening analysis, a somewhat higher price for electricity (for cooling) was used to adequately reflect the national benefits of reducing peak summer electricity demand. In part, to give additional weight to the presence of buildings with relatively higher summer electric peak loads, electricity prices in the screening analysis were uniformly adjusted upward by 5%. Table 3.1 shows the final sets of regional energy prices for selected years, including the electricity price adjustment used in the screening analysis.

Toward the end of the analysis, a quick assessment of the electricity price was done using Ernest Orlando Lawrence Berkley National Laboratory’s (LBNL) existing database of utility rate structures. The initial assessment was that, averaged across 30 utilities representing 26% of all commercial customers nationwide, the effective marginal price that would be appropriate for reductions in cooling energy consumption was higher (3% to 4%) than the average price, just slightly less than the 5% adjustment factor used in the screening analysis.

(a) Memorandum from Steven Nadel and Keith Emerson to the SSPC 90.1 HVAC panel dated March 7, 1994, regarding demand charges for cooling equipment.

Table 3.1. Electricity and Gas Prices Used for Screening Analysis

Region	Electricity (cents per kWh) 2000	2005	2010	2020	2030
Northeast	9.8	9.3	8.3	7.9	7.9
Mid-Atlantic	9.8	8.4	7.9	7.8	7.8
East North Central	7.4	6.6	6.2	6.0	6.0
West North Central	6.9	6.4	6.4	6.1	6.1
South Atlantic	6.7	6.2	6.2	6.0	6.0
East South Central	6.7	6.3	6.2	6.1	6.1
West South Central	6.9	6.5	6.4	6.3	6.3
Mountain North	6.2	6.1	6.1	5.8	5.8
Mountain South	7.8	7.6	7.6	7.3	7.3
Pacific North	5.0	4.5	4.4	4.3	4.3
Pacific South	9.5	8.5	8.3	8.2	8.2
U.S. Average	7.6	6.9	6.7	6.5	6.5
	Natural Gas (dollars per million Btu)				
Region	**2000**	**2005**	**2010**	**2020**	**2030**
Northeast	7.08	7.02	6.93	6.71	6.71
Mid-Atlantic	5.30	5.34	5.39	5.39	5.39
East North Central	5.37	5.35	5.36	5.35	5.35
West North Central	4.96	5.04	5.03	5.03	5.03
South Atlantic	6.45	6.21	6.19	6.09	6.09
East South Central	5.81	5.68	5.76	5.82	5.82
West South Central	4.84	4.76	4.87	5.01	5.01
Mountain North	4.63	4.95	5.24	5.26	5.26
Mountain South	4.63	4.95	5.24	5.26	5.26
Pacific North	5.79	5.97	6.00	5.69	5.69
Pacific South	5.79	5.97	6.00	5.69	5.69
U.S. Average	5.47	5.48	5.53	5.50	5.50

3.2.2 Energy Conversion Factors

The final national estimates of energy savings for the screening analysis are defined on a primary energy basis and, thus, include generation and transmission losses in addition to the energy delivered to the building. For electricity, the conversion from delivered to primary energy is based on the commercial-sector projections of delivered electricity and electricity losses from the AEO 2000. Table 2 from the AEO 2000 provides delivered electricity and associated losses for 1998, 2005, 2010, 2015, and 2020 (EIA 1999a, Reference Case, Table 2, p. 118). The ratios of [(delivered + losses)/(delivered)] were calculated for these years and then interpolated for the intervening years. The resulting conversion factors were then used to convert the annual electricity consumption estimates for the various efficiency levels to primary energy (trillion Btu or TBtu) estimates.

Some losses are also incurred in the transmission and distribution of natural gas (e.g., natural gas used to power pumps along gas pipelines). The screening analysis used the estimate of 11% losses (as used in the residential water heater analysis).

3.2.3 Discount Rate

For the calculations of LCC and NPV, the preliminary screening analysis used a constant 7% (real) discount rate. This value has been used in prior DOE analyses of residential appliances to generate estimates of national NPV from more stringent equipment efficiency standards. This particular value is motivated by the recommendation of the Office of Management and Budget (OMB) in Circular A-94, (OMB 1992). Circular A-94 indicates that this value corresponds to the approximate marginal pretax rate of return on the average investment in the private sector in recent years.

3.2.4 Shipment Forecasts

Section 2.0 describes the data sources and assumptions to estimate total shipments of each product for a recent year, nominally chosen as 1999. The estimates of national energy savings and carbon emissions through 2030 depend upon the differences in unit energy savings from higher efficiency as well as the projected total shipments over the time frame. A constant 1% growth rate was applied to the estimate of 1999 shipments to generate the projected levels of shipments over the analysis period. The 1% growth rate was motivated by the AEO 2000 (EIA 1999a) projection of the growth rate in total commercial building floor space between 1998 and 2020 of 0.9% per year. The use of a common growth rate for all products results in comparisons of potential energy savings that reflect only the economics of higher efficiency levels and the current shipments.

3.2.5 Equipment Price Markups

The development of contractor costs for all equipment analyzed in the screening analysis was discussed in detail in Section 2.0. As discussed in Section 2.8.1, the equipment cost is generally marked up as part of the contractor's final price to the builder owner. Following the assumptions in related work (Barwig et al. 1996; data used during Standard 90.1-1999 development), a 25% markup factor was applied to contractor costs for all equipment.

3.3 National Energy Consumption and Energy Savings

As stated above, the energy consumption and energy savings are based on the estimates of FLEOH generated in the engineering analysis and on the aggregation procedures described in Section 2.0. The economic analysis focuses on an LCC approach, which yields some insight into the distribution of cost savings by market segment, as well as measures of aggregate economic benefit to the nation. This section lays out the method to compute the energy savings and economic benefit measures.

3.3.1 Methodology

The engineering analysis yields an estimate of the FLEOH for each market segment. With the estimate of FLEOH, annual energy consumption for a unit of equipment in each market segment can be expressed by Equation (2.4). Total consumption in each market segment is based on unit annual energy consumption multiplied by projected shipments to that segment. The estimates of shipments to the market segments are based on a projected distribution by market segment applied to total national shipments (a single value for each year).[a] Using the letter (k) to designate the level of efficiency, national energy consumption is calculated by summing the estimated consumption for all market segments, as in

$$\text{National Energy Consumption}(k) = \frac{\left(\sum_{i}^{7}\sum_{j}^{11} \text{MS}_{i,j} \text{ x Shipments x Rated Capacity x FLEOH}_{i,j}\right)}{\text{Rated Efficiency}_k} \tag{3.1}$$

where $MS_{i,j}$ = share of national shipments installed in market segment i,j
i = building type
j = subcensus division
Shipments = total units shipped, nationally.

Because of the linearity of the entire process, the value of national energy consumption from Equation (3.1) is identical to the value calculated from a national average FLEOH ($FLEOH_{US}$) and total national shipments.[b] This alternative formulation is shown as:

$$\text{National Energy Consumption}(k) = \frac{(\text{Shipments x Rated Capacity x FLEOH}_{US})}{\text{Rated Efficiency}_k} \tag{3.2}$$

For water heaters, the existence of standby losses complicates the expression in Equation (3.1) [or (3.2)] to some degree. Standby losses are expressed in British thermal units per hour (Btu/h) and thus the annual consumption is expressed as the product of the number of hours the water heater is not firing (8760 – FLEOH) times the standby loss per hour. Thus, national energy consumption for water heaters is calculated as:

$$\text{National Energy Consumption}(k) = \text{Shipments x}\left(\frac{(\text{Rated Capacity x FLEOH}_{US})}{\text{Rated Efficiency}_k} + (8760 - \text{FLEOH}) \text{ x Standby loss}\right) \tag{3.3}$$

(a) The definitions of the market segments and methodology to project shipments to each market segment are discussed in Appendix B.
(b) The derivation of $FLEOH_{US}$ is described at the end of Appendix B.

