APPENDIX A:

FY2005 Technical Support Document (TSD)

Table of Contents

Table of Contents (continued)

Table of Contents (continued)

Table of Contents (continued)

List of Figures

List of Tables

List of Tables (continued)

A1 Introduction

The primary goal of this Technical Support Document (TSD) is to explain the derivation of energy consumption and savings estimates for the products listed in Table A1-1. This TSD updates segments of the analysis contained in the FY2003 priority-setting TSD and also includes analysis for products not contained in the FY2003 TSD. In anticipation of the possible passage of new federal energy legislation in 2004, the Department decided to prepare data sheets for products identified in the draft legislation. Should legislation be enacted, these products could be prioritized along with the products already in the Appliance Standards Program (or in the coverage process).

Table A1-1: Products Addressed in Technical Support Document

Existing Products	Products in Coverage and/or Pending Legislation	Other, Previously Unevaluated Products
Cooking Products – Gas & Electric Ranges (Ovens and Cooktops) and Microwave Ovens	Battery Chargers / External Power Supplies	Large Unitary Air Conditioners ($\geq$ 240 kBtu/hr)
Direct Heating Equipment, Gas	Beverage Merchandisers and Beverage Vending Machines	
*Dishwashers (Residential)	Ceiling Fans	
Electric Motors, 1-200 HP	Commercial Reach-in Refrigerators, Freezers, and Refrigerator-Freezers	
Pool Heaters, Gas	Gas Unit Heaters / Gas Duct Furnaces	
Refrigerators and Refrigerator-Freezers, Freezers, and Compact Refrigerators	Illuminated Exit Signs	
Room Air Conditioners	Lamps, Incandescent Reflector – ER/BR	
	Residential Furnace Fans	
	Torchieres	
	Traffic Signal Modules	

* Update to FY2003 Technical Support Document.

In addition, this TSD provides product-specific information relating to the priority setting criteria shown in Table A1-2. These criteria are considered in varying degrees in setting the proposed priorities.

Table A1-2: Product Priority-Setting Criteria

Criteria
Energy savings potential
Potential economic benefits / burdens
Potential environmental or energy security benefits
Applicable deadlines for rulemakings
Incremental DOE resources required to complete rulemaking process
Evidence of market-driven or voluntary efficiency improvements
Status of required changes to test procedures
Impact of potential regulation on product innovation
Fuel neutrality
Impact on peak demand for electricity
Impact of potential regulation on small businesses
Cumulative regulative burden on products, related products manufactured by the same manufacturers

Sections A1.1 and A1.2 provide an explanation of the general methodology used to calculate energy consumption and savings for most products. Sections A2 through A19 provide product-specific information for each product listed in Table A1-1.

A1.1 Overview of Methodology for Energy Consumption and Savings Estimates

The energy consumption and savings estimates presented in Sections A2 through A19 share three common and general steps: data collection, critical evaluation of data, and the development of energy consumption and savings estimates (Figure A1-1).

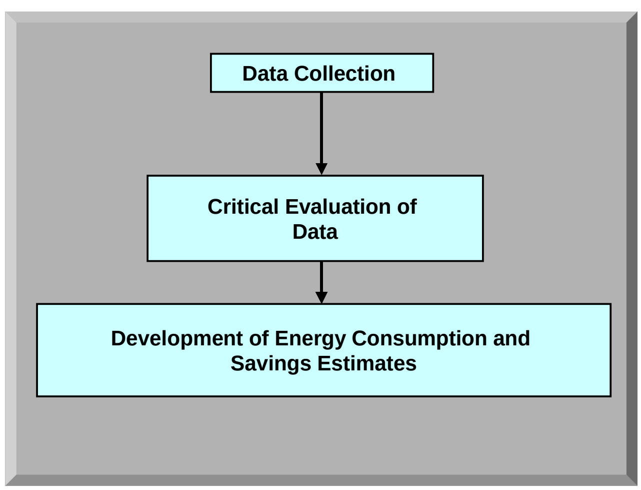

Figure A1-1: The Development of Product Energy Consumption and Savings Estimates

The Department accessed the most complete and current information available for each evaluated product. If possible, the products' Annual Energy Consumption (AEC) and Energy

Savings Potential calculations are based upon data from previous detailed studies. "Bottom-up" engineering analyses are particularly useful in this process, as they provide a detailed breakdown of energy consumption (e.g., by usage mode), which improves the energy savings calculations. In cases where detailed studies could not be found, the energy estimates were developed from a range of sources including: prior building energy consumption reports, industry data sources, and industry contacts.

In general, the AEC and energy savings estimates do *not* address several market dynamics that would impact future energy consumption or savings (see Table A1-3).

Table A1-3: Market Dynamics not Considered in Annual Energy Consumption and Energy Savings Estimates

Market Dynamic	Example
Future increases or decreases in device installed base	Pool Heaters, Gas - The market's preference for solar pool heating devices may lead to a decrease in the installed base of gas pool heaters.
Future market penetration of technologies without regulatory actions	Traffic Signal Modules - LED traffic signal modules are displacing incandescent modules in the absence of regulatory actions.
Future evolution of products, including additional product features	Smart Appliances - Refrigerators equipped with flat screen televisions.

A1.2 Calculation Approach for Energy Consumption and Savings Estimates

A1.2.1 Device Annual Energy Consumption (AEC) Estimates

Figure A1-2 illustrates the basic methodology used to develop the annual energy consumption (AEC) estimates for a device or product. Deviations from this methodology are explained in the product-specific sections.

The unit energy (or electricity) consumption (UEC) denotes the energy consumed by an average device over the course of a year. The UEC equals the sum of the products of the power draw in each mode, P_m, and the approximate number of hours, T_m, that each device operates in a particular mode, m, in the course of one year:

$$UEC = \Sigma\ UEC_m = \Sigma\ P_m * T_m$$

An estimate of the stock of the device, S (or installed base), was obtained or developed. The product of the installed base and the device UEC equals the total annual energy consumption, AEC, for a particular product:

$$AEC = S * UEC$$

Devices and products can operate in up to four different modes: active, standby, suspended or sleep, and off. For example, as shown in Figure A1-2, there are four UEC_m, summing to the device UEC. Figure A1-2 illustrates the expanded model for devices that operate in all four modes. This figure can be adapted and applied to products that operate in fewer modes (e.g., active and off only).

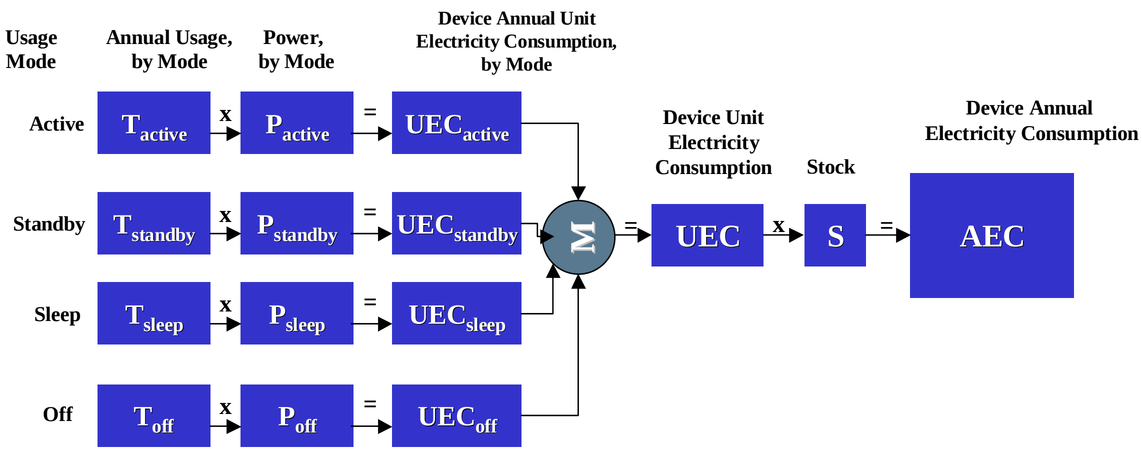

Figure A1-2: AEC Calculation Methodology (from ADL, 2002)

For devices powered by electricity, electric energy can be converted to primary energy via the factor of 10,958 Btu/kWh (BTS, 2000).

The following sub-sections describe the general approach used to develop values for P_m, T_m, and S.

A1.2.1.1 Power draw by mode, P_m

Energy consumption estimates for a given product incorporate power draw data for each mode of operation. It is assumed that for a given product in a given mode, there is no variation in power draw. The power draw by mode, $P_{m,}$ is based on industry data or studies.

Moreover, whenever possible, the power draw levels reflect actual power draw measurements for the 'active' power draw, as opposed to the device rated power draw. Rated power draws represent the maximum power that the device's power supply can handle and do not equal the actual power draw. The improper use of rated power draws to estimate energy consumption usually leads to gross over-estimation of energy consumption.

A1.2.1.2 Annual Usage, T_m

The device usage pattern refers to the number of hours per week that, on average, a device operates in a given mode. In general, the energy consumption model uses up to four typical usage modes (see Table A1-4) and different devices may have different combinations of these modes. For example, computer monitors, powered by external power supplies (see Section A9), operate in all four modes, while functioning exit signs (see Section A14) have just one mode - active. The annual usage, T_m, in each mode is extrapolated from the weekly usage.

Table A1-4: Usage Pattern Mode Definitions

Mode Type	Description	Example
Active	Device carrying out intended operation.	Computer monitor displays image.
Stand-by	Device ready to, but not, carrying out intended operation.	Computer monitor displays screen saver.
Suspended or Sleep	Device not ready to carry out intended operation, but on.	Computer monitor powered down, but turned on.
Off	Device not turned on but plugged in.	Computer monitor off, but plugged in.

Usage data are extracted from studies and/or surveys where researchers have monitored and recorded the usage pattern in a building for a period of time, ranging from days to several weeks.

A1.2.1.3 Product Installed Base, S

The installed base, S, of a device denotes the number of devices in use in commercial buildings, industries, residential buildings etc., or a combination of these, depending on which segment is under investigation. When available, the stock estimates come from other studies (e.g., industry market reports). However, many commercial stock estimates come from historical sales data and average product lifetimes, simply by summing the sales data from the past y years, where y equals the average product lifetime.

A1.2.2 Cumulative Energy Savings Estimates

Using the above methodology, estimates of the AEC for representative technology levels such as “current new,” “typical new,” and the “best available” products are made. AEC estimates may also be made at potential standard levels other than “typical new” and “best available.” Definitions of these technology/standard levels are provided in Table A1-5.

Table A1-5: Definition of Technology/Standard Levels

AEC Estimates	Explanation	Example
Current Device	Based on the product most representative of the installed base (stock).	Traffic signal modules with incandescent lamps.
Typical new	Based on the product most representative of new products.	Traffic signal modules with LED lamps.
Best Available	Based on the device that consumes the least amount of energy in the market.	Traffic signal modules with most efficient LED lamps available today.

The analyses in the following sections typically assume that the installed base of each product type in the standard year (e.g., 2010) does not increase from its current level.

The cumulative energy savings from the standard year (e.g., 2010) to the terminal year (e.g., 2035) are calculated based on the assumption that the new technology/standard diffuses into the stock linearly over the average lifetime of the device (as illustrated in Figure A1-3). The area under the shaded portion in the graph corresponds to the estimated cumulative energy savings and is given by:

Cumulative Energy Savings = (TY – SY + 1)*Annual Energy Savings – 0.5*(T*Annual Energy Savings)

Where:

TY = terminal year
SY = standard year
T = average product lifetime

.
For this approximation, the annual energy savings represents the annual energy saved by replacing the entire installed base of the product (assumed to consume energy at the “typical new” level) with product consuming energy at the new technology/standard level.

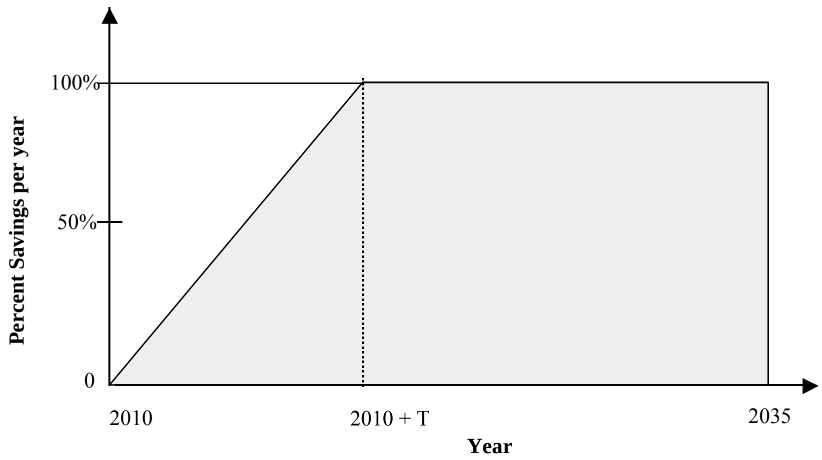

Figure A1-3: Energy Savings Potential Model for 2010-2035

Newly completed analysis for FY2005 uses a standard year of 2010 and a terminal year of 2035. Ideally, all data sheets would be consistent with the use of these dates. For data sheets completed in previous years that reference existing reports, the standard and terminal years vary.

A2 Cooking Products – Gas & Electric Ranges (Ovens and Cooktops) and Microwave Ovens

A2.1 Background

In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for cooking products (NAECA 1987). NAECA required only that gas cooking products having an electrical supply cord not be equipped with standing pilots. Cooking products include: (1) gas ovens, cooktops, and ranges, (2) electric ovens, cooktops, and ranges, and (3) microwave ovens. As established by DOE's test procedure, the energy efficiency descriptor for cooking products is the Energy Factor. The Energy Factor is expressed as a percent and is the ratio of the annual useful cooking energy output (i.e., the energy being conveyed to the item being cooked) to its total annual energy consumption. The annual energy consumption includes the cooking energy plus the energy consumed by other features such as a clock, standing pilot, electric ignition system, or self-cleaning cycles. Because DOE does not require minimum Energy Factor requirements for cooking products, cooking products currently are not labeled or tested for energy consumption.

Updated minimum standards for cooking products were proposed in 1994 (DOE 1994). Because NAECA did not establish product classes for cooking products, DOE established the following product classes in its proposed standards: (1) electric cooktops, coil elements, (2) electric cooktops, smooth elements, (3) gas cooktops, (4) electric ovens, non-self-cleaning, (5) electric ovens, self-cleaning, (6) gas ovens, non-self-cleaning, (7) gas ovens, self-cleaning, and (8) microwave ovens. The individual components of an electric and gas range, consisting of an oven, cooktop, and occasionally a microwave oven, would have been required to meet the applicable component proposed standards. DOE issued a Final Rule in 1998 making the determination that minimum efficiency performance standards are not required for electric cooking products, including microwave ovens (DOE 1998). Gas cooking products were held out for further consideration, primarily to further assess the elimination of standing pilots for all gas cooking products.

Table A2-1 provides background data on the installed base, annual shipments, lifetime, and national annual energy consumption of cooking products.

Table A2-1: Cooking Product Background Data

Data type	Value[1]	Source/Comments
Gas Cooking Products[2]		
Installed Base, million	45.7	Based on historical shipments and 19 year equipment lifetime
Annual Shipments, million	2.85	(AHAM 2003)
Equipment Lifetime, years	19	(DOE 1997)
AEC, quad	0.37	Based on installed based and stock annual energy use
Electric Cooking Products[2]		
Installed Base, million	64.1	Based on historical shipments and 19 year equipment lifetime
Annual Shipments, million	4.56	(AHAM 2003)
Equipment Lifetime, years	19	(DOE 1996)
AEC, quad	0.18	Based on installed based and stock annual energy use
Microwave Ovens		
Installed Base, million	102.8	Based on historical shipments and 30 year equipment lifetime
Annual Shipments, million	13.31	(AHAM 2003)
Equipment Lifetime, years	10	(DOE 1996)
AEC, quad	0.16	Based on installed based and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002.

[2] Represents values for Ranges. Individual Ovens and Cooktops are accounted for by treating one Oven and one Cooktop as a single Range.

A2.2 Product Technology Description and Market Presence

Coil element electric cooktops typically consist of two six-inch (1250 watt) and two eight-inch (2100 watt) elements. Improving the contact conductance of the elements and using reflective surfaces are means in which to improve the efficiency of the coil elements. Neither design was found to be cost-effective by DOE (DOE 1998).

Smooth element electric cooktops typically consist of two six-inch (1500 watt) and two eight-inch (2000 watt) solid disk elements. Other smooth type elements include: halogen lamp, induction, and radiant types. While halogen and induction elements are both more efficient than solid disk elements, neither were found to be cost-effective by DOE (DOE 1998). Radiant elements are actually less efficient than solid disk elements (DOE 1996).

The efficiency of non-self-cleaning and self-cleaning electric ovens can be improved by using: improved insulation in the cabinet walls, improved door seals, reducing the vent rate and conduction losses, utilizing oven separators, utilizing forced convection, and incorporating the features of a bi-radiant design. Bi-radiant ovens were developed in the late 1970's and had three features for reducing energy use: highly reflective cavity walls, highly absorptive finish, and lower-temperature heating elements. Although all of the above design features improve efficiency, DOE found that none were cost-effective (DOE 1998).

Microwave ovens can be improved through the use of more efficient power supplies, fans, magnetrons, and reflective surfaces. But like conventional electric ovens, DOE found that none of the above design features for microwave ovens were cost-effective (DOE 1998).

Gas cooktops typically consist of four open 9000 Btu/hr burners. Efficiency can be improved through the use of sealed burners, reflective surfaces, and thermostatic burners. DOE determined that all of the above designs are not cost-effective for consumers (i.e., the designs resulted in increased consumer life-cycle costs) (DOE 1996).

With the exception of the bi-radiant design, all design features available to improve the efficiency of electric ovens can also be used to improve the efficiency of non-self-cleaning and self-cleaning ovens gas ovens. But DOE found none of these design features for gas ovens to be cost-effective (i.e., the designs resulted in increased consumer life-cycle costs) (DOE 1996).