By convention, for the baseline efficiency, k is assigned a value of 0. With this notation, energy savings for any selected efficiency level higher than the baseline is given by:

$$\begin{aligned}&\text{National Energy Savings }(k) = \\ &\text{National Energy Consumption}(0) - \text{National Energy Consumption}(k)\end{aligned} \tag{3.4}$$

While shipments in Equations (3.1) through (3.3) can be either annual or cumulative, to estimate national energy savings in any future year, we must account for the influence of equipment turnover. Assuming that all units are replaced at the end of their assumed lifetime, total national energy consumption is the sum of the previous N years of shipments (yielding the currently installed stock) times the unit energy consumption. The annual savings in any year is the difference in the energy consumption of the stock evaluated at the two efficiency levels.

3.3.2 Energy Savings Results

The national energy savings estimates for all of the efficiency levels analyzed in the screening analysis are presented in Tables 3.2 through 3.4. Table 3.2 shows the estimates for the 22 cooling products analyzed. The first two columns show the baseline energy consumption and EER for each cooling product, based upon the efficiency level specified in EPCA 92. Baseline energy consumption is defined as the cumulative energy consumption of all products in that size category sold between 2004 and 2030. The top three products in terms of overall energy consumption are the 3-phase single-package air conditioner (<65 kBtu/h), the central air source air conditioner (≥65 kBtu/h and <135 kBtu/h), and the central air source air conditioner (≥135 kBtu/h and <240 kBtu/h).

The 3-phase unitary and HP equipment are available up to a SEER of 15. At these efficiency levels, the potential savings through 2030 would exceed four quads of primary energy.

For the small central air source AC unit (≥65 kBtu and ≤135 kBtu), the adoption of Standard 90.1-1999 is expected to achieve about 0.9 quads (900 TBtu) of savings over the 2004 to 2030 time frame. This level of energy savings results from an increase in EER from 8.5 to 9.7. For an efficiency of 11.5 EER, the additional energy savings potential is nearly one quad.

The energy savings potentials for heating products are shown in Table 3.3. In terms of total energy consumption, the category is dominated by gas-fired furnaces (as part of packaged space-conditioning equipment). Baseline energy consumption for the two size categories of furnaces over the 2004 to 2030 period is nearly 16 quads, while consumption for all of the boiler classes is less than 5 quads. All of the efficiency metrics are in terms of thermal efficiency. Thermal efficiency generally ranges from 3-to-5 percentage points less than the combustion efficiency levels for these products.

Table 3.4 shows the national energy savings potential for the commercial water-heating equipment considered in the analysis. To maintain simplicity in the table, only the thermal efficiency requirement of the storage water heaters is shown in the table. In some cases, two levels of energy savings are shown for the same thermal efficiency; this result arises from different standby loss requirements.

Table 3.2. National Baseline Energy Consumption and Energy Savings – Space-Cooling Equipment

Product	EPCA 1992		Standard 90.1-1999 *Relative to EPCA 92*		Efficiency Level 1 *Relative to 90.1-1999*		Efficiency Level 2 *Relative to 90.1-1999*		Efficiency Level 3 *Relative to 90.1-1999*		Efficiency Level 4 *Relative to 90.1-1999*	
	2004-2030 Baseline Consumption (TBtu)	**EER**	**EER**	**Energy Savings (TBtu)**	**EER**	**Energy Savings (TBtu)**	**EER**	**Energy Savings (TBtu)**	**EER**	**Energy Savings (TBtu)**	**EER**	**Energy Savings (TBtu)**
3-Phase, Single-Packaged, Air-Source AC, <65 kBtu/h[a]	7,371	9.7	9.7	0.0	11.0	871	12.0	1,413	13.0	1,871	15.0	2,604
3-Phase, Single-Packaged, Air-Source HP, <65 kBtu/h[a]	958	9.7	9.7	0.0	11.0	113	12.0	184	13.0	243	15.0	338
3-Phase, Split-system, Air-Source AC, <65 kBtu/h[a]	3,064	10.0	10.0	0.0	11.0	279	12.0	511	13.0	707	15.0	1,021
3-Phase, Split-system, Air-Source HP, <65 kBtu/h[a]	398	10.0	10.0	0.0	11.0	36	12.0	66	13.0	92	15.0	133
Central, Air-Source AC, ≥65 and <135 kBtu/h	8,813	8.9	10.3	1,198	10.5	145	10.8	353	11.0	485	12.5	1,340
Central, Air-Source HP, ≥65 and <135 kBtu/h	908	8.9	10.1	108	10.5	31	10.6	38	11.0	66	11.7	109
Central, Water-Cooled AC, <65 kBtu/h	28	9.3	12.1	7	12.5	1	13.1	2	14.0	3	12.5	1
Central, Water-Source HP, <17 kBtu/h	333	9.3	11.2	57	12.5	29	13.1	40	14.0	55	15.8	81
Central, Water-Source HP, ≥17 and <65 kBtu/h	2,096	9.3	12.0	472	12.5	65	13.1	136	14.0	232	15.2	342
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	41	10.5	11.5	4	12.0	2	12.4	3	14.0	7	NA	NA
Central, Water-Source HP, ≥65 and <135 kBtu/h	256	10.5	12.0	32	12.5	9	13.0	17	14.0	32	NA	NA
Central, Air-Source AC, ≥135 and <240 kBtu/h	7,270	8.5	9.7	899	10.2	312	10.4	429	10.8	649	11.5	997
Central, Air-Source HP, ≥135 and <240 kBtu/h	324	8.5	9.3	28	9.8	15	10.4	31	10.8	41	10.5	34
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	67	9.6	11.0	9	11.1	1	11.2	1	11.3	2	11.5	3
Packaged Terminal AC, <7 kBtu/h	75	8.9	9.4	4	11.0	10	11.2	12	0.0	NA	11.6	13
Packaged Terminal AC, 7-10 kBtu/h	567	8.6	9.0	27	10.6	82	10.8	92	11.5	118	11.5	118
Packaged Terminal AC, 10-13 kBtu/h	848	8.1	8.3	27	9.9	132	10.2	150	10.5	169	10.7	181
Packaged Terminal AC, >13 kBtu/h	488	7.8	7.9	10	9.5	80	9.8	91	10.0	100	10.0	100
Packaged Terminal HP, <7 kBtu/h	66	8.9	9.3	3	10.8	9	11.0	10	0.0	NA	11.6	13
Packaged Terminal HP, 7-10 kBtu/h	543	8.6	8.9	20	10.4	76	10.6	86	11.4	116	11.5	119
Packaged Terminal HP, 10-13 kBtu/h	647	8.1	8.2	13	9.7	98	10.0	112	10.5	136	10.7	146
Packaged Terminal HP, >13 kBtu/h	410	7.8	7.8	3	9.3	66	9.6	75	10.0	89	10.0	89

(a) SEER Rating

Table 3.3. National Baseline Energy Consumption and Energy Savings – Space-Heating Equipment

	EPCA 1992		**Standard 90.1-1999** ***Relative to EPCA 92***		**Efficiency Level 1** ***Relative to 90.1-1999***		**Efficiency Level 2** ***Relative to 90.1-1999***		**Efficiency Level 3** ***Relative to 90.1-1999***		**Efficiency Level 4** ***Relative to 90.1-1999***	
Product	**2004-2030 Baseline Consumption (TBtu)**	**Thermal Efficiency (%)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**
Packaged Boilers, Gas-Fired, 400 kBtu/h, HW	684	75.0	75.0	0	78.0	26	79.0	35	81.0	51	88.0	101
Packaged Boilers, Gas-Fired, 800 kBtu/h, HW	1,493	75.0	75.0	0	76.0	20	78.0	57	79.0	76	88.0	221
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, HW	491	75.0	75.0	0	77.0	13	78.0	19	79.0	25	88.0	73
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, HW	324	75.0	75.0	0	78.0	13	79.0	16	80.0	20	88.0	48
Packaged Boilers, Gas-Fired, 400 kBtu/h, Steam	320	72.0	75.0	13	76.0	4	77.0	8	79.0	16	82.0	26
Packaged Boilers, Gas-Fired, 800 kBtu/h, Steam	875	72.0	75.0	35	76.0	11	78.0	32	79.0	43	82.0	72
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, Steam	402	72.0	75.0	16	77.0	10	78.0	15	79.0	20	81.0	29
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, Steam	256	72.0	72.0	0	78.0	20	79.0	23	80.0	26	82.0	31
Warm-Air Furnaces, Gas-Fired, 250 kBtu/h	7,392	75.1	77.5	237	78.5	91	79.5	180	0.0	NA	85.5	669
Warm-Air Furnaces, Gas-Fired, 400 kBtu/h	7,562	75.1	77.5	242	78.5	93	79.5	184	0.0	NA	85.5	685

Table 3.4. National Baseline Energy Consumption and Energy Savings – Water-Heating Equipment

	EPCA 1992		Standard 90.1-1999 *Relative to EPCA 92*		Efficiency Level 1 *Relative to 90.1-1999*		Efficiency Level 2 *Relative to 90.1-1999*		Efficiency Level 3 *Relative to 90.1-1999*		Efficiency Level 4 *Relative to 90.1-1999*	
Product	**2004-2030 Baseline Consumption (TBtu)**	**Thermal Efficiency (%)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**	**Thermal Efficiency (%)**	**Energy Savings (TBtu)**
Storage Water Heater, Gas-Fired, 120 kBtu/h	408	78.0	80.0	13	82.0	9	82.0	11	86.0	36	94.0	64
Storage Water Heater, Gas-Fired, 199 kBtu/h	1,282	78.0	80.0	23	82.0	28	82.0	33	86.0	112	94.0	204
Storage Water Heater, Gas-Fired, 360 kBtu/h	2,188	78.0	80.0	31	82.0	50	82.0	54	86.0	189	94.0	350
Instantaneous Water Heater, Gas-Fired, 400 kBtu/h	2,822	80.0	80.0	0	83.0	41	NA	NA	86.0	79	94.0	168
Instantaneous Water Heater, Gas-Fired, 1,000 kBtu/h	2,822	80.0	80.0	0	83.0	102	NA	NA	86.0	197	94.0	420
Instantaneous Tank Type, Water Heater, Gas-Fired, 500 kBtu/h	155	77.0	80.0	5	82.0	4	82.0	4	86.0	12	94.0	24
Electric (120 gal)	738	99.4	99.3	-7	99.4	7	NA	NA	0.0	NA	NA	NA

For gas-fired storage water heaters, the estimated total energy savings from adopting Standard 90.1-1999 is about 125 TBtu. With fully condensing units at 94% efficiency, the savings would climb to over 500 TBtu (or over one-half quad).

Based on the available information, the estimated consumption of instantaneous-type water heaters is significant in the commercial sector. At the baseline level of efficiency, these units may consume over 50% of the total natural gas used for water heating in the commercial sector. Because ASHRAE did not address these products in Standard 90.1-1999, the energy savings in the first set of columns is zero. As with storage water heaters, the selection of condensing technology for these products (94% thermal efficiency) would yield over one-half quad of energy savings.

One size of electric water heater was also analyzed. As discussed in Section 2.0, the Standard 90.1-1999 appears to have relaxed the standby loss requirements for electric water heaters. This factor leads to a calculated increase in energy use (negative energy savings) of a little more than 7 TBtu as shown in Table 3.4.

3.3.3 Estimates of National NPV

National NPV provides an aggregate measure of the discounted total dollar savings to the nation from the use of higher-efficiency equipment. For the screening analysis, the national NPV is based on the sum of the discounted LCC savings for all 77 market segments discussed in Section 3.1. The final expression for calculating NPV is shown in Equation 3.13 (Section 3.4.2).

Tables 3.5 through 3.7 provide a summary of the national NPV for up to four efficiency levels beyond those in the Standard 90.1-1999.

Table 3.5 shows the NPV for cooling products. The first row of the table presents the results for 3-phase single package cooling equipment. The “Efficiency Level 2” has the maximum NPV [897.7 million (1998) dollars] of the four efficiency levels considered in the screening analysis.

The higher efficiency levels for this product, at EERs of 13 and 15 show negative NPV values. In these instances, the discounted energy cost savings from higher efficiency levels are insufficient to offset the increase in first cost of the equipment. As is shown in the subsequent section, these results reflect the underlying life-cycle costs that tend to increase for higher levels of efficiency. For some products, [(e.g., central air source AC (≥65 kBtu/h and <135 kBtu/h)] all efficiency levels beyond the Standard 90.1-1999 have a negative NPV.

Other cooling products with relatively high values of NPV for efficiency levels beyond Standard 90.1-1999 levels include large central air-source A/C equipment (≥135 kBtu/h and <240 kBtu/h) and several of the packaged terminal A/C and HP equipment.

Table 3.5. NPV for Efficiency Levels Exceeding Standard 90.1-1999 – Space-Cooling Equipment