For gas cooking products, only the removal of standing pilot ignition systems through the use of electric or electronic ignition systems seem to be cost-effective. Standing pilot systems are only utilized by gas cooktops, ovens, and ranges without electrical cords. Note that because self-cleaning gas ovens and ranges require electricity to operate, all are required by NAECA to use non-standing pilot systems. Because gas cooking products without power cords do not require electricity to operate, the incorporation of an electric or electronic ignition device requires electrical service to be brought to the unit. As a result, costs associated with the installation of electrical service would be incurred by consumers that do not have electrical outlets already in their kitchens. In addition, based on data from the mid-1990's, electronic or electric ignition systems also incur greater maintenance costs than standing pilot systems (DOE 1997). Finally, if electric-based ignition systems are used, a significant amount of electricity is used by the appliance to operate the hot surface ignition device, thereby partially offsetting the reduction in gas consumption realized by eliminating the pilot. Electronic ignition systems utilizing spark igniters consume negligible amounts of electrical energy.

A DOE analysis demonstrated that electric and electronic ignition systems are cost-effective for those consumers that do not require the installation of an electrical outlet. For consumers that need to install an electrical outlet, only electronic ignition systems in gas ranges are cost-effective (DOE 1997). But the same DOE analysis demonstrated that, based on historical shipment trends, only 25 percent of consumers in 2010 will still utilize gas cooking products with standing pilot systems. Thus, the national energy savings realized from requiring electric or electronic ignition systems are estimated to be minimal.

Table A2-2 summarizes the UECs corresponding to various efficiency levels for cooking products. The UEC data in Table A2-2 are based on analyses performed by DOE (DOE 1996; DOE 1997). The gas cooking product UECs in Table A2-2 are weighted-average values taking into account the market share of non-self-cleaning and self-cleaning ranges as well as the market share of products with electric and electronic ignition devices. Based on historical market share data, gas non-self-cleaning and self-cleaning ranges each are assumed to capture 50 percent of the market while 75 percent of non-self-cleaning ranges are assumed to use electric or electronic ignition systems (DOE 1997). The electric cooking products UECs are weighted-average values taking into account the market shares of coil-type and smooth-type cooktops and non-self-cleaning and self-cleaning ovens. Based on historical market share data, coil-type cooktops are assumed to capture 85 percent of the electric cooktop market while it is assumed that 73 percent of the electric range market is comprised of self-cleaning units (DOE 1997).

Table A2-2: Cooking Product UEC Values

Technology Level	UEC (MMBtu/yr)	UEC (kWh/yr)	Source
Gas Cooking Products[1]			
Baseline	3.2	33	(DOE 1997)
Electronic or Electric Ignition	2.8	33	(DOE 1997)
Design Option Combinations[2]	2.4	53	(DOE 1996)
Electric Cooking Products[1]			
Baseline	NA	530	(DOE 1996)
Design Option Combinations[3]	NA	420	(DOE 1996)
Microwave Ovens			
Baseline	NA	143	(DOE 1996)
Design Option Combinations[4]	NA	132	(DOE 1996)

[1] Represents the UEC for ranges.

[2] Design options include: Gas cooktops – electronic ignition, sealed burners, reflective surfaces, thermostatic burners; Gas ovens –electronic ignition, improved insulation, improved door seals, forced convection, reduced vent rate, reduced conduction losses, oven separator.

[3] Design options include: Electric cooktops – improved contact conductance, reflective surfaces, induction element; Electric ovens – improved insulation, improved door seals, forced convection, reduced vent rate, reduced conduction losses, oven separator, bi-radiant design.

[4] Design options include: more efficient power supply, fan, magnetron and reflective surfaces.

Table A2-3 provides retail price information corresponding to the UECs specified in Table A2-2. Table A2-3 also includes the installation and annual maintenance costs for gas cooking products. Baseline price data were provided by the 2003 AHAM Fact Book (AHAM 2003). Retail prices are generated for more efficient products from the percentage price increases indicated by the price versus efficiency relationship in DOE's 1996 and 1997 analyses on cooking products (DOE 1996; DOE 1997).

Table A2-3: Cooking Product Retail Prices

Technology Level	UEC (MMBtu/yr)	UEC (kWh/yr)	Retail Price ($2002)	Installation Price[1] ($2002)	Annual Maintenance Cost[1] ($2002)	Source
Gas Cooking Products						
Baseline	3.2	33	$513	NA	NA	(AHAM 2003)
Electronic or Electric Ignition	2.8	33	$516	$2	$1	(DOE 1997)
Design Option Combinations	2.4	53	$698	$2	$1	(DOE 1996)
Electric Cooking Products						
Baseline	NA	530	$508	NA	NA	(AHAM 2003)
Design Option Combinations	NA	420	$766	NA	NA	(DOE 1996)
Microwave Ovens						
Baseline	NA	143	$145	NA	NA	(AHAM 2003)
Design Option Combinations	NA	132	$196	NA	NA	(DOE 1996)

[1] Installation and maintenance costs are increased costs relative to the baseline and represent the weighted-average cost to consumers taking into account the percentage of consumers that already have electrical outlets (DOE 1997).

A2.3 Test Procedure Status

The Department adopted a Final Rule of the test procedure for cooking products on October 3, 1997 (DOE 1997a).

A2.4 Energy Savings Estimates and Calculations

Table A2-4 presents the energy savings potential for the efficiency levels specified in Table A2-2. Also provided in Table A2-4 is the economic benefit or burden to consumers for each efficiency level. Note that none of the efficiency levels with the exception of electric or electronic ignition for gas cooking products result in economic benefits to consumers. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[1]

Table A2-4: Cooking Product Potential Energy Savings and Economic Impact Estimates

Technology	UEC (MMBtu/yr)	UEC (kWh/yr)	Energy Saving Potential, 2010-2035 (quads)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
Gas Cooking Products				
Baseline	3.2	33	NA	NA
Electronic or Electric Ignition	2.8	33	0.44	0.57
Design Option Combinations	2.4	53	0.65	-3.10
Electric Cooking Products				
Baseline	NA	530	NA	NA
Design Option Combinations	NA	420	1.66	-5.71
Microwave Ovens				
Baseline	NA	143	NA	NA
Design Option Combinations	NA	132	0.32	-4.66

A2.5 Regulatory Actions and Cumulative Burdens

In the Fiscal Year 2004 Priority-Setting memorandum, cooking products were listed as a low-priority product (DOE 2003). No significant changes have occurred since then.

A2.6 Issues Impacting Potential Energy Efficiency Standards

As noted earlier, historical shipment trends indicate that gas cooking products may eventually phase-out the use of standing pilot ignition systems. Thus, the moderate national energy savings currently estimated may be significantly diminished in the near future.

Also with respect to gas ignition systems, the maintenance costs associated with the electronic ignition system assumed for this analysis (based on mid-1990's data) may no longer be representative of electronic devices currently being used. Because manufacturers have had additional years to improve the reliability of electronic ignition systems since the mid-1990's, the

[1] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

maintenance costs associated with these systems may be equivalent to those associated with standing pilot systems. As a result, electronic ignition systems may be more cost-effective as a means in which to reduce the energy use of gas cooking appliances than shown by this analysis.

References

Association of Home Appliance Manufacturers (AHAM). 2003. “Fact Book 2003.” Chicago, IL.

National Appliance Energy Conservation Act (NAECA), 1987, Pub. L. 100-12

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 1994. “Energy Conservation Program for Consumer Products; Proposed Rule.” Federal Register 59 (43): 10464-10532.

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1996. “Draft Report on Potential Impact of Alternative Efficiency Levels for Residential Cooking Products.” Washington, DC. April, 1996.

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1997. “Supplemental Analysis for Cooking Products.” Washington, DC. April, 1997.

U.S. Department of Energy (DOE)-Office of Conservation and Renewable Energy. 1997a. "Energy Conservation Program for Consumer Products: Test Procedures for Kitchen Ranges, Cooktop, Ovens, and Microwave Ovens." Federal Register 62 (192): 51976-51991.

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 1998. “Energy Conservation Program for Consumer Products: Energy Conservation Standards for Electric Cooking Products (Electric Cooktops, Electric Self-Cleaning Ovens, and Microwave Ovens); Final Rule.” Federal Register 63 (173): 48038-48057.

U.S. Department of Energy (DOE)-Building Technologies Program. 2003. “Fiscal Year 2004 Priorities for the Appliance Standards Rulemaking Process.” Available online: http://www.eere.energy.gov/buildings/appliance_standards/pdfs/october_memo.pdf

U.S. Department of Energy (DOE), Energy Information Administration. 2004. “Annual Energy Outlook 2004 with projections to 2025.” Washington, DC. DOE/EIA-0383(2004). January 2004.

A3 Direct Heating Equipment, Gas

A3.1 Background

In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for direct heating equipment (NAECA 1987). Direct heating equipment is comprised of gas-fired products whose flue products are vented outdoors and deliver heated air to the conditioned space without the use of ducts. The energy efficiency descriptor for direct heating equipment is the Annual Fuel Utilization Efficiency (AFUE), which accounts only for the gas consumption of the appliance. But because over 90 percent of shipped direct heating equipment products currently only utilize gas, the AFUE is an adequate measure of the overall performance of an overwhelming majority of equipment. Minimum efficiency standards for direct heating equipment vary based on physical configuration (i.e. wall furnaces, floor furnaces, or room heaters), input capacity, and the means in which heated air is delivered (i.e., gravity- or fan-types). As a result, NAECA established 16 distinct product classes for this equipment. Minimum standards for gravity-type equipment range from 56 to 65 percent AFUE while standards for fan type equipment range from 73 to 74 percent AFUE.

During the mid-1990's, vented hearth products became popular and product sales grew at a rate of 20 to 35 percent. Because these systems are at least partially used to provide space heat (as opposed to being purely decorative) and their venting systems are similar to conventional direct heat equipment, existing minimum standards for direct heating equipment also apply to hearth products. Hearth products consist of vented fireplaces, fireplace inserts, stoves, and log sets.

Updated minimum standards for direct heating equipment were proposed in 1994 but the proposed standards were never finalized by DOE (DOE 1994). Table A3-1 provides background data on the installed base, annual shipments, lifetime, and national annual energy consumption of direct heating equipment. Separate data sets for conventional products (wall furnaces, floor furnaces, and room heaters) and hearth products are provided in Table A3-1.

Table A3-1: Direct Heating Equipment Background Data

Data type	Value[1]	Source/Comments
Conventional Equipment		
Installed Base, million (2002)	3.4	Based on historical shipments and 15 year equipment lifetime
Annual Shipments, million (2002)	0.208	(Appliance 2003)
Equipment Lifetime, years	15	(DOE 1993)
AEC, quad (2002)	0.11	Based on installed based and stock annual energy use
Hearth Products		
Installed Base, million (2002)	5.4	Based on historical shipments and 30 year equipment lifetime
Annual Shipments, million (2002)	0.897	(Hearth Products Association 2004)
Equipment Lifetime, years	30	(GRI 1997)
AEC, quad (2002)	0.07	Based on installed based and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002.

A3.2 Product Technology Description and Market Presence

Conventional direct heating equipment has two common characteristics: (1) heat is conveyed without ducts and (2) flue products (i.e., products of combustion) are vented outside. In conventional systems, combustion products pass through the inside of a heat exchanger. Air passes over the outside of the heat exchanger either through natural convection, as used by gravity-type units, or forced convection through the use of air-circulation fans, as used by fan-type units. Flue products are typically either vented: (1) up though the roof utilizing B-vents or (2) through-the-wall utilizing direct vents. In direct vent systems, flue products are vented through the center of the vent while outdoor air for combustion is aspirated through the outer ring of the vent.

Conventional systems come in three basic configurations: room heaters, wall furnaces, and floor furnaces. Room heaters are free-standing and are installed directly within the space they are heating. All room heaters are sold as gravity-type units but optional air-circulation fans can be installed with the units to improve efficiency. Wall furnaces are either installed on the wall as a free-standing unit or recessed within the wall. A majority of wall furnaces are gravity-type units while some are sold as fan-type units. As their name implies, fan-type wall furnaces utilize air-circulation fans to force air over the heat exchanger in a counterflow direction to the flue products. Because counterflow air circulation greatly improves the heat exchange process, fan-type wall furnaces are more efficient than gravity-type units. Floor furnaces are suspended from the floor of the heated space within an unconditioned crawl space. All floor furnaces are sold as gravity-type units.

Vented hearth products are sold either as fireplaces, fireplace inserts, gas stoves, or log sets. Flue products are either vented through the use of B-vents or direct-vents. Because fireplace inserts, gas stoves, and log sets often are used for decorative purposes rather than providing space heat, it is uncertain as to whether the minimum efficiency standards for direct heating equipment apply to these products. DOE in the past has required decorative hearth products to meet the efficiency requirements if the appliance either has a thermostat or if the manufacturer promotes the appliance's efficiency or heating function. For purposes of this analysis, it was assumed that all vented hearth products had to meet the applicable existing minimum efficiency standards.

The primary method for reducing gas consumption in both conventional and hearth product direct heating equipment is by eliminating the standing pilot through the use of electronic ignition. But most direct heating equipment are gravity-type units that do not require electricity to operate. As a result, the incorporation of an electronic ignition device requires electrical service to be brought to the unit resulting in higher installation costs. Electronic ignition systems also incur greater maintenance costs than standing pilot systems. In addition, electronic ignition systems use electricity. Thus, the reduction in gas consumption realized by eliminating the standing pilot is partially offset by the electricity consumption of the electronic ignition device.

Table A3-2 summarizes the efficiency improvements for direct heating equipment. In addition to the electronic ignition efficiency measure, a combination of design options was also considered for conventional direct heating equipment. The efficiency and UEC data in Table A3-2 are based on analyses performed by the Gas Research Institute (GRI 1994; GRI 1997; GRI 1997). Rather than providing efficiency data for every direct heating product type, the efficiency measures were evaluated from a shipment-weighted average baseline unit for each class of equipment (i.e., conventional equipment and hearth products). For conventional equipment, the baseline is a shipment-weighted composite of all product classes, including fan-type units. Because fan-type units consume electricity to drive the fan, electrical energy is consumed in the baseline design. For hearth products, almost 70 percent of products surveyed by GRI utilize electronic ignition (GRI 1997). As a result, the baseline hearth product design also consumes electricity.

Table A3-2: Direct Heating Equipment Efficiency Levels and UEC Values

Technology Level	AFUE	UEC (MMBtu/yr)	UEC (kWh/yr)	Source
Conventional Equipment				
Baseline	64.2%	30.4	5.3	(GRI 1994)
Electronic Ignition	66.1%	28.0	102.3	(GRI 1994)
Design Option Combinations[1]	70.0%	26.3	123.3	(GRI 1994)
Hearth Products				
Baseline	73.4%	11.2	30.5	(GRI 1996; GRI 1997)
Electronic Ignition	75.0%	10.9	95.0	(GRI 1996; GRI 1997)

[1] Design options include: electronic ignition, 20% de-rating, and burner box or stack dampers.

Table A3-3 provides retail price information corresponding to the efficiency levels specified in Table A3-2. Table A3-3 also includes the installation and annual maintenance costs. The price data were taken from analyses performed by GRI (GRI 1994; GRI 1996) and inflated to 2002 dollars using consumer price index data from the U.S. Department of Labor (DOL 2004).

Table A3-3: Direct Heating Equipment Retail Prices

Technology Level	AFUE	Retail Price ($2002)	Installation Price ($2002)	Annual Maintenance Cost ($2002)	Source
Conventional Equipment					
Baseline	64.2%	$520	$211	$3	(GRI 1994)
Electronic Ignition	66.1%	$631	$229	$8	(GRI 1994)
Design Option Combinations	70.0%	$771	$276	$14	(GRI 1994)
Hearth Products					
Baseline	73.4%	$1532	NA	$3	(GRI 1996; GRI 1997)
Electronic Ignition	75.0%	$1608	$6[1]	$5	(GRI 1996; GRI 1997)

[1] Installation price is the price increase relative to the baseline.

A3.3 Test Procedure Status

The Department adopted a Final Rule of the test procedure for direct heating equipment on May 12, 1997 (DOE 1997).

A3.4 Energy Savings Estimates and Calculations

Table A3-4 presents the energy savings potential for the efficiency levels specified in Table A3-2. Also provided in Table A3-4 is the economic benefit or burden to consumers for each efficiency level. Note that none of the efficiency levels result in economic benefits to consumers. Also note that the electronic ignition design option for hearth products actually results in negative energy savings due to the additional electricity consumption of the ignition device. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[2]

Table A3-4: Direct Heating Equipment Potential Energy Savings and Economic Impact Estimates

Technology	AFUE	Energy Saving Potential, 2010-2035 (quad)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
Conventional Equipment			
Baseline	64.2%	NA	NA
Electronic Ignition	66.1%	0.10	-0.15
Design Option Combinations	70.0%	0.19	-0.45
Hearth Products			
Baseline	73.4%	NA	NA
Electronic Ignition	75.0%	-0.10	-1.25

A3.5 Regulatory Actions and Cumulative Burdens

In the Fiscal Year 2004 Priority-Setting memorandum, direct heating equipment was listed as a low-priority product (DOE 2003). No significant changes have occurred since then.

A3.6 Issues Impacting Potential Energy Efficiency Standards

The smoke from wood-burning fireplaces contributes to outdoor air pollution. In the western U.S., atmospheric inversions are common: warmer air above traps cooler air below, resulting in a highly stable atmospheric condition where pollutants disperse slowly. Because of such "brown cloud" inversions, many western states have restricted wood burning. Restrictions are also in place in parts of the northeast. Usually the restrictions amount to levying fines for wood burning on certain days. Although the laws are seldom enforced, they do affect consumer behavior. Due to the restrictions placed on wood-burning fireplaces, many consumers are turning to gas-fired hearth products as an alternative. Because gas-hearth products are being used by consumers in response to air quality regulations, it may not be wise to impose efficiency regulations on these products, especially if such regulations significantly increase the retail price of the equipment and dissuade consumers from purchasing these products.

[2] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

With respect to gas ignition systems, the maintenance costs associated with the electronic ignition system assumed for this analysis (based on early 1990's data) may no longer be representative of electronic devices that can now be used by direct heating equipment. Because manufacturers have had additional years to improve the reliability of electronic ignition systems since the early 1990's, the maintenance costs associated with these systems may be equivalent to those associated with standing pilot systems. As a result, electronic ignition systems may be more cost-effective as a means in which to reduce the energy use of direct heating equipment than shown by this analysis.