Product	ASHRAE 90.1-1999	**Efficiency Level 1** *Relative to 90.1-1999*		**Efficiency Level 3** *Relative to 90.1-1999*		**Efficiency Level 3** *Relative to 90.1-1999*		**Efficiency Level 4** *Relative to 90.1-1999*	
	EER	EER	NPV (mill.98$)	EER	NPV (mill.98$)	EER	NPV (mill.98$)	EER	NPV (mill.98$)
3-Phase, Single-Packaged, Air-Source AC, <65 kBtu/h[(a)]	9.7	11.0	521.6	12.0	897.7	13.0	-290.6	15.0	-2,649.5
3-Phase, Single-Packaged, Air-Source HP, <65 kBtu/h[(a)]	9.7	11.0	88.2	12.0	91.3	13.0	-102.7	15.0	-430.6
3-Phase, Split-system, Air-Source AC, <65 kBtu/h[(a)]	10.0	11.0	109.1	12.0	14.9	13.0	-344.4	15.0	-1,857.4
3-Phase, Split-system, Air-Source HP, <65 kBtu/h[(a)]	10.0	11.0	36.5	12.0	47.0	13.0	27.0	15.0	-121.5
Central, Air-Source AC, ≥65 and <135 kBtu/h	10.3	10.5	-102.9	10.8	-362.0	11.0	-689.6	12.5	-8,623.1
Central, Air-Source HP, ≥65 and <135 kBtu/h	10.1	10.5	-65.0	10.6	-86.5	11.0	-242.5	11.7	-795.9
Central, Water-Cooled AC, <65 kBtu/h	12.1	12.5	-0.4	13.1	-1.6	14.0	-6.1	12.5	-$0.4
Central, Water-Source HP, <17 kBtu/h	11.2	12.5	-18.3	13.1	-54.7	14.0	-149.9	15.8	NA
Central, Water-Source HP, ≥17 and <65 kBtu/h	12.0	12.5	23.0	13.1	-8.4	14.0	-186.9	15.2	NA
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	11.5	12.0	0.7	12.4	0.8	14.0	-2.0	0.0	NA
Central, Water-Source HP, ≥65 and <135 kBtu/h	12.0	12.5	-0.6	13.0	-8.3	14.0	-48.2	0.0	NA
Central, Air-Source AC, ≥135 and <240 kBtu/h	9.7	10.2	372.2	10.4	417.9	10.8	NA	11.5	NA
Central, Air-Source HP, ≥135 and <240 kBtu/h	9.3	9.8	3.2	10.4	3.2	10.8	NA	10.5	NA
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	11.0	11.1	1.1	11.2	1.1	11.3	1.7	11.5	3.0
Packaged Terminal AC, <7 kBtu/h	9.4	11.0	-2.2	11.2	-6.4	0.0	NA	11.6	NA
Packaged Terminal AC, 7-10 kBtu/h	9.0	10.6	72.2	10.8	72.0	11.5	7.4	11.5	7.4
Packaged Terminal AC, 10-13 kBtu/h	8.3	9.9	97.6	10.2	103.4	10.5	102.7	10.7	NA
Packaged Terminal AC, >13 kBtu/h	7.9	9.5	99.1	9.8	88.6	10.0	45.8	10.0	45.8
Packaged Terminal HP, <7 kBtu/h	9.3	10.8	-2.1	11.0	-6.7	0.0	NA	11.6	NA
Packaged Terminal HP, 7-10 kBtu/h	8.9	10.4	70.1	10.6	77.4	11.4	36.0	11.5	NA
Packaged Terminal HP, 10-13 kBtu/h	8.2	9.7	103.0	10.0	85.9	10.5	16.2	10.7	NA
Packaged Terminal HP, >13 kBtu/h	7.8	9.3	61.6	9.6	57.8	10.0	39.0	10.0	39.0

(a) SEER Rating

Table 3.6. NPV for Efficiency Levels Exceeding Standard 90.1-1999 – Space-Heating Equipment

Products	ASHRAE 90.1-1999	Efficiency Level 2 *Relative to 90.1-1999*		Efficiency Level 2 *Relative to 90.1-1999*		Efficiency Level 3 *Relative to 90.1-1999*		Efficiency Level 4 *Relative to 90.1-1999*	
	Thermal Efficiency (%)	**Thermal Efficiency (%)**	**NPV (mill. 98$)**	**Thermal Efficiency (%)**	**NPV (mill. 98$)**	**Thermal Efficiency (%)**	**NPV (mill. 98$)**	**Thermal Efficiency (%)**	**NPV (mill. 98$)**
Packaged Boilers, Gas-Fired, 400 kBtu/h, HW	75.0	78.0	17.9	79.0	4.5	81.0	-89.4	88.0	-180.2
Packaged Boilers, Gas-Fired, 800 kBtu/h, HW	75.0	76.0	5.9	78.0	42.5	79.0	-20.3	88.0	19.6
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, HW	75.0	77.0	17.2	78.0	23.0	79.0	17.7	88.0	64.6
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, HW	75.0	78.0	16.5	79.0	19.3	80.0	24.8	88.0	55.9
Packaged Boilers, Gas-Fired, 400 kBtu/h, Steam	75.0	76.0	1.6	77.0	-8.5	79.0	-70.9	82.0	-87.8
Packaged Boilers, Gas-Fired, 800 kBtu/h, Steam	75.0	76.0	8.9	78.0	-23.8	79.0	-16.3	82.0	-78.5
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, Steam	75.0	77.0	2.8	78.0	1.8	79.0	4.5	81.0	10.5
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, Steam	72.0	78.0	21.2	79.0	24.3	80.0	27.9	82.0	30.8
Warm-Air Furnaces, Gas-Fired, 250 kBtu/h	77.5	78.5	-120.5	79.5	-244.3	0.0	NA	85.5	-3,511.5
Warm-Air Furnaces, Gas-Fired, 400 kBtu/h	77.5	78.5	-68.9	79.5	-141.3	0.0	NA	85.5	-3,549.1

Table 3.7. NPV for Efficiency Levels Exceeding Standard 90.1-1999 – Water-Heating Equipment

Product	Standard 90.1-1999	Efficiency Level 1 *Relative to 90.1-1999*		Efficiency Level 2 *Relative to 90.1-1999*		Efficiency Level 3 *Relative to 90.1-1999*		Efficiency Level 4 *Relative to 90.1-1999*	
	Thermal Efficiency (%)	Thermal Efficiency (%)	NPV (mill.98$)	Thermal Efficiency (%)	NPV (mill.98$)	Thermal Efficiency (%)	NPV (mill.98$)	Thermal Efficiency (%)	NPV (mill.98$)
Storage Water Heater, Gas-Fired, 120 kBtu/h	80.0	82.0	-0.7	82.0	-6.0	86.0	-229.3	94.0	-466.6
Storage Water Heater, Gas-Fired, 199 kBtu/h	80.0	82.0	-2.9	82.0	-15.2	86.0	-656.4	94.0	-1,130.0
Storage Water Heater, Gas-Fired, 360 kBtu/h	80.0	82.0	-7.3	82.0	-19.5	86.0	-1,121.8	94.0	-1,942.4
Instantaneous Water Heater, Gas-Fired, 400 kBtu/h	80.0	83.0	-113.2	NA	NA	86.0	-636.0	94.0	-1,085.7
Instantaneous Water Heater, Gas-Fired, 1,000 kBtu/h	80.0	83.0	45.3	NA	NA	86.0	-79.6	94.0	-314.4
Instantaneous Tank Type, Water Heater, Gas-Fired, 500 kBtu/h	80.0	82.0	-3.4	82.0	-4.0	86.0	-105.0	94.0	-160.1
Electric (120 gal)	99.3	99.4	1.1	0.0	NA	0.0	NA	0.0	NA

The national NPV results for heating equipment are shown in Table 3.6. The highest levels of NPV are estimated for the highest efficiency levels for largest two size categories of hot water boilers. Total potential cost savings to the nation is in excess of $100 million if these efficiency levels were chosen as compared to Standard 90.1-1999 levels.

Table 3.7 displays the results of the NPV calculations for water heaters. The estimate of national NPV is significantly positive for only one product—the larger-sized instantaneous water heater.

3.4 Life-Cycle Cost Analysis

LCC is a measure of the total cost of a unit of equipment over its lifetime, including the initial purchase price of the equipment and the annual operating expenses. Future operating expenses are discounted to the time of equipment purchase and summed over its expected lifetime. LCC is defined as

$$\text{LCC} = \text{EQPCOST} + \sum_{t=1}^{N} \frac{\text{OPCOST(t)}}{(1+r)^{t}} \tag{3.5}$$

where EQPCOST = equipment cost (purchase price)
OPCOST = annual operating expense
R = discount rate (real)
N = expected equipment lifetime (years).

LCC provides a method to evaluate the trade-off between the purchase price and the operating expenses of a particular type of equipment. Alternative measures of this trade-off include payback period and internal rate of return.

The annual operating expense in Equation (3.5) is generally broken into two overall categories: 1) maintenance and repair costs and 2) energy costs. For the present screening analysis, maintenance costs are assumed to remain constant across various equipment efficiencies. This assumption leads to the result that any net *change* in LCC depends solely on the change in the purchase cost offset by the change in (discounted) energy costs.

Based on the information in Section 3.1.1 on energy savings, annual unit energy cost can be expressed as[(a)]

$$\text{Annual Unit Energy Cost} = \frac{\text{Rated Capacity x FLEOH x PFUEL}}{\text{Rated Efficiency}} \tag{3.6}$$

where PFUEL = price of the relevant energy source ($/kWh, $/therm, etc.).

(a) The equations that follow relate to the cooling and heating products. The equations for water heaters would include a term to represent the standby losses, analogous to Equation (3.2).

In the present analysis, we account for changes in future fuel price, as reflected in the projections in the *Annual Energy Outlook 2000* (EIA 1999a). For a given efficiency level, Rated Efficiency$_k$, equipment lifetime N, and discount rate r, we can then combine Equations (3.5) and (3.6) to yield a general expression for LCC as

$$LCC(k) = EQPCOST + \sum_{t=1}^{N} \frac{\text{Rated Capacity x FLEOH x PFUEL}_t}{(1+r)^t \text{ x Rated Efficiency}_k} \qquad (3.7)$$

where t = 0 denotes the time the equipment is installed.

LCC savings per unit of equipment is computed as the difference in the LCC between two efficiency levels. Consistent with the discussion above, the efficiency level index (k) is assigned a value of 0 for the baseline standard. The LCC savings associated with a more stringent standard with an enhanced efficiency level is

$$LCC(k) \text{ savings} = LCC(0) - LCC(k) \qquad (3.8)$$

3.4.1 Market Segment to National Average Results

The development of a national measure of NPV follows the same procedure used to estimate national energy consumption and savings, namely an aggregation of results from the individual market segments. In this case, LCC is calculated for each building type i and subcensus division j as

$$LCC(k)_{i,j} = EQPCOST + \sum_{t=1}^{N} \frac{\text{Rated Capacity x FLEOH}_{i,j} \text{ x PFUEL}_{j,t}}{(1+r)^t \text{ x Rated Efficiency}_k} \qquad (3.9)$$

Note that region-specific fuel prices are used in determining LCC for each market segment.

A national average unit LCC can then be calculated as an appropriately weighted average of the LCC results for the market segments. This aggregation is represented formally as:

$$LCC(k)_{US} = \sum_{i}^{7} \sum_{j}^{11} MS_{i,j} \text{ x } LCC(k)_{i,j} \qquad (3.10)$$

In contrast, an alternative summary measure of the average cost effectiveness of a particular efficiency level relative to baseline efficiency is the change in LCC for a unit operated at the national average number of operating hours ($FLEOH_{US}$) with the national average price of energy ($PFUEL_{US}$). Using the notation in Equation (3.9), the expression for LCC at the national level for efficiency level k is

$$LCC(k)'_{US} = EQPCOST + \sum_{t=1}^{N} \frac{\text{Rated Capacity x FLEOH}_{US} \text{ x PFUEL}_{US,t}}{(1+r)^t \text{ x Rated Efficiency}_k} \qquad (3.11)$$

In general, the existence of interactions between the FLEOH and energy prices by market segment will lead to results from Equation (3.11) differing from those generated by Equation (3.9). Thus, the same congruity of results between the approaches is not achieved for the LCC calculation as it is for national energy consumption [i.e., using Equations (3.1) and (3.2)].

The market segment approach implemented in the screening analysis provides some ability to identify and estimate the percentage of the building population (or, more specifically, final purchasers of the commercial equipment under consideration) that is likely to experience reductions in LCC from a higher level of efficiency and equipment cost. The segmentation approach is intended to capture some of the key variables influencing the distribution of the LCC savings but does not try to reflect all of the factors that may contribute to the variability.(a)

Based on the weighting specification in Equation (3.10), Tables 3.8 through 3.10 present the LCC estimates for each efficiency level, beginning with the EPCA 92 level. The use of projected energy prices in the screening analysis implies that the LCC for each market segment will differ to a small degree for each year of the analysis period, 2004-2030. In the LCC tables, the LCC estimates assume the equipment is purchased in 2010. The annual energy costs thus are based on the energy prices projected for 2010 and extending though the expected life of the equipment [see Equation (3.7)].

Table 3.8 shows the LCC estimates for the 22 cooling products analyzed. Considerable variation in the magnitude of the LCC across the products exists, reflecting the size and associated first cost of the equipment. At the EPCA 92 efficiency level, a packaged terminal AC unit has an estimated LCC of $1,377, while the LCC for a large central AC unit is over $30,000.

For the first product in the table—3-phase single-package AC equipment, the LCC declines from $8,524 for an EER of 9.7 to $8,198 for an EER of 12.0. The nature of the cost-efficiency relationship suggests that LCC would rise for higher efficiency levels. At an EER of 15, the analysis suggests that the LCC would be about $1,500 higher than at the minimum point.

Table 3.9 shows the LCC at each efficiency level for the 10 heating products in the analysis. The magnitude of the LCCs, especially for boilers, are considerably greater than for the cooling products. For the largest class of boilers, the sum of the first cost and discounted energy costs over the assumed 30-year life of the equipment is approximately $400,000. For these large boilers, the cost savings to an individual consumer can be considerable.

(a) Some simple measures associated with the distribution of LCC savings by efficiency level are generated in the screening analysis spreadsheet and are discussed in Appendix C.

Table 3.8. Market Segment Weighted LCC for All Efficiency Levels – Space-Cooling Equipment