References

Appliance Magazine. 2003. “Statistical Review.” May, 2003.

Gas Research Institute (GRI). 1994. “Assessment of Technology for Improving the Efficiency of Gravity Direct Heating Equipment”. Chicago, IL. GRI-94/0342.

Gas Research Institute (GRI). 1996. “Gas Hearth Products Market Fact Base”. Chicago, IL. GRI-96/0013.

Gas Research Institute (GRI). 1997. “Hearth Products Meter Study (1995-1997)”. Chicago, IL. GRI 97/0298.

Hearth Products Association. 2004. Private communications with Carter Keithley.

National Appliance Energy Conservation Act (NAECA), 1987, Pub. L. 100-12

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1993. “Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets.” Washington, DC DOE/EE-0009, Volume H.

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 1994. “Energy Conservation Program for Consumer Products; Proposed Rule.” Federal Register 59 (43): 10464-10532.

U.S. Department of Energy (DOE)-Office of Conservation and Renewable Energy. 1997. "Energy Conservation Program for Consumer Products: Test Procedures for Furnaces/Boilers, Vented Home Heating Equipment, and Pool Heaters." Federal Register 62 (91): 26140-26165.

U.S. Department of Energy (DOE)-Building Technologies Program. 2003. “Fiscal Year 2004 Priorities for the Appliance Standards Rulemaking Process.” Available online: http://www.eere.energy.gov/buildings/appliance_standards/pdfs/october_memo.pdf

U.S. Department of Energy (DOE), Energy Information Administration. 2004. “Annual Energy Outlook 2004 with projections to 2025.” Washington, DC. DOE/EIA-0383(2004). January 2004.

U.S. Department of Labor (DOL), Bureau of Labor Statistics. 2004. Consumer Price Index-All Urban Consumers. Available online: http://www.bls.gov/cpi/

A4 Dishwashers (Residential)

A4.1 Background

Dishwashers use heated water and dishwashing detergent to clean and dry dishes. Collectively, the installed base of approximately 61.7 million residential dishwashers consumes about 0.26 quad of energy per year (see Table A4-1).

Table A4-1: Residential Dishwasher Background Data

Data Type	Value	Source
Installed Base, millions	61.7	Meyers et al. (2002)
Annual Shipments, millions	6.4	Appliance (March 2004)
Equipment Lifetime, years	13	DOE EREN FEMP
AEC, quad	0.26	Meyers et al. (2002), modified to use an updated estimate of 215 average cycles/year, rather than 250 cycles/year, based on CFR 2004.

A4.2 Product Technology Descriptions and Market Presence

For energy consumption considerations, dishwashers are categorized by two metrics—1) whether equipped to sense the amount of soil in the wash load, and 2) the dish load capacity. Dishwashers equipped with soil sensors offer the potential to save energy compared to a timed cycle because the dishwasher only uses the volume of water needed to clean the dishes. The energy used to heat the water is the main component of dishwasher energy use, so any feature that saves water will also reduce energy consumption. Standard size dishwashers are units with a dish load capacity of 8 or more place settings. Compact dishwashers are units with a dish load capacity of less than 8 place settings.

The stock unit energy consumption (UEC) levels (see Table A4-3) include dishwashers at and below the current minimum efficiency standard. ENERGY STAR® qualified dishwashers use 25% less energy than the federal standard for energy efficiency. The federal minimum efficiency standard remains unchanged. However, Energy Factor values (Table A4-2) for the Stock and particularly, the Typical New level are dated. These values do not consider the effect of restating Energy Factor values for soil-sensing dishwashers in light of the new dishwasher procedure, nor do they consider the relative quantity of higher efficiency / soil-sensing dishwashers in the mix of shipped and installed units. It is expected that much of this information will be compiled within the year when all manufacturers must make their annual statements to the Federal Trade Commission.

Table A4-2: Residential Dishwasher Technology Levels and Energy Factor Values

Technology Level	Energy Factor [cycles/kWh]	Comments/Source
Stock	0.41	Meyers et al. (2002)
Minimum Efficiency Standard	0.46	DOE EREN FEMP (2000)
Typical New	0.50	ADL (2000)
ENERGY STAR®	0.58	http://www.energystar.gov
Soil-Sensing	0.60	Typical value for soil-sensing units listed at http://www.energystar.gov
Best Available	1.19	http://www.energystar.gov

The Energy Factor associated with best available technology is taken from the latest data available at the ENERGY STAR® site. However, there is some question whether these data represent data gathered according to the new test procedure.

Some dishwashers use much less energy than the minimum standard and the ENERGY STAR® rating. The best available dishwasher uses approximately 39%[3] of the energy level specified in the minimum efficiency standard and approximately 49% of the energy level specified in the ENERGY STAR® rating. The primary factor in dishwasher energy consumption is water use – the less water used the more energy saved.

A4.3 Test Procedure Status

On August 29, 2003 the Department of Energy published its final rule for the "Uniform Test Method for Measuring the Energy Consumption of Dishwashers" (10 CFR 430 Subpart. B, App. C). This update to the dishwasher test procedure presents several significant additions and revisions, including:

- Addition of three-point test method, specifically for soil-sensing dishwashers
- Addition of a test method to measure standby power for all dishwashers—both soil-sensing and fixed-cycle machines, and
- Reduction of the number of average-use cycles per year

Soil-sensing dishwashers must now be tested with soiled dishware to more accurately reflect their energy and water consumption (effective 2/25/04). A review of dishwasher survey data has shown that relative to the level of soil on dishware in dishwashers, U.S. households distribute into three levels of soil--Light-62%, Medium-33%, and Heavy-5% (ADL, 2001). Further, the review finds survey data to define the mass of food soil at each of these three levels of soil and expresses the masses of food soil in terms of the food soils used in the industry's 'worst-case' cleaning test, ANSI/AHAM DW-1. The test standard, ANSI/AHAM DW-1, soils each place setting with 31.3 grams of specific food soils, such as egg, oatmeal, preserves, potatoes, ground meat, coffee, etc. Based on the findings of the review, the amount of food soil at each soil level is:

Light - 1/2 of 1 soiled place setting (15.65 grams),
Medium - 2 soiled place settings (62.6 grams), and
Heavy - 4 soiled place settings (125.2 grams).

Based on the recommendations of the review, the energy factor for soil-sensing dishwashers is now determined from a weighted average of energy consumption tests conducted at each of the three soil levels. For example, of the eight place settings used in the energy consumption test, the heavy soil level has four of those place settings soiled per DW-1. The weighting of the average of the energy consumption tests results from the distribution of U.S. households relative to the level of soil on the dishware in their dishwashers. Therefore, the calculation of the energy factor of a soil-sensing dishwasher (EFsoil-sensing) is:

---

3 KWh/cycle is the inverse of the Energy Factor value presented in Table A4-2. Thus, the best available technology uses 0.46/1.19 = 39% of the energy used by a product meeting the minimum efficiency standard.

$$EF_{soil\text{-}sensing} = 1/ (0.62 * Energy_{Light\ Soil\ Level} + 0.33* Energy_{Medium\ Soil\ Level} + 0.05 * Energy_{Heavy\ Soil\ Level})$$

The dishwasher test procedure is the first test procedure to include the measurement of standby power for all dishwashers. However, a dishwasher's standby power is not included in its energy factor calculation and therefore does not impact the minimum standard. The standby power measurement is factored into a dishwasher's estimated annual operating cost (EAOC) and is reported on its EnergyGuide label.

The number of average-use cycles per year for a dishwasher has been reduced to a value of 215 (264 was the value used prior to FY2003). This average-use number represents a midpoint in a range of average-use numbers determined from a review of five surveys of consumers' usage habits, including the 2001 RECS data (ADL 2001).

In addition to these major modifications, other updates included the addition of definitions to support the soil-sensing test method, and modifications to improve the clarity and repeatability of the test procedure.

A4.4 Energy Savings Estimates and Calculations

Table A4.3 presents the estimates of the current energy consumption and potential energy savings for residential dishwashers. The energy savings calculations assume that the entire installed base of dishwashers consume energy at the "typical new" level.

Table A4-3: Residential Dishwasher Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (MMBtu/yr)	Annual Energy Savings Potential (quad)	Energy Saving Potential, 2010-2035 (quads)
Typical Dishwasher (Current Stock)	4.05	NA	NA
'Typical New'	3.28	NA	NA
ENERGY STAR®	2.83	0.028	0.52
Soil-Sensing	2.73	0.034	0.63
Best Available	1.40	0.12	2.17

The energy savings potential between ENERGY STAR® and best available dishwasher technology shows a wide range of potential energy savings. However, as noted above the data on best available dishwasher technology may not reflect testing against the new test procedure. Further there is a relatively low saturation level, ~60%, of homes with dishwashers, which gives room for much more saturation and lends some additional uncertainty in potential energy savings.

Additional dishwasher energy savings could be realized if consumers' habit of pre-treating dishes with water can be avoided. It is well documented that approximately 70% of households with dishwashers pre-treat dishes with water before putting them into the dishwasher (ADL

2001). Estimates of water consumption vary widely and little information is available on the amount of hot water used. Therefore, estimating this potential energy savings is currently difficult and likely to be uncertain.

A4.5 Regulatory Actions and Cumulative Burden

Dishwashers are regulated for energy efficiency under NAECA and have the minimum energy efficiency level listed in Table A4-2. The extent to which regulation impacts dishwashers, including health and safety, was not determined.

Companies that manufacture dishwashers typically produce other white goods that have been subject to past energy efficiency regulations under NAECA, including clothes washers & dryers, refrigerators, and freezers.

A4.6 Issues Impacting Potential Energy Efficiency Standards

With increasing use of microprocessors to control the dishwashing cycle and improved electronic user interfaces (e.g., visual displays), the potential for standby losses increases. Standby energy consumption on the order of 5 Watts could increase typical new dishwasher AEC by approximately 10%.

References

ADL, 2000, "Guide for Evaluation of Energy Savings Potential". Report to the US Department of Energy, Office of Building Technology, State and Community Programs (BTS), February, 2000.

ADL, 2001, "Review of Survey Data to Support Revisions to DOE's Dishwasher Test Procedure", Report to U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs, December 18, 2001.

Appliance Magazine, 2004, appliance industry statistics, page 16
Appliance Magazine, March.

Appliance Magazine, 2001, "Appliance Statistical Review: 48th Annual Report". *Appliance Magazine*, May.

CFR, 2004, 10 Code of Federal Regulations - Energy, as of March 15, 2004.

DOE, 2000, Energy Efficiency and Renewable Energy Network (EREN), Federal Energy Management Program (FEMP), "Dishwasher Cost-Effectiveness Example", Available at: http://www.eren.doe.gov/femp/procurement/dish_cost.html .

Meyers, S., McMahon, J., McNeil, M., and Liu, X., 2002, "Historical and Projected Impacts of U.S. Federal Efficiency Standards for Residential Appliances", Lawrence Berkeley National Laboratory Report, LBNL-49504, May.

A5 Electric Motors, 1-200 HP

A5.1 Background

Industrial motor systems are the largest single electrical end use in the U.S. economy. According to the United States Industrial Electric Motor Systems Market Opportunity Assessment (OIT-2002), a study published by the United States Department of Energy, electric motors used in industrial processes consumed 679 billion kWh (approximately 7.5 quads of primary energy) in 1994. This accounts for 23 percent of all United States electricity consumption. (OIT-2002)

Motors covered by the Energy Policy Act (EPAct) account for 50-70 percent of all integral horsepower motors sold, and 23-32 percent of annual energy consumed by integral horsepower motors. (OIT-2002) Table A5-1 shows background data on industrial sector motors in the size range covered by EPAct. Industrial motors in the size range covered by EPAct consumed 380 billion kWh site energy, or 4.2 quads of primary energy, in 1994. Most industrial motors in the EPAct size range are in fact subject to EPAct (that is, they are considered general purpose; many motors used in the commercial sector are considered special purpose and therefore are not subject to EPAct efficiency standards). Thus energy consumption for the size range gives a reasonable approximation of the total industrial sector energy consumption subject to EPAct. Table A5-2 shows the same data for commercial sector motors.

Table A5-1: Industrial Sector Motors, 1-200HP Background Data

Data Type	Units	Value	Source
Installed Base	Million units	12.3	(OIT-2002)
Annual Shipments, 2002	Million units	1.5[4]	(Census-2002)
Equipment Lifetime (years)	Years	15-20 years for 80% turnover	(OIT-2002)
1994 AEC, 1-200 HP Motors[5]	quads	4.2	(OIT-2002)

Table A5-2: Commercial Sector Motors, 1-200HP, Subject to EPAct, Background Data

Data Type	Units	Value	Source
Installed Base	Million units	4.1	(ADL-1999)
Annual Shipments	Million units	0.54	(ADL-1999)
Equipment Lifetime (years)	Years	15	(ADL-1999)
AEC, 1-200 HP EPAct Motors[6]	quad	0.7	(ADL-1999)

[4] This figure is actually the total number of shipped motors in the size range; it is not restricted to industrial motors only.
[5] This figure assumes that the distribution of motor system energy consumption by horsepower size for all industrial motors is identical to the distribution for motors from the manufacturing sector. This annual energy consumption (AEC) figure includes *all* motors in the EPAct size range, and thus may include energy consumed by some definite and special purpose motors not subject to EPAct.
[6] This figure is based on Tables 4-3 and 4-4 of (ADL-1999). Most of the energy subject to EPAct (in the 1-200HP size range, and not a special purpose motor such as a compressor) is consumed by blower motors in medium unitary air conditioners, large unitary air conditioners, Central Station Air Handling Units, and pumps in Hydronic heating systems.

Commercial sector motors are much more numerous than industrial motors, and tend to be smaller: in 1995, there were 123 million commercial sector motors total; approximately 70 percent of those (87 million) are smaller than 1HP, and thus not subject to EPAct. About 36 million commercial motors fall in the EPAct size range. The number of commercial sector motors greater than 200HP is very small. The Annual Energy Consumption for commercial sector motors in 1995 was 356 billion kWh. Of that, 31 percent was consumed by fractional horsepower motors, and 7 percent by motors greater than 200HP. About 220 billion kWh was consumed by commercial motors in the 1-200HP range. 196 billion kWh (55 percent of the total) was consumed by motors in the range 1-20HP. (ADL-1999) Despite these apparently large numbers, most energy in the commercial sector is consumed by refrigerant compressors and other motors that are considered special purpose and thus not subject to EPAct.

A5.2 Product Technology Descriptions and Market Presence

A5.2.1 Motor Types

For the purpose of efficiency standards, motors designed for use under *usual service conditions* without restriction to a particular application or type of application are known as "general-purpose motors." (NEMA-2001). Usual service conditions include limits on variables such as temperature, altitude, power supply quality, mounting conditions, and ventilation conditions. (LINCOLN-1995) Motors that operate using alternating electrical current are known as AC Motors; motors powered by direct current are known as DC motors. Because AC motors are simpler in construction, and because electric grids provide AC power, AC motors are typically used in industrial settings. Polyphase motors are simpler in construction, more reliable, and provide higher power/size ratios than corresponding single phase motors, and thus are the norm for industrial applications. (LINCOLN-1995)

AC Polyphase motor types

The most common form of polyphase induction motor (again because of simplicity) is the squirrel cage, so-named for the appearance of its rotor. The other types of AC polyphase motors are the wound rotor induction motor, and synchronous motor. The existing EPAct standards apply just to squirrel cage polyphase induction motors.

Motor size

Motors below 1HP are known as fractional horsepower motors; those 1HP and above are known as integral.

Drive

If the power source driving the motor can only supply a fixed voltage and frequency, it is described as a single speed drive. If the source can vary the supply voltage or frequency in order to control the motor speed, it is termed an Adjustable Speed Drive (ASD), or Variable Speed Drive (VSD). Some motor applications, such as pumps and blowers, can match flow requirements by operating at different speeds appropriate to each application. Although ASDs typically result in a moderate (approximately 5%) decrease in motor system efficiency, they can realize large reductions in motor system energy consumption in applications that favorably accommodate operation of motors at reduced speed. For example, an ASD can reduce the energy consumed by a central station air handler by approximately 40% (ADL-1999). Most induction motor ASDs are not integral parts of the motor; thus, they do not impact the tested full-load motor efficiency (see the "Test Procedure" section).

Enclosure

The most common types of industrial motor enclosures are Open Drip-Proof (ODP), and Totally Enclosed Fan-Cooled (TEFC). ODP motors have open vents, but are designed to tolerate drops of liquid falling on them from angles within 15 degrees of vertical. TEFC motors are more protected than ODP motors, as an enclosure completely covers the motor internals. Cooling is provided by fan-driven airflow over the exterior of the motor enclosure. Although TEFC motors are entirely enclosed, they are not airtight. ("Encapsulated motors," with airtight enclosures, are available for more specialized applications including safety, but these are far less common than ODP or TEFC enclosures.)

Existing regulations apply to ODP and TEFC motors. The efficiency regulations for the two types of enclosed motors are different.

A5.2.2 Motor Design Efficiency Measures

The efficiency of induction motors can be improved in several ways. In practice, all represent a balance between performance gain and cost. *Better quality core materials* for the motor rotor and stator can reduce eddy current and hysteresis losses (collectively known as "iron losses"). *Increased winding slot fill* increases the amount of material (typically copper) in the stator windings, which reduces resistance to electric flow in the stator windings and associated resistive "copper" loss. *Reduced rotor bar conductor resistance* reduces losses from motor slip by switching the conductor material to copper or a different aluminum alloy. *Improved manufacturing quality* encompasses several potential measures that decrease motor losses (e.g., reduced lamination edge shorts on the stator and rotor to improve suppression of eddy currents, improved motor design and manufacturing processes to reduce stray load losses, improved rotor bar-lamination isolation to reduce resistive losses). *Increasing the stack length* enables attainment of required torque and power ratings with lower flux and current loadings thereby lowering iron and copper losses, but requires a greater expenditure of material and perhaps an increase in motor frame size. *Improved bearings and lubricants* could reduce bearing friction loss. *Improved fan designs* and other aerodynamic improvements could reduce windage loss.

Other motor technologies, such as permanent magnet and switched reluctance motors, have the potential to realize higher motor efficiencies than EPAct-level induction motors, particularly at smaller motor sizes.

Increasing the efficiency of motors may require changes to other motor parameters such as inrush current, startup torque, and slip. In certain applications, motor efficiency cannot be increased beyond a certain point without altering other motor parameters beyond what is feasible for the application.

A5.2.3 Regulations and Voluntary Energy Efficiency Programs

The Energy Policy Act of 1992 (EPAct) requires that general purpose, polyphase, single speed, squirrel-cage induction motors rated from 1-200hp manufactured for sale in the US from

October, 1997 onward meet minimum efficiency standards. EPAct also requires standardized testing procedures and labeling. (EPACT-1992). The EPAct standard was adapted from earlier standards promulgated by the National Electrical Manufacturer's Association (NEMA). Specifically, EPAct dictates that the nominal full load efficiencies for open and enclosed motors of 3600, 1800, and 1200 rpm are consistent with the energy efficiencies listed in NEMA Standard MG1, Part 12, (NEMA-1998) according to tests specified in IEEE Standard 112 Method B (IEEE-1996), carried out by a NIST/NVLAP approved independent testing laboratory (NIST-1995).

NEMA maintains a more stringent voluntary standard known as NEMA Premium™. The Consortium for Energy Efficiency (CEE) launched a Premium Efficiency Motors Initiative in 1996. In 2001, CEE aligned its standards with NEMA Premium™, so there is no longer a distinct CEE standard. The United States Environmental Protection Agency considered introducing the EnergyStar® label for integral horsepower electric motors, but decided not to, in part because the combined CEE / NEMA Premium™ standard appeared to provide a broadly recognized and consistent means for identifying more efficient motors. Furthermore, manufacturer support for an alternative, potentially competing label was not strong. (EPA-2001)

The Motor Challenge program of the US Department of Energy (DOE) was an effort to improve motor efficiency through education, rather than regulation. This program has been integrated into DOE's broader BestPractices program[7], which provides energy efficiency resources for a variety of industrial systems, not just motors.

"Motor Decisions Matter" is a national campaign encouraging the use of sound motor management and planning as a tool to cut motor energy costs and increase productivity. The campaign is sponsored by a consortium of motor industry manufacturers and service centers, trade associations, electric utilities and government agencies. The campaign is sponsored or supported by CEE, NEMA, EPA, DOE, major motor manufacturers, utility and state energy-efficiency programs, and other stakeholders. (DECISIONS-2004).

The purpose of the Efficiency of Electric Motors (EEM) program of the National Institute of Standards and Technology (NIST), part of the National Voluntary Laboratory Accreditation Program (NVLAP), is to accredit testing laboratories to assure that standard test procedures for efficiency are followed in testing electric motors. Specifically, the EEM program addresses testing the efficiency of electric motors for EPAct and NEMA Premium™ standards. (NIST-1995) (NIST-2004).

Both EPAct and NEMA Premium™ use the same testing procedures, described later in section A5.3. The main difference between the EPAct and the NEMA Premium™ standards are the required efficiency levels. Table A5-3 below compares EPAct and NEMA Premium™ efficiency levels for 2 pole, 4 pole, and 6 pole Open Drip Proof motors at five representative motor size bands. Table A5-4 provides the same comparison for Totally Enclosed Fan Cooled Motors. The two standards differ in scope, that is, EPAct only applies to motors from 1 to 200 HP, whereas the NEMA Premium standard is defined for motors from 1 to 500 HP. Also,

[7] More information is available at: http://www.oit.doe.gov/bestpractices/motors .

NEMA Premium specifies an additional set of efficiency standards for medium voltage motors (600V to 5kV), in the range 250 HP-500 HP.

Table A5-3: Open Drip-Proof (ODP) Motor Full-load Efficiencies at Representative Levels (based on EPACT-1992, CEE-2001, NEMA 2001)

Full Load Efficiencies [%]						
	6-Pole / 1200 RPMs		4-Pole / 1800 RPMs		2-Pole / 3600 RPMs	
HP	EPAct Standard	NEMA Premium	EPAct Standard	NEMA Premium	EPAct Standard	NEMA Premium
1	80.0	82.5	82.5	85.5	N/A	77[8]
5	87.5	89.5	87.5	89.5	85.5	86.5
20	91	92.4	91	93	90.2	91.0
50	93	94.1	93	94.5	92.4	93.0
100	94.1	95.0	94.1	95.4	93	93.6
200	94.5	95.4	95.0	95.8	94.5	95.0

Table A5-4: Totally Enclosed Fan-Cooled (TEFC) Motor Full-load Efficiencies at Representative Levels (based on EPACT-1992, CEE-2001, NEMA-2001)

Full Load Efficiencies [%]						
	6-Pole / 1200 RPMs		4-Pole / 1800 RPMs		2-Pole / 3600 RPMs	
	EPAct Standard	NEMA Premium	EPAct Standard	NEMA Premium	EPAct Standard	NEMA Premium
HP						
1	80.0	82.5	82.5	85.5	75.5	77[9]
5	87.5	89.5	87.5	89.5	87.5	88.5
20	90.2	91.7	91	93	90.2	91.0
50	93	94.1	93	94.5	92.4	93.0
100	94.1	95.0	94.5	95.4	93.6	94.1
200	95.0	95.8	95.0	96.2	95.0	95.4

Installed-base efficiency estimates for industrial motors, from (OIT-2002), are shown in the Table A5-5. The same data for commercial motors, from (ADL-1999), are shown in Table A5-6.

[8] CEE and NEMA tables differ in this entry. NEMA figure is shown.
[9] CEE and NEMA tables differ in this entry. NEMA figure is shown.

Table A5-5: Installed base efficiency estimates for industrial motors, 1998 (OIT-2002)

HP	Efficiency [%]
>1-1.5	79.3
>5-7.5	85.16
>20-25	88.91
>50-60	91.29
>100-125	92.17
>150-200	93.03

Table A5-6: Installed base efficiency estimates for commercial motors, 1999 (ADL-1999)

HP	Efficiency [%]
1	75
5	83
20	88
50	89
100	90
200	91

A5.3 Test Procedure Status

The various energy efficiency standards for motors (EPAct and NEMA / CEE) all rely on the same efficiency test procedures, the so-called "Method B" of IEEE Standard 112, "IEEE Standard Test Procedure for Polyphase Induction Motors and Generators." (IEEE-1996)

Method B of IEEE Standard 112 is described as "Input-output with segregation of losses and indirect measurement of stray-load loss." In this test, according to IEEE-1996, "the apparent total loss (input minus output) is segregated into its various components with stray-load loss defined as the difference between the apparent total loss and the sum of the conventional losses (stator and rotor I^2R loss, core loss, and friction and windage loss). The value of stray-load loss thus determined is plotted vs. torque squared, and a linear regression is used to reduce the effect of random errors in the test measurements. The smoothed stray-load loss data are used to calculate the final value of total loss and the efficiency."

The specific test procedure for Method B consists of a series of measurements that must be performed in order, with interspersed calculations. The numbers below are the relevant section headings from IEEE-1996.

6.4.1.1 Rated load temperature test
6.4.1.2 Test under load
6.4.1.3 No load test
6.4.2.1 Friction and windage loss
6.4.2.2 Core loss
6.4.2.3 Stator I^2R loss
6.4.2.4 Rotor I^2R loss
6.4.2.5 Apparent total loss

6.4.2.6 Stray-load loss determination (indirect method)
6.4.2.7 Smoothing of the stray-load loss

The procedure for 6.4.1.2 is described as follows (taken from 6.3.1, which 6.4.1.2 references):

> *The machine is loaded by means of a mechanical brake or dynamometer (see 4.3.1).*
>
> *Readings of electrical power, current, voltage, frequency, slip, torque, ambient temperature, and stator winding temperature or stator winding resistance shall be obtained for four load points approximately equally spaced between not less than 25% and up to and including 100% load, and two load points suitably chosen above 100% load but not exceeding 150% load. (IEEE-1996)*

The nominal efficiency, i.e., the efficiency listed on the motor nameplate and the regulated efficiency value, is the efficiency at 100% load. A more realistic typical load level for industrial motors in the 1HP – 200HP size class would be 55%. Sub-appendix Table A5-A1 (please see column 3 and footnote 2) presents more detailed information on typical motor loading levels. The relative error resulting from this approximation should be small, as efficiency of partially loaded motors does not drop off drastically until below 50%. Please see (ADL-1999) Figure 2-2 (after NEMA-1994) for a characterization of efficiency as a function of loading.

As of 1998, just 9 percent of industrial motors had ASDs; these motors were responsible for just 4 percent of total motor energy consumption. (OIT-2002)

A5.4 Energy Savings Estimates and Calculations

Table A5-7 shows the change in Annual Energy Consumption that would result from shifting from EPAct to NEMA Premium standards. The table shows that the proposed change in regulation could save 0.06 quad per year of primary energy (5.4 billion kWh per year).[10]

In a scenario in which the market penetration of NEMA Premium™ level industrial motors ramps linearly from 0 in 2010 to 100% in 2025, and then remains at 100% through 2035, the total benefit resulting from mandating the NEMA Premium™ efficiency standard instead of EPACT would be approximately 1.0 quad, as shown in the third column of the table.

[10] This calculation is based on the formula *AEC (kWh) = Motor Size (HP) x 0.746 x Operating Hours x Loading x Installed Base / Efficiency*. The data for Operating Hours, Loading, and Population in each size class comes from OIT-2002. *Benefit* = $AEC_{EPACT} - AEC_{NEMA\ Premium}$. The calculation details appear in the appendix.

Table A5-7: AEC Savings from Increasing 1-200HP EPAct Motor Efficiency Levels to NEMA Premium Levels, Industrial Motors

Size Class (HP)	AEC Savings [quad]	Total AEC Savings, 2010-2035 [quad]
1 to 5	0.0094	0.16
5 to 20	0.014	0.25
20 to 50	0.015	0.27
50 to 100	0.0098	0.17
100 to 200	0.011	0.19
Total	**0.060**	**1.0**

(OIT-2002) estimates that industrial motor Annual Energy Consumption could be reduced by as much as 0.82 to 1.3 quads (75 to 122 billion kWh), or 11 to 18 percent, *if all cost-effective applications of mature proven efficiency technologies and practices* were employed, in the manufacturing sector alone. (OIT 2002) This estimate includes savings from both motor efficiency upgrades, and system efficiency upgrades.

Table A5-8: AEC Savings from Increasing 1-200HP EPAct Motor Efficiency Levels to NEMA Premium Levels, Commercial Motors

Size Class (HP)	AEC Savings [quad]	Total AEC Savings, 2010-2035 [quad]
1 to 5	0.0025	0.043
5 to 20	0.013	0.23
20 to 50	0.0	0.0
50 to 100	0.0	0.0
100 to 200	0.0	0.0
Totals	**0.016**	**0.28**

Table A5-8 shows AEC savings for the commercial sector.[11] One source of uncertainty in this calculation is the estimate of installed base efficiency. Also, this calculation includes energy consumption from just a few motor applications that account for most of the consumed energy that is subject to EPAct.

Estimates of motor operating hours are another significant source of uncertainty for our calculations. This uncertainty directly affects our savings calculation for industrial motors, and indirectly affects our commercial savings estimates. (Our commercial calculation is based on an Annual Energy Consumption figure from (ADL-1999) that in turn depends on an operating hours estimate.) While the changes in efficiency being contemplated are small, on the order of a few percentage points, it seems plausible that the uncertainty in motor operating hours is much larger, as an individual motor can easily run at any duty cycle from 0 to 100 percent. On the other hand,

[11] The data in this table were calculated based on AEC data for commercial motors from ADL-1999 [figure ES-3, p. x] ("$AEC_{DEFAULT}$"), and assumed installed base efficiencies for commercial motors from ADL-1999 [figure 4-4, p. 4-5], shown in this document as Table 1-6 ("$EFF_{DEFAULT}$"). The formula used to calculate the table is
$Benefit = AEC_{EPACT} - AEC_{NEMA\ Premium}$, where
$AEC_{EPACT} = AEC_{DEFAULT} \times EFF_{DEFAULT} / EFF_{EPACT}$. Similarly,
$AEC_{NEMA\ Premium} = AEC_{DEFAULT} \times EFF_{DEFAULT} / EFF_{NEMA\ Premium}$.

the same estimate of operating hours appears in both the EPAct and the NEMA Premium scenario calculations.

In a scenario in which the market penetration of NEMA Premium™ level commercial motors ramps linearly from 0 in 2010 to 100% in 2025, and then remains at 100% through 2035, the total benefit resulting from mandating the NEMA Premium™ efficiency standard instead of EPACT would be approximately 0.28 quad, as shown in the third column of Table A5-8.

Table A5-9 below summarizes the cumulative Annual Energy Consumption savings that could be realized in the period 2010-2035 by increasing the 1-200HP EPAct efficiency levels to NEMA Premium levels: approximately 1.3 quads of primary energy.

Table A5-9: AEC Savings from 2010-2035 from Increasing 1-200HP EPAct Motor Efficiency Levels to NEMA Premium Levels

Motor Type	Total AEC Savings, 2010-2035 [quads]
Industrial	1.0
Commercial	0.28
Total	**1.3**

A5.5 Regulatory Actions and Cumulative Burden

EPAct regulates the full-load efficiency of 50-70 percent of all integral horsepower motors sold. (OIT-2002) In addition, many 1-200HP motors – both those covered EPAct and special-purpose motors not covered by EPAct – are major components of equipment regulated by EPAct, e.g., unitary A/C compressors and blowers.

Two main kinds of motor manufacturers exist. Some motor manufacturers primarily manufacture motors and do not produce significant quantities of other products that face energy efficiency regulations. Most remaining motor manufacturers are a motors-focused division of a parent company. In the second case, other divisions of the parent may produce equipment that faces efficiency regulation, such as appliances.

A5.6 Issues Impacting Potential Energy Efficiency Standards

In the upcoming years, it is likely that the continued decreases in the cost of ASDs will increase their market share. Other (non-induction) motor technologies may achieve greater market share, particularly at the lower end of the 1 to 200HP range. In the future, some motors may directly incorporate an ASD in the motor design. However, these motors would not be subject to EPAct regulation, and thus do not represent an issue for the contemplated change in efficiency standards.

Premium Efficiency motors are not feasible for all applications, because the high efficiency levels would require changes to other motor parameters that would be inconsistent with application requirements.

Because of their higher cost, Premium Efficiency motors tend to be economical, in the sense of providing payback within two years, if they are run for 4000 hours or more per year. Premium Efficiency motors that are run for 2000 or fewer hours per year tend not to yield a timely payback. (CEE-1999) For motors that are run for a small number of annual operating hours, the dollars invested in an efficiency upgrade might yield more energy savings if applied elsewhere.

References

ADL, 1999, "Opportunities for Energy Savings in the Residential and Commercial Sectors with High-Efficiency Electric Motors", Final Report by Arthur D. Little, Inc., to the U.S. Department of Energy, December. Available at: http://www.eere.energy.gov/buildings/documents/pdfs/doemotor2_2_00.pdf .

ADL-2000, "Guide for Evaluation of Energy Savings Potential". Report to the US Department of Energy, Office of Building Technology, State and Community Programs (BTS), February.

BESTPRACTICES-2003. Website: http://www.oit.doe.gov/bestpractices/motors/.

CEE-1999, "Efficient Motors: Selection and Application Consideration," Consortium for Energy Efficiency, Boston, MA, 1999.
http://www.cee1.org/ind/motrs/motr-broch.pdf

CEE-2001, "CEE Premium-Efficiency Motors Initiative Efficiency Specifications," http://www.cee1.org/ind/motrs/Cee-nema.pdf. Initiative web page http://www.cee1.org/ind/motrs/motrs-main.php3.

CENSUS-2002, "Motors and Generators: 2002." US Census Bureau report, MA335H(02)-1. Published by Information Services Center, MCD, Washington, D.C, 1993.

CFR-1999, 10 Code of Federal Regulations - Energy, Revised as of January 1, 1999.

DECISIONS-2003. Motor Decisions Matter program web site: http://www.motorsmatter.org/

EPACT-1992, Energy Efficiency Program for Certain Commercial and Industrial Equipment: Test Procedures, Labeling, and Certification Requirements for Electric Motors; Final Rule. 10 CFR Part 431. Federal Register, Volume 64, No. 192, October 5, 1999.

EPA-2001, Kathleen Hogan, Director, Climate Protection Partnerships Division, Office of Air and Radiation, United States Environmental Protection Agency, "Letter to all interested parties," October, 2001.

IEEE-1996, "IEEE Standard Test Procedure for Polyphase Induction Motors and Generators," IEEE Std 112-1996 (Revision of IEEE Std 112-1991). ISBN 1-55937-891-3. Published by IEEE, New York, 1997.

LINCOLN-1995, "Fundamentals of polyphase electric motors," Published by Lincoln Electric Motor Division, Cleveland, OH, 1995. Available on website:
http://www.lincolnmotors.com/pdf/d-funds.pdf

NEMA-1998, "Motors and Generators," MG1-1998. Definitive standard defining NEMA Premium™ Efficiency levels. Published by NEMA, Rosslyn, VA, 1999.

NEMA-2001, "Information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motor Standards." A condensation of NEMA-1998. Published by NEMA, Rosslyn, VA, 2002.

NIST-1995 Handbook 150-10, Efficiency of Electric Motors (EEM). A publication of the National Voluntary Laboratory Accreditation Program (NVLAP) of the National Institute of Standards and Technology. Published by US Government Printing Office, Washington D.C., 1995.

NIST – 2004 Directory of Accredited Laboratories, Efficiency of Electric Motors. Website: http://ts.nist.gov/ts/htdocs/210/214/scopes/eemot.htm. Most recent update as of this writing January 2004.

OIT-2002, "United States Industrial Electric Motor Systems Market Opportunities Assessment," Published by the US Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) and its Office of Industrial Technologies (OIT), Washington, D.C., 2002.