Product	EPCA 1992		Standard 90.1 1999		Efficiency Level 1		Efficiency Level 2		Efficiency Level 3		Efficiency Level 4	
	EER	LCC 98 $/unit	EER	LCC 98 $/unit	EER	LCC 98 $/unit	EER	LCC 98 $/unit	EER	LCC 98 $/unit	EER	LCC 98 $/unit
3-Phase, Single-Packaged, Air-Source AC, <65 kBtu/h[(a)]	9.7	8,777	9.7	8,777	11.0	8,560	12.0	8,403	13.0	8,900	15.0	9,888
3-Phase, Single-Packaged, Air-Source HP, <65 kBtu/h[(a)]	9.7	9,258	9.7	9,258	11.0	8,975	12.0	8,966	13.0	9,591	15.0	10,647
3-Phase, Split-system, Air-Source AC, <65 kBtu/h[(a)]	10.0	8,643	10.0	8,643	11.0	8,537	12.0	8,629	13.0	8,980	15.0	10,458
3-Phase, Split-system, Air-Source HP, <65 kBtu/h[(a)]	10.0	8,587	10.0	8,587	11.0	8,313	12.0	8,236	13.0	8,386	15.0	9,503
Central, Air-Source AC, ≥65 and <135 kBtu/h	8.9	13,453	10.3	13,090	10.5	13,146	10.8	13,286	11.0	13,464	12.5	17,765
Central, Air-Source HP, ≥65 and <135 kBtu/h	8.9	14,573	10.1	14,533	10.5	14,875	10.6	14,989	11.0	15,809	11.7	18,721
Central, Water-Cooled AC, <65 kBtu/h	9.3	10,621	12.1	10,027	12.5	10,073	13.1	10,236	14.0	10,804	12.5	10,073
Central, Water-Source HP, <17 kBtu/h	9.3	2,214	11.2	2,091	12.5	2,131	13.1	2,210	14.0	2,418	15.8	NA
Central, Water-Source HP, ≥17 and <65 kBtu/h	9.3	5,417	12.0	4,732	12.5	4,708	13.1	4,741	14.0	4,926	15.2	NA
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	10.5	12,728	11.5	12,486	12.0	12,409	12.4	12,400	14.0	12,712	0.0	NA
Central, Water-Source HP, ≥65 and <135 kBtu/h	10.5	12,553	12.0	12,004	12.5	12,015	13.0	12,154	14.0	12,868	0.0	NA
Central, Air-Source AC, ≥135 and <240 kBtu/h	8.5	28,308	9.7	26,877	10.2	26,366	10.4	26,303	10.8	NA	11.5	NA
Central, Air-Source HP, ≥135 and <240 kBtu/h	8.5	30,256	9.3	29,680	9.8	29,582	10.4	29,583	10.8	NA	10.5	NA
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	9.6	28,399	11.0	27,145	11.1	26,988	11.2	26,980	11.3	26,888	11.5	26,705
Packaged Terminal AC, <7 kBtu/h	8.9	1,467	9.4	1,441	11.0	1,452	11.2	1,473	0.0	NA	11.6	NA
Packaged Terminal AC, 7-10 kBtu/h	8.6	1,882	9.0	1,851	10.6	1,782	10.8	1,782	11.5	1,844	11.5	1,844
Packaged Terminal AC, 10-13 kBtu/h	8.1	2,256	8.3	2,229	9.9	2,139	10.2	2,134	10.5	2,134	10.7	NA
Packaged Terminal AC, >13 kBtu/h	7.8	2,861	7.9	2,827	9.5	2,626	9.8	2,647	10.0	2,734	10.0	2,734
Packaged Terminal HP, <7 kBtu/h	8.9	1,547	9.3	1,525	10.8	1,536	11.0	1,562	0.0	NA	11.6	NA
Packaged Terminal HP, 7-10 kBtu/h	8.6	1,964	8.9	1,951	10.4	1,881	10.6	1,874	11.4	1,915	11.5	NA
Packaged Terminal HP, 10-13 kBtu/h	8.1	2,334	8.2	2,309	9.7	2,185	10.0	2,206	10.5	2,290	10.7	NA
Packaged Terminal HP, >13 kBtu/h	7.8	2,921	7.8	2,909	9.3	2,760	9.6	2,770	10.0	2,815	10.0	2,815

(a) SEER Rating

Table 3.9. Market Segment Weighted LCC for All Efficiency Levels – Space-Heating Equipment

Product	EPCA 1992		Standard 90.1 1999		Efficiency Level 1		Efficiency Level 2		Efficiency Level 3		Efficiency Level 4	
	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit
Packaged Boilers, Gas-Fired, 400 kBtu/h, HW	75.0	39,588	75.0	39,588	78.0	39,022	79.0	39,447	81.0	42,422	88.0	45,303
Packaged Boilers, Gas-Fired, 800 kBtu/h, HW	75.0	76,282	75.0	76,282	76.0	76,109	78.0	75,047	79.0	76,873	88.0	75,716
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, HW	75.0	140,462	75.0	140,462	77.0	137,621	78.0	136,656	79.0	137,536	88.0	129,770
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, HW	75.0	276,835	75.0	276,835	78.0	268,564	79.0	267,120	80.0	264,382	88.0	248,775
Packaged Boilers, Gas-Fired, 400 kBtu/h, Steam	72.0	42,890	75.0	42,130	76.0	42,016	77.0	42,732	79.0	47,134	82.0	48,320
Packaged Boilers, Gas-Fired, 800 kBtu/h, Steam	72.0	81,190	75.0	79,664	76.0	79,206	78.0	80,896	79.0	80,507	82.0	83,719
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, Steam	72.0	150,969	75.0	146,346	77.0	145,765	78.0	145,964	79.0	145,391	81.0	144,137
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, Steam	72.0	293,020	72.0	293,020	78.0	278,973	79.0	276,939	80.0	274,533	82.0	272,651
Warm-Air Furnaces, Gas-Fired, 250 kBtu/h	75.1	16,311	77.5	16,404	78.5	16,501	79.5	16,602	0.0	NA	85.5	19,242
Warm-Air Furnaces, Gas-Fired, 400 kBtu/h	75.1	25,737	77.5	25,409	78.5	25,496	79.5	25,588	0.0	NA	85.5	29,896

Table 3.10. Market Segment Weighted LCC for All Efficiency Levels – Water-Heating Equipment

Product	EPCA 1992		Standard 90.1 1999		Efficiency Level 1		Efficiency Level 2		Efficiency Level 3		Efficiency Level 4	
	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit	Thermal Efficiency (%)	LCC 98 $/unit
Storage Water Heater, Gas-Fired, 120 kBtu/h	78.0	4,881	80.0	4,858	82.0	4,861	82.0	4,883	86.0	5,831	94.0	6,837
Storage Water Heater, Gas-Fired, 199 kBtu/h	78.0	6,954	80.0	6,975	82.0	6,981	82.0	7,007	86.0	8,366	94.0	9,370
Storage Water Heater, Gas-Fired, 360 kBtu/h	78.0	11,879	80.0	11,954	82.0	11,969	82.0	11,995	86.0	14,332	94.0	16,072
Instantaneous Water Heater, Gas-Fired, 400 kBtu/h	80.0	15,857	80.0	15,857	83.0	16,192	NA	NA	86.0	17,741	94.0	19,072
Instantaneous Water Heater, Gas-Fired, 1,000 kBtu/h	80.0	36,280	80.0	36,280	83.0	35,945	NA	NA	86.0	36,869	94.0	38,607
Instantaneous Tank Type, Water Heater, Gas-Fired, 500 kBtu/h	77.0	16,433	80.0	16,457	82.0	16,592	82.0	16,618	86.0	20,668	94.0	22,874
Electric (120 gal)	99.4	8,001	99.3	8,056	99.4	8,052	0.0	NA	0.0	NA	0.0	NA

For the large boiler (>3,000 kBtu/h), the cost saving from going to a condensing model (at 88% thermal efficiency) is nearly $50,000 compared with the current standard (both EPCA 92 and 90.1-1999) of 75%[a].

The LCC by efficiency level for water-heating equipment is shown in Table 3.10. The shorter lifetimes of the storage water heaters—compared with the instantaneous type—are reflected in smaller LCCs. Except for the large instantaneous water heater (the fifth product listed in Table 3.10), the minimum LCC is generally at the Standard 90.10-1999 level.

3.4.2 Methodology Used to Compute National NPV

The discussion on Equations (3.7) through (3.11) focuses exclusively on the LCC and LCC savings for a single unit of equipment. Of course, the potential national economic benefits of setting an efficiency standard for any specific product depends on both the unit LCC savings and the size of the market (total shipments) for that product.

Following the approach in previous analyses of national equipment efficiency standards, a convenient summary metric of the benefits is the national NPV of the cost savings. For the screening analysis, the method used to compute this metric first involved estimating the present value of the total LCC savings associated with each year's shipments.[b]

At the efficiency level k, the national LCC savings (NLCCS) from total shipments in year "y" meeting the standard can be expressed as

$$\text{NLCCS}(y,k) = \text{Shipments}(y) \ x \sum_{i}^{7} \sum_{j}^{11} \text{MS}_{i,j} \ x \ [(\text{LCC}(y,0)_{i,j} - \text{LCC}(y,k)_{i,j}] \qquad (3.12)$$

Note that in Equation (3.12) the expressions for LCC include the year y as an argument, recognizing that the LCC may vary for each year depending on the levels of energy prices. For the preliminary screening analysis, the national NPV is evaluated for the year 2000 using a time horizon that extends to 2030.[a] National NPV is thus based on discounting the national LCC savings associated with each year's shipments back to the "present" year 2000 and summing the results. Thus, we have

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(a) In all LCC discussions, an "individual" user represents the *average* consumer across the market segments. Depending on climate and energy prices, some consumers would experience greater savings and others would have smaller savings.

(b) This analysis assumes a common discount rate that is used in the LCC calculations and in the NPV calculation. With this assumption, the LCC savings and NPV would be the same for units shipped in the "present" year and where the energy cost savings is discounted to this year. The "net" in the NPV compares the present value of the purchase price offset by the present (i.e., discounted) value of the energy savings. When applied to vintages of equipment shipments over a period of future years, the NPV calculation recognizes that national economic benefits in these more distant future years are not as valuable as near-term benefits.

$$\text{National NPV}(k) = \sum_{y=2000}^{2030} \frac{\text{NLCCS}(y,k)}{(1+r)^{y-2000}} \qquad (3.13)$$

3.5 Reductions in Environmental Emissions

The reductions in energy consumption from the use of more energy-efficient commercial equipment help to lower the nation's total environmental emissions associated with the burning of fossil fuels. Two categories of emissions were considered in the screening analysis: 1) carbon (as part of CO_2 released in combustion process) and 2) nitrous oxides (NO_x). The results in Table 3.11 show the estimated reductions in carbon emissions for all products in the screening analysis. More detailed results, which include the estimates of NOx emissions, are shown in Appendices C and D.

The factors to convert electricity and natural gas savings to reductions in these emissions were extracted from a table used by the DOE Office of Energy Efficiency and Renewable Energy (EERE) in its assessment of various DOE energy conservation programs (DOE 1999).

The values in the EERE table are derived from conversion factors developed by EIA. EIA, however, provides emissions factors only for primary fuels and not for electricity. EERE has subsequently developed emissions factors for electricity that reflect a projection of fuels that would likely be impacted due to marginal reductions in electricity consumption.

In Table 3.11, the energy savings from adopting the Standard 90.1-1999 efficiency level, as well as a higher efficiency level (corresponding to maximum national NPV), were translated into estimates of millions of metric tons (MMtons) of carbon emissions reductions. The total carbon emissions reduction from the adoption of Standard 90.1-1999 is estimated to be about 52 MMtons. An additional 51 MMtons could be reduced by moving to the efficiency level with maximum NPV.

The *Annual Energy Outlook 2000* (EIA 1999a) projects carbon emissions through 2020 for each major end use sector (residential, commercial, industrial, transportation) consistent with their energy consumption projections. Based on extrapolating the AEO projections to 2030 by using the 2015-2020 annual growth rate, the cumulative commercial-sector carbon emissions between 2004 and 2030 are estimated to be about 8,100 MMtons. Thus, adopting Standard 90.1-1999 would cut total emissions over this period by roughly 0.7%. Based on the data used in the screening analysis, an additional 0.6% could be reduced with more stringent standards.

Table 3.11. Energy Savings and Carbon Reductions from Adopting Standard 90.1-1999 and from Maximum NPV

Product	Standard 90.1 1999			Efficiency with Maximum NPV		
	EER/ Thermal Efficiency (%)	Energy Savings (TBtu)	Carbon Reduction (MMtons)	EER/ Thermal Efficiency (%)	Additional Energy Savings (TBtu)	Additional Carbon Reduction (MMtons)
Cooling Equipment						
3-Phase, Single-Packaged, Air-Source AC, <65 kBtu/h[a]	9.7	0	0.0	12.0	1,413	20.8
3-Phase, Single-Packaged, Air-Source HP, <65 kBtu/h[a]	9.7	0	0.0	12.0	184	2.7
3-Phase, Split-system, Air-Source AC, <65 kBtu/h[a]	10.0	0	0.0	11.0	279	4.1
3-Phase, Split-system, Air-Source HP, <65 kBtu/h[a]	10.0	0	0.0	12.0	66	1.0
Central, Air-Source AC, ≥65 and <135 kBtu/h	10.3	1198	17.6	10.3	0	0.0
Central, Air-Source HP, ≥65 and <135 kBtu/h	10.1	108	1.6	10.1	0	0.0
Central, Water-Cooled AC, <65 kBtu/h	12.1	7	0.1	12.1	0	0.0
Central, Water-Source HP, <17 kBtu/h	11.2	57	0.8	11.2	0	0.0
Central, Water-Source HP, ≥17 and <65 kBtu/h	12.0	472	6.9	12.5	65	1.0
Central, Water-Cooled AC, ≥65 and <135 kBtu/h	11.5	4	0.1	12.4	3	0.0
Central, Water-Source HP, ≥65 and <135 kBtu/h	12.0	32	0.5	12.0	0	0.0
Central, Air-Source AC, ≥135 and <240 kBtu/h	9.7	899	13.2	10.4	429	6.3
Central, Air-Source HP, ≥135 and <240 kBtu/h	9.3	28	0.4	10.4	31	0.5
Central, Water-Cooled AC, ≥135 and <240 kBtu/h	11.0	9	0.1	11.5	3	0.0
Packaged Terminal AC, <7 kBtu/h	9.4	4	0.1	9.4	0	0.0
Packaged Terminal AC, 7-10 kBtu/h	9.0	27	0.4	10.6	82	1.2
Packaged Terminal AC, 10-13 kBtu/h	8.3	27	0.4	10.2	150	2.2
Packaged Terminal AC, >13 kBtu/h	7.9	10	0.1	9.5	80	1.2
Packaged Terminal HP, <7 kBtu/h	9.3	3	0.0	9.3	0	0.0
Packaged Terminal HP, 7-10 kBtu/h	8.9	20	0.3	10.6	86	1.3
Packaged Terminal HP, 10-13 kBtu/h	8.2	13	0.2	9.7	98	1.4
Packaged Terminal HP, >13 kBtu/h	7.8	3	0.0	9.3	66	1.0
Heating Equipment						
Packaged Boilers, Gas-Fired, 400 kBtu/h, HW	75.0	0	0.0	78.0	26	0.3
Packaged Boilers, Gas-Fired, 800 kBtu/h, HW	75.0	0	0.0	78.0	57	0.8
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, HW	75.0	0	0.0	88.0	73	0.9
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, HW	75.0	0	0.0	88.0	48	0.6
Packaged Boilers, Gas-Fired, 400 kBtu/h, Steam	75.0	13	0.2	76.0	4	0.1
Packaged Boilers, Gas-Fired, 800 kBtu/h, Steam	75.0	35	0.5	76.0	11	0.1
Packaged Boilers, Gas-Fired, 1,500 kBtu/h, Steam	75.0	16	0.2	81.0	29	0.4
Packaged Boilers, Gas-Fired, 3,000 kBtu/h, Steam	72.0	0	0.0	82.0	31	0.4
Warm-Air Furnaces, Gas-Fired, 250 kBtu/h	77.5	237	3.1	77.5	0	0.0
Warm-Air Furnaces, Gas-Fired, 400 kBtu/h	77.5	242	3.2	77.5	0	0.0