Sub-Appendix: Detailed calculations

Table A5-A1. Annual Energy Consumption, Industrial Motors, Default scenario

Annual Energy Consumption, Default scenario						
Size Class	**Unit Operating hours (1)**	**Loading (2)**	**Efficiency (3)**	**Unit Energy Consumption**	**Number of Motors (6)**	**Annual Energy Consumption**
HP	**Hours / Year**	**Percent**	**Percent**	**kWh / Year**		**kWh / Year**
1 to 5	2745	56.6	82.0	4.24E+03	7306080	3.10E+10
5 to 20	3391	51.7	86.5	1.89E+04	3288035	6.21E+10
20 to 50	4067	57.1	90.0	6.74E+04	1129527	7.61E+10
50 to 100	5329	52.2	91.5	1.70E+05	363940	6.19E+10
100 to 200	5200	66.1	92.5	4.16E+05	220908	9.19E+10
Totals				**6.76E+05**	**1.23E+07**	**3.23E+11**

Table A5-A2. Annual Energy Consumption, Industrial Motors, EPACT scenario

Annual Energy Consumption, EPACT scenario						
Size Class	**Unit Operating hours (1)**	**Loading (2)**	**Efficiency (4)**	**Unit Energy Consumption**	**Number of Motors (6)**	**Annual Energy Consumption**
HP	**Hours / Year**	**Percent**	**Percent**	**kWh / Year**		**kWh / Year**
1 to 5	2745	56.6	85.0	4.09E+03	7306080	2.99E+10
5 to 20	3391	51.7	89.25	1.83E+04	3288035	6.02E+10
20 to 50	4067	57.1	92.0	6.59E+04	1129527	7.44E+10
50 to 100	5329	52.2	93.55	1.66E+05	363940	6.05E+10
100 to 200	5200	66.1	94.55	4.07E+05	220908	8.99E+10
Totals				**6.61E+05**	**1.23E+07**	**3.15E+11**

Table A5-A3. Annual Energy Consumption, Industrial Motors, NEMA Premium scenario

Annual Energy Consumption, NEMA Premium scenario						
Size Class	**Unit Operating hours (1)**	**Loading (2)**	**Efficiency (5)**	**Unit Energy Consumption**	**Number of Motors (6)**	**Annual Energy Consumption**
HP	**Hours / Year**	**Percent**	**Percent**	**kWh / Year**		**kWh / Year**
1 to 5	2745	56.6	87.5	3.97E+03	7306080	2.90E+10
5 to 20	3391	51.7	91.25	1.79E+04	3288035	5.89E+10
20 to 50	4067	57.1	93.75	6.47E+04	1129527	7.31E+10
50 to 100	5329	52.2	94.95	1.64E+05	363940	5.97E+10
100 to 200	5200	66.1	95.6	4.02E+05	220908	8.89E+10
Totals				**6.53E+05**	**1.23E+07**	**3.10E+11**

Table A5-A4 Savings comparison: EPACT vs. NEMA Premium, Industrial Motors

EPACT vs. NEMA Premium Absolute Savings comparison			
Size Class	**EPACT Savings**	**NEMA Premium Savings**	**Benefit**
HP	kWh	kWh	kWh
1 to 5	1.09E+09	1.95E+09	8.54E+08
5 to 20	1.91E+09	3.23E+09	1.32E+09
20 to 50	1.65E+09	3.04E+09	1.39E+09
50 to 100	1.36E+09	2.25E+09	8.93E+08
100 to 200	1.99E+09	2.98E+09	9.87E+08
Totals	**8.01E+09**	**1.35E+10**	**5.44E+09**

Notes:

(1) OIT-2002, p. B-2

(2) Expected load values based on Table 1-19, "Loading by Horsepower," OIT-2002, p. 46. This table provides a 'distribution' of loading levels: within each horsepower class, it lists the fraction of motors loaded less than 40%, 40-120%, or above 120%. The values we used are the expected value of the loading, assuming that the distribution is uniform within each of the three load level classes. Also, we assumed that motors were never loaded beyond 130% of their rated load.

(3) OIT-2002, Table 2-10, p. 65, 1800 RPM, midrange value taken (i.e., this table is very fine-grained, 1-1.5 HP, 1.5-2HP, etc. We picked a representative efficiency from the middle of our HP size classes.

(4) Efficiency standards for 4 pole (1800 RPMS) ODP motors. The EPACT efficiencies for the low and high end of the HP ranges were averaged to produce the EPACT efficiency number.

(5) Efficiency standards for 4 pole (1800 RPMS) ODP motors. The NEMA Premium™ efficiencies for the low and high end of the HP ranges were averaged to produce the NEMA Premium™ efficiency number.

(6) OIT-2002, p. B-2.

(7) Relative to 1994 AEC for 1-200HP Industrial motors: 3.81E+11 kWh. This AEC figure assumes: (a) 1994 AEC for all industrial motors of 6.79E+11 (OIT-2002, p. 1), and (b) we can apply distribution of motor system energy with respect to horsepower size for *manufacturing sector* motors (OIT-2002, p. 40) to all industrial motors.

A6 Pool Heaters, Gas

A6.1 Background

In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for gas-fired pool heaters. As defined by NAECA, a pool heater is "an appliance designed for heating non-potable water contained at atmospheric pressure, including heating water in swimming pools, spas, hot tubs, and similar applications" (NAECA 1987). This definition is limited to residential gas-fired pools and spas by the general application of NAECA to consumer products only. Pool heaters are a covered product. The energy efficiency descriptor for pool heaters is thermal efficiency. As prescribed by NAECA, all pool heaters must meet a minimum thermal efficiency of 78 percent. Updated minimum standards for pool heaters were proposed in 1994 but DOE never finalized the proposed standards (DOE 1994). Table A6-1 provides background data on the installed base, annual shipments, lifetime, and national annual energy consumption of pool heaters.

Table A6-1: Pool Heater Background Data

Data type	Value[1]	Source/Comments
Installed Base, million	2.5	Based on historical shipments and equipment lifetime of 1r years
Annual Shipments, million	0.205	(DOE 1993)
Equipment Lifetime, years	15	(DOE 1993)
AEC, quad	0.082	Based on installed based and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002.

A6.2 Product Technology Description and Market Presence

Water is heated as it passes through the pool heater. The pool heater does not store heated water. The heaters are installed on the water line that circulates pool water through the filter. This plumbing arrangement avoids an additional pump for the heater. When the circulating pool water temperature is too low, a thermostat turns on the heater. After the pool water reaches the desired temperature, the heater is turned off.

The majority of pool heaters being manufactured consist of finned copper tube heat exchangers in a rectangular combustion chamber. Most pool heaters are designed for outdoor installation. The venting is directly out of the combustion chamber, with some extra baffling on the vent for protection from the elements. Baseline pool heaters have a standing pilot. Electronic ignition can be used to replace the standing pilot and reduce gas consumption, although the benefit of electronic ignition is not reflected in the thermal efficiency rating. The non-condensing limit was considered to have a thermal efficiency of 80 percent. Two condensing levels were also analyzed. Table A6-2 summarizes the various efficiency levels considered by DOE in 1994 when updated minimum efficiency standards were being considered (DOE 1993).

Table A6-2: Pool Heater Technology Levels and UEC Values

Technology Level	Thermal Efficiency	UEC (MMBtu/yr)	Source
Baseline	78%	30.5	(DOE 1993)
Electronic Ignition	78%	26.0	(DOE 1993)
Non-Condensing Limit	80%	24.7	(DOE 1993)
Condensing (Induced Draft)	91%	22.4	(DOE 1993)
Condensing (Pulse)	96%	21.2	(DOE 1993)

Table A6-3 provides retail price information corresponding to the efficiency levels specified in Table A6-2. Retail price data were taken from DOE's 1993 Technical Support Document and inflated to 2002 dollars using consumer price index data from the U.S. Department of Labor (DOL 2004).

Table A6-3: Pool Heater Retail Prices

Technology Level	Thermal Efficiency	Retail Price ($2002)	Source
Baseline	78%	$1785	(DOE 1993)
Electronic Ignition	78%	$1905	(DOE 1993)
Non-Condensing Limit	80%	$2080	(DOE 1993)
Condensing (Induced Draft)	91%	$3196	(DOE 1993)
Condensing (Pulse)	96%	$4318	(DOE 1993)

A6.3 Test Procedure Status

The Department adopted a Final Rule of the test procedure for gas-fired pool heaters on May 12, 1997 (DOE, 1997).

A6.4 Energy Savings Estimates and Calculations

Table A6-4 presents the energy savings potential for the efficiency levels specified in Table A6-2. Also provided in Table A6-4 is the economic benefit or burden to consumers for each efficiency level. Note that the condensing designs do not yield an economic benefit to consumers. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the

DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[12]

Table A6-4: Pool Heater Potential Energy Savings and Economic Impact Estimates

Technology	UEC (MMBtu/yr)	Energy Saving Potential, 2010-2035 (quad)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
Baseline	30.5	NA	NA
Electronic Ignition	26.0	0.29	0.40
Non-Condensing Limit	24.7	0.37	0.28
Condensing (Induced Draft)	22.4	0.52	-1.22
Condensing (Pulse)	21.2	0.59	-2.88

A6.5 Regulatory Actions and Cumulative Burdens

In the Fiscal Year 2004 Priority-Setting memorandum, pool heaters were listed as a low-priority product (DOE 2003). No significant changes have occurred since then.

A6.6 Issues Impacting Potential Energy Efficiency Standards

Although not directly impacting gas-fired pool heaters, DOE actively promotes the use of solar pool heating. In particular, there is a DOE program called "Million Solar Roofs" which has resulted in increased use of solar pool heating (DOE 2004b). DOE also provides consumer guides detailing the benefits of solar pool heating (DOE 2004c). For example, DOE states in their Energy Smart Management website for solar pool heating systems: "The most cost-effective use of solar energy today is to heat swimming pools. Swimming pools require low temperature heat which is where solar collectors are most efficient."

Because the market share of solar pool heating is growing, it will tend to reduce the savings from gas-fired pool heater standards below what are provided here (Table A6-4).

[12] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

References

National Appliance Energy Conservation Act (NAECA), 1987, Pub. L. 100-12

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1993. "Technical Support Document: Energy Efficiency Standards for Consumer Products: Room Air Conditioners, Water Heaters, Direct Heating Equipment, Mobile Home Furnaces, Kitchen Ranges and Ovens, Pool Heaters, Fluorescent Lamp Ballasts & Television Sets." Washington, DC DOE/EE-0009, Volume G.

U.S. Department of Energy (DOE)-U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy. 1994. "Energy Conservation Program for Consumer Products; Proposed Rule." Federal Register 59 (43): 10464-10532.

U.S. Department of Energy (DOE)-U.S. Department of Energy-Office of Conservation and Renewable Energy. 1997. "Energy Conservation Program for Consumer Products: Test Procedures for Furnaces/Boilers, Vented Home Heating Equipment, and Pool Heaters." Federal Register 62 (91): 26140-26165.

U.S. Department of Energy (DOE)-Building Technologies Program. 2003. "Fiscal Year 2004 Priorities for the Appliance Standards Rulemaking Process." Available online: http://www.eere.energy.gov/buildings/appliance_standards/pdfs/october_memo.pdf

U.S. Department of Labor (DOL), Bureau of Labor Statistics. 2004. Consumer Price Index-All Urban Consumers. Available online: http://www.bls.gov/cpi/

U.S. Department of Energy (DOE), Energy Information Administration. 2004a. "Annual Energy Outlook 2004 with projections to 2025." Washington, DC. DOE/EIA-0383(2004). January 2004.

U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy. 2004b. "Million Solar Roofs: A Technology Success Story". http://www.millionsolarroofs.com/articles//static/1/binaries/ChristyMSRIPresentation0703.pdf

U.S. Department of Energy (DOE), Energy Efficiency and Renewable Energy. 2004c. "Reduce Swimming Pool Energy Costs", Energy Smart Management: Solar Pool Heating Systems. http://www.eere.energy.gov/rspec/solar.html

A7 Refrigerators and Refrigerator-Freezers, Freezers, and Compact Refrigerators

A7.1 Background

Refrigerators, refrigerator-freezers, and freezers are major household appliances designed for the refrigerated storage of food products. A refrigerator consists of a refrigerated cabinet designed for the refrigerated storage of food at temperatures above 0°C (32°F) and below 3.9°C (39°F), configured for general refrigerated food storage, and having a source of refrigeration requiring single phase, alternating current electric energy input only. A refrigerator may include a compartment for the storage of food at temperatures below 0°C (32°F), but does not provide a separate low temperature compartment designed for freezing and storage of food at temperatures below -13.3°C (8°F). A refrigerator-freezer is a cabinet which consists of at least one compartment designed for the refrigerated storage of food at temperatures above 0°C (32°F) and at least one other compartment designed for the freezing and storage of food at temperatures below -13.3°C (8°F). A freezer consists of a cabinet for the storage and freezing of foods at -17.8°C (0°F) or below. Compact refrigerators are defined by the DOE as having less than a 7.75 cubic foot capacity and 36 inches or less in height.

In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for refrigerators, refrigerator-freezers, and freezers. For twelve product classes, NAECA specified the maximum allowable energy in kilowatt-hours per year for products manufactured on or after January 1, 1990 (NAECA 1987). Subsequent to the NAECA requirements, a new set of minimum efficiency standards became effective first in 1993 then again in 2001 (DOE 1997). The new minimum efficiency standards in 1993 eliminated 99 percent of the models and increased efficiency by 25 to 30 percent relative to the NAECA requirements. The minimum efficiency standards that became effective on July 1, 2001 increase the efficiency of the most popular product class, top mount refrigerator-freezers with auto-defrost, by approximately 30 percent relative to the 1993 standards.

Table A7-1 provides background data on the installed base, annual shipments, lifetime, and national annual energy consumption for refrigerator-freezers and freezers. The background data are divided into three categories: standard size refrigerators and refrigerator-freezers, freezers, and compact refrigerators.

Table A7-1: Standard Refrigerator, Freezer, and Compact Refrigerator Background Data

Type	Data type	Value[1]	Source/Comments
Refrigerator & Refrigerator-Freezers	Installed Base, millions	142	Based on historical shipments and equipment lifetime of 19 years
	Annual Shipments, millions	9.74	(Appliance 2004)
	Equipment Lifetime, years	19	(DOE 1995)
	AEC, quad	0.86	Based on installed base and stock annual energy use
Freezers	Installed Base, millions	29	Based on historical shipments and equipment lifetime of 19 years
	Annual Shipments, millions	1.49	(Appliance 2004)
	Equipment Lifetime, years	19	(DOE 1995)
	AEC, quad	0.14	Based on installed base and stock annual energy use
Compact Refrigertors	Installed Base, millions	12	Based on historical shipments and equipment lifetime of 19 years
	Annual Shipments, millions	1.40	(Appliance 2004)
	Equipment Lifetime, years	11	(DOE 1995)
	AEC, quad	0.04	Based on installed base and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002.

A7.2 Product Technology Description and Market Presence

Technology for improving refrigerator and freezer performance include: using more efficient compressors, reducing the power consumption of fans, using smart defrost technology to minimize the amount of defrost that is needed and adding insulation.

The saturation of refrigerators/refrigerator-freezers was 96 percent in 2001, based on the number of households with at least one refrigerator (AHAM 2003). The sales of compact refrigerators have increased appreciably in the last several years. While most seem to be sold to residential consumers, significant amounts are also prevalent in non-residential applications such as hotels, dormitories and offices.

The Federal Energy Management Program (FEMP), ENERGY STAR®, and the Consortium for Energy Efficiency (CEE) specify voluntary efficiency requirements for refrigerators, refrigerator-freezers, and freezers (FEMP 2004; ENERGY STAR® 2004; CEE 2004). FEMP provides efficiency targets only for standard size refrigerator-freezers. For example, for top-mount refrigerator-freezers with auto-defrost, the specified annual energy use reduction target is four percent lower than the current minimum standard. FEMP is in the process of revising its purchasing recommendations for refrigerators, in order to be in alignment with ENERGY STAR® specifications. The difference between FEMP and ENERGY STAR® will be that while

ENERGY STAR® specifies an efficiency curve, FEMP divides recommendations into bins based on capacity and reports their recommendations in kWh/year rather than as a percentage increase in efficiency.

ENERGY STAR® specifies annual energy use reduction targets of 15, 10, and 20 percent for standard size refrigerator-freezers, freezers, and compact refrigerators respectively. CEE targets only standard-size refrigerator-freezers. CEE specifies three tier levels specifying annual energy use reduction targets of 20, 25, and 30 percent relative to current minimum efficiency standards.

The market presence of higher efficiency refrigerators and freezers can be gauged somewhat by the number refrigerators meeting the ENERGY STAR® specifications and CEE tier levels. The AHAM 2003 Fact Book reports that 25 percent of sales of refrigerator products over 6.5 cu. ft. in capacity meet ENERGY STAR® levels (AHAM 2003). On January 1, 2004, the ENERGY STAR® criteria changed for all full size refrigerators (above 7.75 cu. ft in capacity). For top-mount refrigerator-freezers with volumes between 16.5 to 18.4 cu. ft., 33 models currently meet the ENERGY STAR® criteria. For chest freezers, twelve models currently meet the ENERGY STAR® criteria; however, none were in the 22.5 to 24.4 cu. ft. range. For single-door refrigerators, 23 models currently meet the ENERGY STAR® criteria (ENERGY STAR® 2004). All single-door refrigerator models meeting ENERGY STAR® have volumes less than 7.75 cu.ft., qualifying them as compact refrigerators. According to information compiled by ENERGY STAR®, several refrigerator-freezer models meet the CEE tier levels. Over 50 refrigerator-freezer models lie between the first two CEE tier levels (i.e., energy use of 20 to 25 percent lower than existing minimum standards), five models lie between the second and third CEE tier levels (i.e., energy use of 25 to 30 percent lower than existing minimum standards), and six models have lower energy consumption than the third CEE tier level (ENERGY STAR® 2004).

Tables A7-2 through A7-4 provide the UEC values corresponding to various efficiency levels of standard-size refrigerator-freezers, freezers, and compact refrigerators.

Table A7-2: Standard-Size Refrigerator-Freezer Technology Levels and UEC Values

Technology Level	UEC[1] (kWh/year)	Source
Typical New	552	(AHAM 2003)
Minimum Efficiency Standard	484[2]	(DOE 1997)
FEMP[3] (4% decrease)	530	(FEMP 2004)
ENERGY STAR® (15% decrease)	469	(ENERGY STAR® 2004)
CEE Tier 1 (20% decrease)	442	(CEE 2004)
CEE Tier 2 (25% decrease)	414	(CEE 2004)
CEE Tier 3 (30% decrease)	338	(CEE 2004)

[1] UEC values are a shipment-weighted average of all standard-size refrigerator-freezers.