(a) SEER Rating

Table 3.11. (contd)

Product	Standard 90.1 1999 EER/ Thermal Efficiency (%)	Standard 90.1 1999 Energy Savings (TBtu)	Standard 90.1 1999 Carbon Reduction (MMtons)	Efficiency with Maximum NPV EER/ Thermal Efficiency (%)	Efficiency with Maximum NPV Additional Energy Savings (TBtu)	Efficiency with Maximum NPV Additional Carbon Reduction (MMtons)
Water Heating Equipment						
Storage Water Heater, Gas-Fired, 120 kBtu/h	80.0	13	0.2	80.0	0	0.0
Storage Water Heater, Gas-Fired, 199 kBtu/h	80.0	23	0.3	80.0	0	0.0
Storage Water Heater, Gas-Fired, 360 kBtu/h	80.0	31	0.5	80.0	0	0.0
Instantaneous Water Heater, Gas-Fired, 400 kBtu/h	80.0	0	0.0	80.0	0	0.0
Instantaneous Water Heater, Gas-Fired, 1,000 kBtu/h	80.0	0	0.0	83.0	102	1.5
Instantaneous Tank Type, Water Heater, Gas-Fired, 500 kBtu/h	80.0	5	0.1	80.0	0	0.0
Electric (120 gal)	99.3	-7	-0.1	99.4	7	0.1
Total			52.2			50.8

3.6 Summary of Results

Several of the product categories were analyzed at different representative sizes; e.g., the screening analysis included six different sizes of packaged gas-fired boilers with capacities <2,500 kBtu/h. Because the EPCA 1992 level and the Standard 90.1-1999 level are for a single category of gas-fired boilers with capacities <2,500 kBtu/h, the results presented in Table 3.3 were aggregated.

This aggregation was done for the following product categories:

- packaged terminal air conditioners
- packaged terminal heat pumps
- large gas-fired hot water boilers (>2,500 kBtu/h)
- large gas-fired steam boilers (>2,500 kBtu/h)
- small gas-fired boilers (<2,500 kBtu/h)
- gas storage water heaters (>155 kBtu/h)
- gas storage water heaters (<155 kBtu/h)
- instantaneous water heaters with tanks.

The efficiency levels were aggregated across the different capacities of equipment analyzed using the baseline energy consumption as relative weights. The baseline energy consumption, the energy savings, the NPV, and the carbon reductions were all summed up across the different capacities of the particular equipment category. The aggregated results are presented in Table 3.12.

Table 3.12. Aggregated Energy Savings and NPV for Efficiency Levels with Maximum NPV

Product	Efficiency Level			Energy Savings (TBtu)		Carbon Reduction (MMtons)		NPV[(a)] (mill. 98$)
	EPCA	90.1-1999	Max NPV[(a)]	90.1 Over EPCA	Max NPV[(a)] Over 90.1	90.1 Over EPCA	Max NPV[(a)] Over 90.1	
Central Air-Source AC (135 to 240 kBtu/h)	8.5	9.7	10.4	899.4	428.8	13.2	6.3	417.9
Central Air-Source HP (135 to 240 kBtu/h)	8.5	9.3	10.4	27.9	31.4	0.4	0.5	3.2
Central Water-Cooled AC (135 to 240 kBtu/h)	9.6	11.0	11.5	8.5	2.5	0.1	0.0	3.0
Central Air-Source AC (65 to 135 kBtu/h)	8.9	10.3	10.3	1197.9	0.0	17.6	0.0	0.0
Central Air-Source HP (65 to 135 kBtu/h)	8.9	10.1	10.1	107.9	0.0	1.6	0.0	0.0
Central Water-Source HP (65 to 135 kBtu/h)	10.5	12.0	12.0	32.0	0.0	0.5	0.0	0.0
Central Water Cooled AC (65 to 135 kBtu/h)	10.5	11.5	12.4	3.6	2.7	0.1	0.1	0.8
Packaged Terminal Air Conditioners	8.5	8.8	10.5	67.5	311.7	1.0	4.6	274.7
Packaged Terminal Heat Pumps	8.2	8.4	9.9	38.7	249.0	0.6	3.7	241.9
3-Phase, Single-Package Air-Source AC (<65 kBtu/h)	9.7	9.7	12.0	0.0	1412.7	0.0	20.8	897.7
3-Phase, Split-System Air-Source AC (<65 kBtu/h)	10.0	10.0	11.0	0.0	278.6	0.0	4.1	109.1
3-Phase, Single-Package Air-Source HP (<65 kBtu/h)	9.7	9.7	12.0	0.0	183.6	0.0	2.7	91.3
3-Phase, Split-System Air Source HP (<65 kBtu/h)	10	10.0	12.0	0.0	66.4	0.0	1.0	47.0
Central Water-Cooled AC (<65 kBtu/h)	9.3	12.1	12.1	6.6	0.0	0.1	0.0	0.0
Central Water-Source HP (17 to 65 kBtu/h)	9.3	12.0	12.5	471.6	65.0	6.9	1.0	23.0
Central Water-Source HP (<17 kBtu/h)	9.3	11.2	11.2	56.5	0.0	0.8	0.0	0.0
Large Gas-Fired Hot Water Boilers (>2,500 kBtu/h)	80%[(b)]	80%[(b)]	88%[(c)]					
Large Gas-Fired Steam Boilers (>2,500 kBtu/h)	80%[(b)]	80%[(b)]	82%[(c)]	0.0	79.0	0.0	1.0	86.6
Small Gas-Fired Boilers (<2,500 kBtu/h)	80%[(b)]	75%[(c)]	78.7%[(]	63.9	200.0	0.8	2.6	146.0
Gas-Fired Warm-Air Furnaces	80%[(c)]	80%[(c)]	80%[(c)]	478.4	0.0	6.3[d]	0.0	0.0
Gas Storage Water Heaters (>155 kBtu/h)	78%[(c)]	80.4%[(]	80.4%[(]	53.9	0.0	0.8	0.0	0.0
Gas Storage Water Heaters (<155 kBtu/h)	78%[(c)]	80%[(c)]	80%[(c)]	12.5	0.0	0.2	0.0	0.0
Electric Water Heaters	See Note[(d)]	See Note[(e)]	See Note[(f)]	-7.2	5.3	-0.1	0.1	1.1
Tankless Instantaneous Water Heaters	80%[(a)]	80%[(c)]	81.5%[(]	0.0	102.0	0.0	1.5	45.3
Instantaneous Water Heaters with Tanks	77%[(c)]	80%[(c)]	80%[(c)]	6.9	0.0	0.1	0.0	0.0

(a) NPV = national net present value.
(b) Combustion efficiency (%).
(c) Thermal efficiency (%).
(d) Savings due to tighter jacket loss requirement.
(d) 30+27/V (%/h) V=Measured storage volume in gals.
(e) 20+35Sqrt(V) (Btu/h) V=Rated volume in gals.
(f) 1.73V+155 (Btu/h) V=Rated volume in gals.

4.0 References

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