[2] Minimum standard for top- mount refrigerator-freezer with auto defrost, 21.4 cu. ft. adjusted volume.

[3] FEMP is in the process of revising its purchasing recommendations for refrigerators, in order to be in alignment with ENERGY STAR® specifications. The difference between FEMP and ENERGY STAR® will be that while ENERGY STAR® specifies an efficiency curve, FEMP divides recommendations into bins based on capacity and reports their recommendations in kWh/year rather than as a percentage increase in efficiency.

Table A7-3: Freezer Technology Levels and UEC Values

Technology Level	UEC[1] (kWh/year)	Source
Typical New	444	(AHAM 2003)
ENERGY STAR® (10% decrease)	400	(ENERGY STAR® 2004)

[1] UEC values are a shipment-weighted average of all freezers.

Table A7-4: Compact Refrigerator Technology Levels and UEC Values

Technology Level	UEC[1] (kWh/year)	Comment/Source
Typical New	300	(AHAM 1996)
ENERGY STAR® (20% decrease)	240	(ENERGY STAR® 2004)

[1] UEC values are a shipment-weighted average of all compact refrigerators.

Tables A7-5 through A7-7 provide retail price information corresponding to the efficiency levels specified in Tables A7-2 through A7-4. Retail price data for typical new standard-size refrigerator-freezers and freezers are provided by AHAM in their 2003 Fact Book (AHAM 2003). A representative retail price for a typical new compact refrigerator was obtained from a retailer website (WalMart 2004). Retail prices are generated for high efficiency levels from the percentage price increases indicated by the price versus efficiency relationships in DOE's 1995 refrigerator Technical Support Document (TSD) (DOE 1995).

Table A7-5: Standard-Size Refrigerator-Freezer Retail Prices

Technology Level	UEC (kWh/year)	Retail Price ($2002)	Source
Typical New	552	$788	(AHAM 2003)
FEMP (4% decrease)	530	$796	(DOE 1995)[1]
ENERGY STAR® (15% decrease)	469	$856	(DOE 1995)[1]
CEE Tier 1 (20% decrease)	442	$903	(DOE 1995)[1]
CEE Tier 2 (25% decrease)	414	$961	(DOE 1995)[1]
CEE Tier 3 (30% decrease)	338	$1031	(DOE 1995)[1]

[1] Price vs. efficiency relationship, top-mount refrigerator-freezer with auto-defrost, Table 4.1.

Table A7-6 Freezer Retail Prices

Technology Level	UEC (kWh/year)	Retail Price ($2002)	Source
Typical New	444	$405	(AHAM 2003)
ENERGY STAR® (10% decrease)	400	$415	(DOE 1995)[1]

[1] Price vs. efficiency relationship, chest manual defrost freezer, Table 4.8, baseline to design option 2 efficiency range.

Table A7-7: Compact Refrigerator Retail Prices

Technology Level	UEC (kWh/year)	Retail Price ($2002)	Source
Typical New	300	$125	(WalMart 2004)
ENERGY STAR® (20% decrease)	240	$131	(DOE 1995)[1]

[1] Price vs. efficiency relationship, compact manual defrost refrigerator, Table 4.9.

A7.3 Test Procedure Status

Standard-size refrigerators, refrigerator-freezers, freezers, and compact refrigerators are all covered under the same DOE test procedure. They are tested at an ambient temperature of 90°F while internal volume temperatures are kept within specified temperature conditions. DOE has recently taken action on a couple of issues regarding the test procedure. Also, there have been recent actions to improve AHAM's test standard. The National Institute of Standards and Technology (NIST) has investigated the possibility of harmonizing the U.S. test procedure with international test standards. All of these recent actions are described in more detail below.

Credit for a more efficient defrost system

DOE issued a direct final rule, which became effective in May 2003, amending the calculation of the test time period for "long-time" automatic defrost units (DOE 2003). This change gives credit for a control capable of detecting frost so that the defrosting occurs other than during a compressor-on cycle, thereby saving energy by taking advantage of the natural warming of the evaporator during the compressor-off cycle. This revision has no effect on the testing of refrigerators and refrigerator-freezers that do not employ a long-time automatic defrost system.

Change in electric refrigerator definition to exclude wine coolers

Several manufacturers of wine coolers requested exemptions from the refrigerator energy efficiency standards. Some wine coolers are made with glass front doors, which make them less energy efficient than standard refrigerators. As a result, the DOE amended the definition of "electric refrigerator", effective December 19, 2001, to include a maximum temperature of the fresh food storage compartment, and to exclude certain appliances whose physical configuration makes them unsuitable for general storage of perishable foods. The purpose of the revised electric refrigerator definition was to exclude wine coolers from the energy efficiency regulation (DOE 2001). This rule may also affect other compact refrigerators designed to store and cool beverages other than wine. For example, since the time of the test procedure revision, a new product has entered the market that is both a compact refrigerator and wine cooler whose performance cannot be rated by the existing test procedure.

Repeatability issues for testing compact refrigerators

Because of inconsistencies in test results for compact refrigerators, the National Institute of Standards and Technology (NIST) investigated repeatability and reproducibility issues and published a report entitled "Repeatability of Energy Consumption Test Results for Compact Refrigerators". In addition, NIST participated in a task force formed by the Association of Home Appliance Manufacturers (AHAM) to revise their AHAM HRF-1 test procedure. The latest version of AHAM's test procedure is now AHAM HRF-1, 2003. But the existing DOE test procedure still references an older version of the AHAM test procedure, AHAM HRF-1, 1979. DOE may need to amend the test procedure to reference the most recent version of AHAM HRF-1.

Harmonizing with international standards

NIST has done comparisons between ISO's international test standards and the North American test standard. The two test procedures are similar but not identical. Differences include the ambient temperature at which the refrigerators are tested and the ISO specified test load. There is some interest in harmonizing and unifying the two test procedures by manufacturers interested in international trade. Recently, the United States, Canada, and Mexico have harmonized their test procedures.

A7.4 Energy Savings Estimates and Calculations

Table A7-8 presents the energy savings potential for the FEMP, ENERGY STAR®, and CEE efficiency levels specified in Tables A7-2 through A7-4. Also provided in Table A7-8 is the economic benefit or burden to consumers for each efficiency level. Note that only the FEMP and ENERGY STAR® efficiency levels yield an economic benefit to consumers. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[13]

Table A7-8: Refrigerator Potential Energy and Economic Impact Estimates

Technology Level	UEC (kWh/yr)	Energy Saving Potential, 2010-2035 (quads)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
Standard-Size Refrigerator-Freezers			
Base Case	552	NA	NA
FEMP	530	0.77	1.00
ENERGY STAR®	469	2.89	0.52
CEE Tier 1	442	3.85	-1.28
CEE Tier 2	414	4.82	-4.07
CEE Tier 3	386	5.78	-7.85
Freezers			
Base Case	444	NA	NA
ENERGY STAR®	400	0.38	0.61
Compact Refrigerators			
Base Case	300	NA	NA
ENERGY STAR®	240	0.48	0.87

[13] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

A7.5 Regulatory Actions and Cumulative Burden

For full line manufacturers of white goods, consideration needs to be given to what other regulatory actions are in effect for other products.

Also, refrigerator manufacturers had to recently comply with U.S. EPA regulations on the phase-out of HCFC-141b in 2003, the blowing agent that was used for foam insulation. Any consideration given to updated minimum efficiency requirements needs to account for the effort and cost manufacturers expended for meeting this regulation.

A7.6 Issues Impacting Potential Energy Efficiency Standards

DOE's most recent energy efficiency standards became effective on July 1, 2001. This set of standards is the third set of minimum efficiency requirements that the industry has faced since 1990. The first set of standards took effect in 1990 and the second set in 1993.

Wine cooler and beverage centers as well as combination refrigerator/beverage coolers, need definitions and possible test procedures and standards.

Compact refrigerators are a fast growing part of the overall refrigerator market. Thus, due to their increased national energy consumption, potential energy savings could become greater in the future.

References

Appliance Magazine. 2004. "Healthy Times Ahead." January, 2004.

Association of Home Appliance Manufacturers (AHAM). 1996. Data on compact refrigerators. Chicago, IL.

Association of Home Appliance Manufacturers (AHAM). 2003. "Fact Book 2003." Chicago, IL.

Consortium for Energy Efficiency (CEE). 2004. www.cee1.org

ENERGY STAR®. 2004. www.energystar.gov

Federal Energy Management Program (FEMP). 2004. http://www.eere.energy.gov/femp/technologies/eeproducts.cfm

National Appliance Energy Conservation Act (NAECA), 1987, Pub. L. 100-12

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1995. "Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, & Freezers ." Washington, DC. DOE/EE-0064.

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 1997. "Energy Conservation Program for Consumer Products: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers and Freezers; Final Rule." Federal Register 62 (81): 23102-23116.

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2001. "Energy Conservation Program for Consumer Products: Amendment to the Definition of Electric Refrigerator; Final Rule." Federal Register 66 (223): 57845-57848.

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2003. "Energy Conservation Program for Consumer Products: Test Procedure for Refrigerators and Refrigerator-Freezers; Direct Final Rule." Federal Register 68 (45): 10957-10961.

U.S. Department of Energy (DOE), Energy Information Administration. 2004. "Annual Energy Outlook 2004 with projections to 2025." Washington, DC. DOE/EIA-0383(2004). January 2004.

WalMart. 2004. Retail price for a Haier 4.2 cu.ft. compact refrigerator. March, 2004. www.walmart.com

A8 Room Air Conditioners

A8.1 Background

A room air conditioner is an encased assembly designed as a unit to be mounted in a window or through a wall that provides cool or warm conditioned air to an enclosed room or space. In 1987, the National Appliance Energy Conservation Act (NAECA) was signed into law establishing minimum energy efficiency standards for room air conditioners (NAECA 1987). The energy efficiency descriptor for room air conditioners is the energy efficiency ratio (EER). The EER is the ratio of the cooling capacity (in Btu/hr) to the input power (in Watts).

Minimum EER standards were first prescribed by NAECA and went into effect on January 1, 1990 ranging from 8.0 to 9.0 EER depending on the product class. A total of twelve product classes were established by NAECA based on the cooling capacity of the unit, the presence of louvered sides (to enhance air flow over the outdoor coil), and the presence of a reversing valve (to allow the unit to provide space-heating through heat pump operation).

A second set of revised minimum efficiency levels went into effect on October 1, 2000 raising the minimum efficiency standards for the most popular product classes to 9.7 or 9.8 EER (DOE 1997). The most popular product classes are cooling-only units equipped with louvered sides and ranging in capacity from less than 6000 Btu/hr to 20,000 Btu/hr. The second set of standards also established minimum efficiency requirements for four additional product classes, two of which explicitly accounted for units designed for mounting in casement windows.

Table A8-1 provides background data on the installed base, annual shipments, lifetime, and national annual energy consumption of room air conditioners.

Table A8-1: Room Air Conditioner Background Data

Data type	Value[1]	Source/Comments
Installed Base, millions	57	Based on historical shipments and equipment lifetime of 13 years
Annual Shipments, millions	6.15 6.06 (year 2006 forecast)	(Appliance 2004)
Equipment Lifetime, years	13	(DOE 1997a)
AEC, quad	0.33	Based on installed based and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002 except where noted.

A8.2 Product Technology Description and Market Presence

Higher room air conditioner efficiencies are typically achieved by improving the performance of the heat exchangers, compressor, fan motor, and fans.

Heat exchanger performance is improved by one or more of the following methods: increased frontal coil area, additional refrigerant tube rows, increased fin density, improved fin design, improved tube design, and adding a sub-cooler to the outdoor condenser coil. Most, if not all room air conditioners, collect the condensate that drips off the indoor evaporator coil into a pan beneath the outdoor condenser coil. The condensate is sprayed on to the condenser coil via a slinger ring attached to the circumference of the condenser fan to improve the heat exchanger performance of the condenser coil.

Room air conditioners typically use rotary-type compressors with efficiencies of up to 11.0 EER at standard rating conditions. Most units utilize a permanent split capacitor (PSC) fan motor to drive both the evaporator blower and condenser fan.

Designs that improve the seasonal or cyclic performance of the unit, such as variable speed or multi-speed compressors, variable-opening expansion devices, and advanced control systems, typically do not improve the steady-state efficiency or EER of the unit. Therefore, these types of designs are typically not utilized in room air conditioners.

ENERGY STAR® and the Consortium for Energy Efficiency (CEE) specify voluntary EER requirements for room air conditioners (ENERGY STAR® 2004; CEE 2004). CEE's efficiency targets of greater than 11.0 EER seem to be quite aggressive, as according to the Association of Home Appliance Manufacturers' (AHAM) 2003 Directory of Certified Room Air Conditioners, few models can meet CEE's EER specifications. However, there are several models meeting the ENERGY STAR® voluntary efficiency requirements of 10.7 and 10.8 EER for units with capacities of less than 20,000 Btu/hr. Table A8-2 provides the EER and UEC values corresponding to various types of room air conditioners. Note that the UEC is based on 533 hours of operation per year as opposed to the 750 hours in DOE's test procedure. The 533 hour value is based on more recent data from the 1997 Technical Support Document for room air conditioners (DOE 1997a).

Table A8-2: Room Air Conditioner Technology and UEC Values

Technology Level	EER	UEC[1] (kWh/yr)	Source
Typical New	9.75	536	(AHAM 2003)
Minimum Efficiency Standard	9.7 to 9.8[2]	538 to 533	(DOE 1997)
ENERGY STAR®	10.7 to 10.8[2] (10% efficiency increase)	486	(ENERGY STAR® 2004)
CEE Tier 1	11.2 to 11.3[2] (15% efficiency increase)	465	(CEE 2004)
CEE Tier 2	11.6 to 11.8[2] (20% efficiency increase)	445	(CEE 2004)

[1] Based typical new cooling capacity of 9800 Btu/hr and 533 hours of operation.
[2] Corresponds to units with cooling capacities less than 20,000 Btu/hr.

Table A8-3 provides retail price information corresponding to the EER levels specified in Table A8-2. Retail price data for a typical new unit is provided by AHAM in their 2003 Fact Book. Retail prices are generated for high EER levels from the percentage price increases indicated by the price versus efficiency relationship in DOE's 1997 room air conditioner TSD for units with cooling capacities between 8000 to 14,000 Btu/hr, with louvered sides, and without reversing valves (DOE 1997a).

Table A8-3: Room Air Conditioner Retail Prices

Technology Level	EER	Retail Price ($2002)	Comment/Source
Typical New	9.75	$322	(AHAM 2003)
ENERGY STAR®	10.7 to 10.8[2] (10% efficiency increase)	$357	(DOE 1997)[1]
CEE Tier 1	11.2 to 11.3[2] (15% efficiency increase)	$460	(DOE 1997)[2]
CEE Tier 2	11.6 to 11.8[2] (20% efficiency increase)	$520	(DOE 1997)[2]

[1] Price vs. efficiency relationship, 8000 to 14,000 Btu/hr with louvered sides, without reversing valve, Table 4.4, 9.3 to 11.0 EER efficiency range.
[2] Price vs. efficiency relationship, 8000 to 14,000 Btu/hr with louvered sides, without reversing valve, Table 4.4, greater than 11.0 EER efficiency range.

A8.3 Test Procedure Status

The DOE test procedure for room air conditioners references ASHRAE Standard 16-69, *Method of Testing for Rating Room Air Conditioners*. While the ASHRAE Standard has been revised in 1983 and reaffirmed in 1999, the DOE test procedure references the 1969 version. The changes made to ASHRAE Standard 16-69 since 1969 have been editorial (i.e., to clarify language for interpretive purposes). Thus there are no substantive technical differences between the 1969 and 1999 versions.

In DOE's Final Rule regarding minimum efficiency standards published on September 24, 1997, the Department recognizes that the current test procedure is not adequate for determining the benefits due to designs that improve seasonal or cyclic performance, such as variable speed compressors. Although the current test procedure cannot measure the benefits of designs that improve seasonal or cyclic performance, the Department has no plans to revise the test procedure.

A8.4 Energy Savings Estimates and Calculations

Table A8-4 presents the energy savings potential for the ENERGY STAR® and CEE efficiency levels specified in Table A8-2. Also provided in Table A8-4 is the economic benefit or burden to consumers for each efficiency level. Note that only the ENERGY STAR® efficiency level yields an economic benefit to consumers. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[14]

[14] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

Table A8-4: Room Air Conditioner Potential Energy Savings and Economic Impact Estimates

Technology Level	UEC (kWh/yr)	Cumulative Energy Savings Potential, 2010-2035 (quads)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
Typical New	536	NA	NA
ENERGY STAR®	486	0.80	0.03
CEE Tier 1	465	1.15	-4.14
CEE Tier 2	445	1.47	-6.29

A8.5 Regulatory Actions and Cumulative Burden

The U.S. Environmental Protection Agency is phasing out the use of R-22 in 2010 for use in new appliances. R-22 is a hydrochlorofluorocarbon that has been found to contribute to atmospheric ozone depletion. Because R-22 is the refrigerant used in room air conditioners, the industry must find a replacement. The central air conditioning and heat pump industry is also faced with the same environmental regulation. As a result, this industry has identified two replacements: R-410a and R-407c. Although R-407c can be used as a "drop-in" replacement, it tends to degrade the efficiency of the equipment. Thus, R-410a seems to be the likely choice by central air conditioning and heat pump industry. But because R-410a has properties that result in higher compressor discharge pressures, equipment may have to be redesigned to accommodate this refrigerant. It is still uncertain which refrigerant the room air conditioner industry will choose to replace R-22. Regardless of the choice, room air conditioner designs will likely change to accommodate the new refrigerant as well as maintain equipment efficiencies in order to meet current minimum efficiency requirements.

A8.6 Issues Impacting Potential Energy Efficiency Standards

The largest single issue facing the industry is the phase-out of R-22. As noted earlier, manufacturers will likely need to redesign their units to accommodate the new refrigerant while preventing any degradation in equipment efficiency.

References

Appliance Magazine. 2004. "Healthy Times Ahead." January, 2004.

Association of Home Appliance Manufacturers (AHAM). 2003. "Fact Book 2003." Chicago, IL.

Consortium for Energy Efficiency (CEE). 2004. www.cee1.org

ENERGY STAR®. 2004. www.energystar.gov

National Appliance Energy Conservation Act (NAECA), 1987, Pub. L. 100-12

U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 1997. "Energy Conservation Program for Consumer Products: Conservation Standards for Room Air Conditioners; Final Rule." Federal Register 62 (185): 50122-50150.

U.S. Department of Energy (DOE)-Office of Codes and Standards, 1997a. "Technical Support Document for Energy Conservation Standards for Room Air Conditioners, Volume 2 – Detailed Analysis of Efficiency Levels (Docket Numbers EE-RM-90-201 & EM-RM-93-801-RAC)." Washington, DC. September, 1997.

U.S. Department of Energy (DOE), Energy Information Administration. 2004. "Annual Energy Outlook 2004 with projections to 2025." Washington, DC. DOE/EIA-0383(2004). January 2004.

A9.1 Background

External power supplies and battery chargers are used by many types of consumer electronic and electrical devices. In some products, the battery charger and power supply are integrated within the electronic or electrical device. For other products, the battery is integrated into the device (e.g., cell phones) and an external power supply is used to charge the battery. Table A9-1 provides background data on battery chargers and external power supplies collected by Lawrence Berkeley National Laboratory (LBNL) and Ecos Consulting. The table shows products used in both the residential and commercial sectors.

Table A9-1: Background Data on Battery Chargers and Power Supplies

Device	Total in Use (millions)	Lifetime (years)	Sales in 2002 (millions)
Electronic Musical Instruments	10.00	6	1.67
Digital camera charger	10.75	6	4.50
Answering Device	47.00	6	5.64
Phone: Conference Phone	1.15	6	0.16
Phone: Cordless	128.40	6	31.27
Phone: Cordless/Answering Machine Combo	76.94	6	15.10
Phone: Other Powered	10.27	5	1.47
Phone: Wireless	140.80	2	57.00
CFL Desk Lamp	0.43	7	0.61
Low-voltage halogen lighting	25.00	7	3.57
Rechargeable Appliances	23.15	4	5.79
Security Systems, Home	3.20	10	0.32
Battery Chargers	8.00	4	2.00
Handheld Computers	8.24	4	2.06
Portable Computer	49.43	4	10.90
Desktop Calculators	40.00	6	6.67
Dictation Equipment Desktop	1.71	6	0.28
Dictation Equipment Portable	2.70	6	0.45
Computer Speakers	59.62	4	20.08
External Modems	5.16	4	1.29
LCD Computer Monitor, external PS (Commercial/Industrial)	4.35	4	2.30
LCD Computer Monitor, external PS (Residential)	2.25	4	1.13
Multifunction device, Inkjet (External PS)	0.22	5	0.74
Printer, Inkjet, external PS	29.50	5	6.76
Printer, Thermal, external PS	4.91	5	0.70
Broadband Internet Devices Hubs in Ports, External PS	35.81	4	8.95
Broadband Internet Devices LAN	8.31	4	2.08
Broadband Internet Devices Routers, External PS	1.56	4	0.39

Source: All data is extracted from a draft spreadsheet being developed by Ecos Consulting and LBNL. Primary sources include Appliance Magazine, technical reports, and internal/professional estimates.

A9.2 Product Technology Description and Market Presence

The distinction between external power supplies and battery chargers is not well defined because for many products, such as cell phones, the power supply's function is to charge the battery. For purposes of this analysis, if the power supply is physically separated from the battery charger, it is referred to as an external power supply. Also for purposes of this analysis, battery chargers are defined as a product whose sole function is to charge batteries.

With regard to power supplies, there are both external and internal types. Power supplies provide the function of reducing primary voltage from 115 volts to a lower voltage. Most often this is also converted to a direct current (DC) voltage. In other cases, the voltage is simply reduced to a lower alternating current (AC) voltage. For this assessment, only external AC to DC power supplies are being considered. Draft legislation currently being considered by Congress also includes AC to AC power supplies (often referred to as transformers) which are used in applications such as door bells.

Up until recently, the most common type of power supply was the linear type. Linear power supplies use a coil of wire (similar to a transformer) to lower voltage. Recently, a new type of power supply using electronic circuitry, called a switch mode power supply (SMPS), entered the market. SMPSs are designed to be more efficient than linear power supplies. SMPSs are typically lighter and smaller in size and can be made more compatible with different frequencies and voltages making them more suitable for the international market. As a result, SMPSs are becoming more widely used in some products. Currently integrated circuit manufacturers sell the power supply chip required for SMPSs to a power supply assembler. Most SMPSs are assembled in Asia, particularly China. The wholesale cost of SMPSs is marginally higher than that for linear power supplies. However, because SMPSs are lighter and smaller in size, their cost may be comparable to linear types after factoring in shipping costs. Future road map analyses sponsored by the Power Sources Manufacturers Association (PSMA) presented at the Applied Power Electronics Conference (APEC) in February 2004, foresees little or no cost difference between linear and SMPS power supplies.

Unit energy consumption (UEC) and efficiency are affected by the operational mode of the battery charger or power supply. Types of operational modes include: no load (i.e., while plugged in a wall socket but not charging a device), active mode (i.e., actively charging a device), and low power or sleep mode. In many cases, even when the device is drawing full load, the power supply is operating at less than its full rated capacity. As exemplified by cell phones, operational modes are affected by how the device is used. In the case of cell phones, the power supply may be: (1) charging the cell phone battery, (2) connected to the cell phone even after the battery is fully charged, (3) left in the wall socket but disconnected from the cell phone, or (4) disconnected from the wall socket. Obviously, the amount of time the charger or power supply spends under a specific load condition affects its UEC. The output voltage also affects the efficiency of the power supply. A high efficiency power supply is more difficult to manufacture at lower output voltages.

ENERGY STAR® has proposed voluntary efficiency requirements for battery chargers and power supplies. It is estimated that approximately 12 percent of power supplies can meet the proposed ENERGY STAR® maximum limits for both no-load and active modes.

The efficiency of power supplies ranges from 30 to 90 percent with most in the range of 60 to 70 percent. Table A9-2 summarizes the typical UECs for the battery charger and power supply devices listed in Table A9-1. The UECs are based on a representative distribution of efficiencies for each device.

Table A9-2: Battery Charger and Power Supply UECs

Device	Typical UEC (kWh/yr)
Electronic Musical Instruments	29.4
Digital camera charger	7.5
Answering Device	34.5
Phone: Conference Phone	30.8
Phone: Cordless	42.3
Phone: Cordless/Answering Machine Combo	50.6
Phone: Other Powered	34.2
Phone: Wireless	14.2
CFL Desk Lamp	23.2
Low-voltage halogen lighting	29.3
Rechargeable Appliances	16.7
Security Systems, Home	122.6
Battery Chargers	7.5
Handheld Computers	0.3
Portable Computer	27.0
Desktop Calculators	14.0
Dictation Equipment Desktop	0.3
Dictation Equipment Portable	0.1
Computer Speakers	19.6
External Modems	47.3
LCD Computer Monitor, external PS (Commercial/Industrial)	101.2
LCD Computer Monitor, external PS (Residential)	56.0
Multifunction device, Inkjet (External PS)	11.9
Printer, Inkjet, external PS	40.8
Printer, Thermal, external PS	40.8
Broadband Internet Devices Hubs in Ports, External PS	11.0
Broadband Internet Devices LAN	35.0
Broadband Internet Devices Routers, External PS	350.4

Source: All data is extracted from a draft spreadsheet being developed by Ecos Consulting and LBNL. Primary sources include Appliance Magazine, technical reports, and internal/professional estimates.

A9.3 Test Procedure Status

Department of Energy (DOE)
DOE does not have a test procedure for either power supplies or battery chargers. Draft legislation being considered by Congress would specify that DOE prescribe by notice and comment, definitions and test procedures for the power use of battery chargers and external power supplies, within 18 months after the date of the legislation's enactment.

Environmental Protection Agency (EPA) & California Energy Commission (CEC)
The EPA and the CEC collaborated in developing a test procedure for external power supplies and battery chargers. Contractors developing the test procedures were Ecos Consulting and EPRI-PEAC. In November 2003, EPA vetted the test procedures of both external power supplies and battery chargers to interested parties. The battery charger test procedure had several issues that could not be resolved. EPA and the interested parties decided that emphasis should be placed on finalizing a test procedure for external power supplies. The test procedure measures energy use and efficiency under no-load conditions and at 25, 50, and 75 percent of rated current loading.

At the Applied Power Electronic Conference in February 2004, EPA announced a draft test procedure and a draft ENERGY STAR® specification for external AC to DC power supplies. Battery chargers and power supplies with integrated battery charging circuitry are currently not included in the EPA specifications.

A9.4 Pending Energy Legislation

As noted above, draft legislation is currently being considered by Congress that would establish definitions and establish a schedule for the development of test procedures for external power supplies and battery chargers.

The draft legislation defines an external power supply to be an external power supply circuit that is used to convert household electric current into either DC current or lower-voltage AC current to operate a consumer product. The draft legislation defines a battery charger to be a device that charges batteries for consumer products and includes battery chargers embedded in other consumer products. The legislations also states: "In establishing these test procedures, the Secretary shall consider, among other factors, existing definitions and test procedures used for measuring energy consumption in standby mode and other modes and assess the current and projected future market for battery chargers and external power supplies."

A9.5 International Test Procedures

EPA issued a draft test procedure for external power supplies in February 2004. EPA has not yet issued a test procedure for battery chargers because testing battery chargers would be more complex than power supplies. Factors that need to be considered include the type of battery to be charged, the rates of charging and discharging and other factors that influence energy consumption.

Recently, EPA distributed to its stakeholders a letter, co-signed by the CEC and representatives of Australia, Brazil, Canada and China, indicating strong international support for a single test procedure for single voltage external AC/DC power supplies.

Other test procedure activities include voluntary specifications by the European Code of Conduct on testing devices at a 100 percent loading. Standby power test procedures affecting power supplies include the IEC test procedure on standby power (IEC 62301) and the U.S. Executive Order on standby power, recommending standby power consumption under one Watt.

A9.6 Energy Savings Estimates and Calculations

The energy savings potential assessment was based on a distribution of power supply and battery charger efficiencies representing the range of efficiencies currently on the market. The assessment was based on the size of the power supply used by each device as well as a distribution of power supply efficiencies for each device. The distribution of efficiencies was based on a sample tested by Ecos Consulting. Energy savings estimates were based on the assumption that 80 percent efficient power supplies were used in all applications.

Energy savings estimated in Table A9-3 are based on estimating the energy usage in four modes of operation: active, ready, low, and off. Not all devices have all four modes. As noted above, the UEC for a device is also based on a distribution of power supply efficiencies as measured by Ecos Consulting. Ecos sorted these power supplies into bins based on their rated output. The power supplies were tested at more than one loading (i.e., percent of rated output current). Based on the testing, efficiency was found not to vary significantly with load, except at very low loads (e.g., no load or light load conditions). The distribution of efficiencies is based on the models Ecos had available to them for testing and is not necessarily representative of a shipment-weighted average of all available power supplies. The lifetime of a power supply is assumed to be at least as long as the product it is used with.

Table A9-3: Battery Charger and Power Supply Savings Potential Estimate

Technology/ Standard Level	Energy Saving Potential, 2010-2035 (quads)
80% efficient in active mode	1.8

A9.7 Issues Impacting Potential Energy Efficiency Standards

Draft Energy Legislation
Perhaps the largest issue impacting potential efficiency standards is the pending energy legislation currently being considered by Congress. If approved and enacted, battery chargers and power supplies will become covered products. Even if the draft legislation is signed into law, there are several issues that DOE will need to contend with in trying to regulate these products including:

- The draft legislation specifies the energy measurement for "standby and other modes" but does not explicitly define the "other" modes.
- The draft legislation uses the term "consumer" to define power supplies and battery chargers. Clarification is needed whether use of the term consumer excludes commercial sector applications.
- Power quality and power factor issues are not addressed. The power factor and power quality can be significantly lower for SMPSs.

Data needs
The high variability in power supply usage as well as the large number of applications greatly affects the certainty of estimated potential energy savings. Thus, additional data need to be collected to better define the overall energy use of power supplies and battery chargers and the savings potential associated with higher efficiency products.

EPA actions
EPA announced in February 2003 a design competition to take place over the next year. This competition will assist in making information available on the efficiency and cost-effectiveness of various external power supply designs. ENERGY STAR® specifications will also be useful in obtaining more information on efficient power supplies.

California Energy Commission
The CEC is interested in establishing efficiency standards for both power supplies and battery chargers. But if the pending energy legislation is not approved by Congress, states will not be pre-empted from taking action on issuing efficiency regulations for these products.

Stakeholder Comments and Concerns
Some stakeholders have recommended that DOE wait until the outcome of the draft energy legislation is known before taking any action to cover and regulate these products.

At the Technical Workshop on Power Supplies and Battery Chargers in San Francisco on November 7th, 2003, a representative from AHAM provided two lists to participants: one regarding external power supplies and the other on battery chargers. These memos ask the CEC, which is considering the regulation of these products, to consider a list of issues before addressing possible regulations. A sample of the issues listed for external power supplies include:

- External power supplies are not an independent product.
- Power supplies may be external for safety reasons and a regulation may encourage companies to put them inside a product.
- Power supplies are used in a wide variety of applications. Some safety regulations may affect the power consumption.
- Adding a power factor correction lowers the efficiency.

Issues listed for battery chargers include:

- Battery chargers are not a stand-alone, independent product.
- Power requirements and stand-by characteristics are different for different products.
- Chargers have different characteristics based on the type of battery they are charging.

A10 Beverage Merchandisers and Beverage Vending Machines

A10.1 Background

Vending machines and beverage merchandisers are refrigerated cabinets that hold bottled or canned beverages at a cool temperature up until the time of purchase by the consumer. The vending machine is designed as self-operating while the beverage merchandiser is designed for use in a restaurant or store where a cashier or merchant is present. Accordingly, vending machines often have bright signs installed on the front to advertise the product and coin slots and dispensers to complete the transaction. The vending machines to be considered are ones that dispense canned beverages, bottled beverages, milk, and juice. Beverage merchandisers usually have a glass door to display the product to the customer. Often, vending machines are sited outdoors at schools, gas stations, etc. On the other hand, most beverage merchandisers are located indoors to discourage theft.

Beverage merchandisers are very similar in construction and size to reach-in refrigerators. The main visual difference is the glass door on a beverage merchandiser compared to the solid door of a typical reach-in refrigerator, which allows more heat leak into the case. An important functional criterion for beverage merchandisers is to be able to rapidly "pull down" the temperature of warm beverages loaded into the merchandiser. For example, one of the largest customers of beverage merchandisers requires beverage merchandisers to bring the temperature of the beverages down to the desired level in a specific amount of time. The glass door and the pull down requirement necessitate bigger refrigeration systems for beverage merchandisers than comparably sized reach-in refrigerators.

Table A10-1 presents the installed base data for vending machines and beverage merchandisers. There are approximately 3.7 million beverage vending machines and 800,000 beverage merchandisers installed in the US. The annual primary energy consumption of the vending machines and beverage merchandisers equals 0.122 and 0.052 quad, respectively.

Table A10-1: Installed Base Data for Vending Machines and Beverage Merchandisers

Equipment type	Data type	Value	Source
Vending Machines	Installed Base, thousands (1994)	3,711	ADL(1996); Appliance Magazine (2002)
	Annual Sales, thousands (2001)	353	
	Equipment Lifetime, years (1994)	7 to 10	
	AEC, quad	0.122	
Beverage Merchandises	Installed Base, thousands (1994)	800	
	Annual Sales, thousands (2001)	175	
	Equipment Lifetime, years (1994)	7 to 10	
	AEC, quad	0.052	

A10.2 Test Procedure Status

Neither vending machines nor beverage merchandisers have a DOE test procedure. Discussion is provided in the following two subsections.

A10.2.1 Vending Machines

For beverage vending machines, energy use is typically expressed in terms of daily power consumption (kWh/day) per vendible capacity of the standard product. Two publicly available test procedures have been developed for rating refrigerated beverage vending machines, and they are widely used by manufacturers. There are also proprietary test procedures developed by bottling companies to evaluate energy consumption and performance of vending machines. The publicly available test procedures are:

- Canadian Standards Association C804-1996 (CAN/CSA C804-96) Energy Performance of Vending Machines, and

- American Society of Heating, Refrigeration, and Air-Conditioning Engineers Standard 32.1-1997 (ASHRAE 32.1-97) Methods of Testing for Rating Vending Machines for Bottled, Canned and Other Sealed Beverages.

The CAN/CSA C804-96 prescribes standards as well as test procedures for a 24-hour steady-state energy consumption test. The standard rating conditions include an ambient temperature of 90° F +/- 1.8° F and a relative humidity of 65% +/- 5%, which corresponds well to a vending machine installed in a hot environment. In addition, a product temperature of 34° F is specified for packaged beverages. The standard product used in the CAN/CSA C804-96 is a 12 oz. can, and the test procedure specifies that the machine be loaded to the minimum rated capacity, as specified by the manufacturer.

The ASHRAE 32.1-97 test procedure is similar to the CAN/CSA C804-96 standard in that it includes a 24-hour steady-state energy consumption test that has the same ambient temperature conditions and a 2° F higher beverage temperature. The product temperature is 36° F and the ambient rating conditions are 90° F +/- 1.8° F ambient temperature and 65% +/- 5% relative humidity. Since the ambient temperature specified is relatively high, it properly represents vending machines installed in a hot environment, such as certain outdoor locations in the summer. This temperature rating condition does not accurately represent machines installed in indoor, air-conditioned locations. The ASHRAE 32.1-97 test procedure specifies the same standard product as CAN/CSA C804-96, a 12 oz. can, but differs in specifying that the machine be fully loaded to capacity. In addition, the ASHRAE 32.1-97 test procedure includes a vend test, where the machine dispenses products at a regular frequency, and a recovery test, where a half empty machine is loaded with warm products. However, the recovery test does not include provisions for measuring the energy consumption during the test. The revised version of the ASHRAE 32.1-1997 test procedure has been recommended by the ASHRAE Standards Project Committee 32.1 for publication. This revised version specifies two energy consumption test temperatures - 90˚ F and 75˚ F. While one committee member wanted indoor vending machines to only be tested at 75˚ F, the committee voted to have these machines tested at both 90˚ F and

75˚ F. The energy consumption test is at steady state and does not include a recovery test. Bottles or cans can be used as the standard test package for the tests.

In addition to the two publicly available test procedures listed above, there are a number of proprietary test procedures developed by bottling companies to evaluate energy use and performance of beverage vending machines. These test procedures include a recovery test specification that limits the amount of time required for a vending machine to cool down warm products introduced into the machine.

Both the CAN/CSA C804-96 and the ASHRAE 32.1-97 are well-defined, easy to implement, and have similar rating conditions. The CAN/CSA C804-96 is widely used in Canada, but not in the US. On the other hand, the ASHRAE 32.1-97 test procedure is widely accepted and used by US manufacturers and state agencies. Therefore, it is recommend that the ASHRAE 32.1-97 be used as the foundation for developing a DOE test method for measuring the energy efficiency of beverage vending machines. The potential limitations of ASHRAE 32.1-97 can be addressed by including provisions to measure the energy consumption during the recovery test and specifying ambient rating temperatures that are consistent with conditions expected for the machine.

A10.2.2 Beverage Merchandisers

No test procedures specifically target beverage merchandisers. However, the California Energy Commission classifies a beverage merchandiser as a glass door reach-in refrigerator, so it uses the ASHRAE 117 test with their specified product temperatures to test beverage merchandisers. Although the ASHRAE 117 test includes door openings, it does not include the energy required to pull down the temperature of warm beverages that have just been loaded into the merchandiser.

It is unclear if the Canadian Standards Association’s CSA C827-98 standard applies to beverage merchandisers. The CSA standard “applies to commercial refrigerator … cabinets that are intended for storing or holding food products and other perishable merchandise” (CSA, 1998). Bottled and canned beverages may not fall under the definition of “food products” and are definitely not perishable.

The ASHRAE 117 test with specified beverage temperatures could be an appropriate test procedure for future energy efficiency standards. It includes energy consumption during standby mode and door openings, a frequent occurrence with beverage merchandisers. The 75°F ambient temperature used in the ASHRAE 117 test also is well-suited to represent the typical indoor location of a beverage merchandiser.

As for the reach-in freezers and refrigerators, the ASHRAE 117 test does not correlate closely with peak load conditions because of its moderate 75°F ambient temperature (relative to hotter temperatures encountered by outdoor units).

A10.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

The potential energy saving estimates are shown in Table A10-2.

Table A10-2: Vending Machines and Beverage Merchandisers - Energy Saving Potential Estimates

Equipment Type	Technology/ Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010-2035), (quads)	Source
Vending Machines	Energy Star Tier 1	0	0	0	% Energy Savings potential from Energy Star Website[15]
	Energy Star Tier 2	13	0.016	0.33	% Energy Savings potential from Energy Star Website[16]
	CEC Design Requirements	14	0.017	0.35	% Energy Savings potential from CEC Appliance Efficiency Regulations[17]
	Royal Vendors - Econo-cool Technology	47	0.057	1.19	% Energy Savings potential from Royal Vendors Website[18] (2002)
	Combination	28	0.034	0.71	% Energy Savings potential from ADL (1996)
	<2 Years Payback (ECM Motors for Evaporator Fans and High Efficiency Compressor)	32	0.039	0.81	% Energy Savings potential from ADL (1996)

---

[15] Available at: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/vend_machines/ES_V1.0_VendingMachine_spec.pdf

[16] Available at: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/vend_machines/ES_V1.0_VendingMachine_spec.pdf

[17] Available at: http://www.energy.ca.gov/reports/2003-09-10_400-03-016.PDF

[18] Available at: http://www.royalvendors.com/royal.html .

	<5 Years Payback (High Efficiency Condenser Fan Motor)	42	0.051	1.06	% Energy Savings potential from ADL (1996)
Beverage Merchandisers	CEC Tier 1	29	0.015	0.31	% Energy Savings potential from CEC Appliance Efficiency Regulations[19]
	CEC Tier 2	36	0.019	0.39	% Energy Savings potential from CEC Appliance Efficiency Regulations[20]
	Combination	35	0.018	0.38	% Energy Savings potential from ADL (1996)
	<2 Years Payback (ECM Motors for Evaporator Fans and High Efficiency Compressor)	44	0.023	0.47	% Energy Savings potential from ADL (1996)
	<5 Years Payback (High Efficiency Condenser Fan Motor)	55	0.029	0.59	% Energy Savings potential from ADL (1996)

ENERGY STAR® has proposed two tiers of efficiency levels for beverage vending machines. The first tier will take effect on April 1, 2004, and the second tier is scheduled for January 1, 2007. The ENERGY STAR® tier 1 level for an 800 can capacity vending machine, the capacity chosen for analysis based on annual sales, equals 8.72 kWh/day which represents a 0% savings from the baseline 8.22 kWh/day. The tier 2 level for the vending machine is 7.14 kWh/day, a 13% savings.

The California Energy Commission (CEC) does not have an energy level, but a design requirement for beverage vending machines. This design requirement states that the internal illumination shall only be T-8 flourescent lamps with electronic ballasts or a lighting system that has no fewer lumens per watt than a system using only T-8 flourescent lamps with electronic ballasts. According to Royal Vendors, Inc, this lighting system will give an energy savings of 14%.

The next energy savings estimate is for a new line of vending machines from Royal Vendors, Inc. The "Econo-cool" line consists of T8 lighting, a brushless DC motor for the evaporator fan, a high efficiency compressor, and computer controls to turn off lighting during non-demand periods. Royal Vendors, Inc. claims a 50% reduction in energy consumption relative to another

[19] Available at: http://www.energy.ca.gov/reports/2003-09-10_400-03-016.PDF
[20] Available at: http://www.energy.ca.gov/reports/2003-09-10_400-03-016.PDF

vending machine made by the same manufacturer that just meets the CEC efficiency levels (Royal Vendors, 2002). An ASHRAE 32.1 energy consumption test of a baseline 800 can capacity vending machine indicated 4.6 kWh/day. After retrofitting with "Econo-cool", the unit consumed 47% less energy than the baseline. Assuming a 47% savings is achieved for all vending machines because of "Econo-cool" the annual primary energy savings potential is 0.057 quad, and the energy savings potential from 2010 to 2035 is 1.19 quads. Implementing this technology has an incremental cost of $75 with a payback of less than one year (ACEEE, 2002a).

The CEC has proposed two tiers of energy efficiency standards for beverage merchandisers. The first tier took effect on March 1, 2003; the second tier is scheduled for August 1, 2004. The CEC tier 1 level for a 27ft^3 total volume beverage merchandiser is 10.42 kWh/day, which is a 29% savings from the baseline 14.71 kWh/day, while the tier 2 level equals 9.41 kWh/day, giving a 36% energy savings. These two tiers give an annual primary energy savings potential of 0.015 and 0.019 quad, respectively, and the energy savings potential from 2010 to 2035 is 0.31 and 0.39 quad, respectively.

The two theoretical combinations of technologies presented in ADL (1996) consist of a high efficiency compressor and a brushless DC evaporator fan motor. Both the compressor and the evaporator fan motor are relatively simple to change and could be deployed on a retrofit basis. The energy savings potential for vending machines equals 28%, with simple payback periods of about 1 year for the high efficiency compressor and about 2 years for the brushless DC evaporator fan motor. The beverage merchandiser combination reduces energy consumption by 35%, with simple payback periods of about 1 year for the high efficiency compressor and 1.4 to 4.4 years for the brushless DC evaporator fan motor. Although the efficiency gains for beverage merchandisers exceed those for vending machines, the larger installed base of vending machines results in higher annual energy savings potential for vending machines.

A10.4 Regulatory Action

The California Energy Commission (CEC) has prepared efficiency standards for glass door reach-in refrigerators that encompass beverage merchandisers (CEC, 2001). In addition, the CEC requires registration of beverage vending machines and has prescribed a design standard mandating the use of energy efficient T8 lamps for sign illumination (CEC, 2001).

Regarding vending machines, the Canadian Standards Association has a maximum daily energy consumption level that depends on the can capacity.

The EPA ENERGY STAR® program has developed voluntary efficiency improvements for beverage vending machines. In addition to the ENERGY STAR® program specification, ACEEE also recommends specifications to be developed by the Consortium for Energy Efficiency (CEE). The CEE has been monitoring the progress of the EPA on the ENERGY STAR® program but has not yet developed a CEE level (ACEEE, 2002b).

Since all beverage merchandisers and vending machines use a vapor compression cycle, most manufacturers have contended with the elimination of ozone-depleting CFC refrigerants from new products imposed by the Montreal Protocol. Most manufacturers produce more than one type of commercial refrigeration equipment, so that regulation of refrigeration equipment as an equipment class would impact a broad range of products for many manufacturers. In addition, some commercial refrigeration manufacturers have other divisions that manufacture other types of equipment that have come under energy efficiency regulations, e.g., unitary air-conditioners. Hence, most manufacturers of beverage merchandisers and vending machines have already borne the cumulative burden of CFC elimination and previous energy efficiency standards (and also face the possible elimination of global warming refrigerants).

A10.5 Issues Impacting Potential Energy Efficiency Standards

In the beverage vending machine industry, there is a large market for refurbished vending machines. Many vending machines are refurbished after about five years and are then put back into the market. The EPA's Energy Star Program Requirements for Refrigerated Beverage Vending Machines does not currently include specifications for remanufactured vending machines but does plan on implementing such a specification after discussions with industry representatives. In addition, there are now residential vending machines on the market that do not have coin mechanisms.

The main issue impacting potential energy efficiency standards is the distinction between a beverage merchandiser and a glass door reach-in refrigerator. Specifically, the energy efficiency standards proposed by the CEC would require beverage merchandiser and glass door reach-in refrigerators to meet the same efficiency levels. Although both types of commercial refrigeration equipment can have similar physical dimensions and holding temperatures, a beverage merchandiser cannot be expected to meet the same energy efficiency standards as a comparably-sized glass door reach-in. Beverage merchandisers usually have an oversized refrigeration system to "pull down" the temperatures of newly-loaded beverages in a short period of time. As a result, the beverage merchandiser will typically cycle (on-off) more often than a glass door reach-in refrigerator, reducing overall device efficiency. Moreover, the larger cooling loads imposed by the "pull down" condition upon beverage merchandiser necessitates a larger evaporator fan, which consumes more energy and dissipates more heat in the units, further reducing unit efficiency. Finally, the beverage merchandiser may also have modest illuminated signs to attract customers, which also consume energy. In sum, due to different application requirements, promulgating the same energy efficiency standards for beverage merchandisers and reach-in refrigerators is inappropriate.

References

ACEEE, 2002a. “Commercial Packaged Refrigeration: An Untapped Lode for Energy Efficiency,” American Council for an Energy-Efficient Economy, Report No. A015, May.

ACEEE, 2002b. “Packaged Commercial Refrigeration Equipment: A Briefing Report for Program Planners and Implementers,” American Council for an Energy-Efficient Economy, Report No. A022, December.

ADL, 1996, “Energy Savings Potential for Commercial Refrigeration Equipment”, Final Report to US Department of Energy, Office of Building Technology, State and Community Programs, June.

Appliance Magazine, 2002, “49th Annual Report”, *Appliance Magazine*, May.

ASHRAE, 1997. “Methods of Testing for Rating Vending Machines for Bottled, Canned, and Other Sealed Beverages”, American Society of Heating, Refrigeration, and Air-Conditioning Engineers Standard 32.1.

CEC, 2001. California Energy Commission Proposed Amendments to California Code of Regulations, Title 20: Division 2, Chapter 4, Article 4, Sections 1601-1608: Appliance Efficiency Regulations. Docket No. 00-AB970-APSTD, April.

CEC, 2003. California Energy Commission California Code of Regulations, Title 20: Division 2, Chapter 4, Article 4, Section 1601-1608: Appliance Efficiency Regulations. Effective August.

CSA, 1996. “Energy Performance of Vending Machines”, Canadian Standards Association, C804-96.

CSA, 1998. “Energy Performance for Food Service Refrigerators and Freezers”, Canadian Standards Association, C8217-98, September.

Energy Star®, 2003(?). “Energy Star® Program Requirements for Refrigerated Beverage Vending Machines”, Version 1.0.

Royal Vendors, 2002, “Econo-Cool Keeps Drinks Cool While Saving Money”, Product Documentation. Available at: http://www.royalvendors.com/royal.html .

A11 Ceiling Fans

A11.1 Background

Most often found in residences, ceiling fans move air to enhance occupant comfort. Used primarily during the cooling season, the installed base of about 192.8 million ceiling fans is weighted toward the Southern portion of the country. The vast majority (about 95%) of ceiling fan installations includes associated lighting, and the energy consumption and savings for the fan motor and lighting are analyzed separately (Table A11-1).

Table A11-1: Ceiling Fan Background Data

Type	Data type	Value	Source
Ceiling Fans Motors	Installed Base, millions (2001)	192.8	Calwell and Horowitz (updated 2003); ADL 1999; RECS (1997 & 2001); Appliance Magazine (2000)
	Equipment Lifetime, years (1997)	13	
	AEC, quad	0.17	
Ceiling fans (lighting only)	Installed Base, millions (1997)	183.2[21]	Calwell and Horowitz (2001); Appliance (2000)
	Equipment Lifetime, years (1997)	13	
	AEC, quad	0.29	

Overall, ceiling fans consume about one-half quad of energy per year, with associated lighting accounting for about 63% of the total.

A11.2 Product Technology Description and Market Presence

All ceiling fans use blades driven by a motor to move air, but the efficiencies of different blade-motor combinations vary substantially. For example, data collected in support of the ceiling fan ENERGY STAR® program showed that fan air-moving efficiency (quantified using a cfm/W metric) varied by more than a factor of two between models. Table A11-2 presents the lighting UEC values for the different lighting options, while Table A11-3 displays the UEC estimates of the different fan and motor technologies, as well as the ENERGY STAR® air-moving efficiency threshold, investigated for ceiling fans (fan motor energy only).

Table A11-2: Ceiling Fan Lighting UEC

Description	Value	Comments
Stock UEC (kWh)	383	Based on a 120 watt baseline unit power consumption, Calwell and Horowitz (updated 2003)
Typical New UEC (kWh)	383	Assumed same as stock
Minimum Efficiency Standard	N/A	No minimum efficiency standard
Current ENERGY STAR ® Efficiency (kWh)	83	Based on a 26 watt average unit power consumption for ENERGY STAR® ceiling fans with lighting, Calwell and Horowitz (updated 2003)

[21] The 183.2 million ceiling fan lighting units reflects an estimate by Calwell and Horowitz (2001 and updated in 2003) that 95% of all ceiling fans have associated lighting.

Table A11-3: Ceiling Fan Motor UEC

Description	Value	Comments
Stock UEC (kWh)	164	Based on 100 cfm/W airflow, Calwell and Horowitz (updated 2003)
Typical New UEC (kWh)	164	Assumed same as stock
Minimum Efficiency Standard	N/A	No minimum efficiency standard
Best Available Efficiency (cfm/W)	165	Aerodynamic fan blade and more efficient motor
Current ENERGY STAR® Efficiency (cfm/W)	122.3	Aerodynamic fan blades
Future Technology (maximum technology) (cfm/W)	260	High-efficiency motor and aerodynamic fan blades, Permanent split capacitor or permanent magnet motor

Ceiling fans do not have minimum efficiency standards for either air moving efficacy or lighting efficacy, but do fall under the voluntary ENERGY STAR® program. The ENERGY STAR® ceiling fan requirement specifies that the ceiling fan motors should have an air moving efficiency that is about 49% lower than that for typical motors. As of February, 2004, 487 fan models without lighting and 19 fan models with lighting have met the ENERGY STAR® requirements.[22] The ENERGY STAR® program requires that the ceiling fan include pin-based compact fluorescent fixtures. The 26 watt level reflects the average wattage of ENERGY STAR® ceiling fans (Calwell and Horowitz, updated in 2003). Future amendments to the ceiling fan ENERGY STAR® program may increase the required fan efficacy, as well as specify additional controls and noise requirements.

The aerodynamic fan blade reflects efficiency gains attained via improved blade design (airfoil shape) to enhance its air moving efficiency. Specifically, the energy savings reflect test data measured for the Hampton Bay "Gossamer Wind"[23] fan, currently for sale at Home Depot. Most ceiling fans use a shaded pole motor (Parker et al., 1999), which have full-speed efficiencies in the 10 to 20% range for sizes typically used in ceiling fans (ADL, 1999). Replacing the shaded pole motor with a more efficient motor type, such as a permanent split capacitor (PSC) or a brushless DC motor,[24] could easily double the efficiency relative to current motors (ADL, 1999). Both PSC and brushless DC motors are available in the size range used by ceiling fan motors. However, the effect of design constraints particular to ceiling fans, such as reversing the position of the rotor and stator, on motor feasibility has yet to be studied. It is also not known whether commercially-available ceiling fans incorporate either PSC or brushless DC motors. The high-efficiency motor and aerodynamic blade performance level simply combines the separate performance gains for the aerodynamic fan design and the high-efficiency motor options. To date, no commercially-available fans offer this technology combination.

[22] Information about ceiling fans meeting the ENERGY STAR® requirements is available at: http://www.energystar.gov/index.cfm?c=ceiling_fans.pr_ceiling_fans.
[23] Based on the / Aeroenvironments CF-1 design; more information available at: http://www.fsec.ucf.edu/~bdac/PROTOTYPE/CFAN.htm .
[24] Also known as an electronically commutated permanent magnet (ECPM) motor.

Economic cost-benefit analyses have yet to be performed for any of the technology options. In particular, the motor options require additional information about how motor design issues specific to ceiling fans – if any – impact motor selection and costs.

A11.3 Test Procedure Status

Ceiling fans do not have a DOE test procedure for a lighting or air moving efficiency. The air moving efficiency of ceiling fans is given in air volume (cubic feet per minute or cfm) divided by electrical input power (W), or cfm/W. There are a number of existing test procedures that have been developed to measure this efficiency, including:

- National Electrical Manufacturers Association Standard Publication No. FM1-1951 (NEMA FM1-51),
- International Electrotechnical Commission Standard 60879-1986 (IEC 60879-86) Performance and Construction of Electric Circulating Fans and Regulators,
- Canadian Standards Association C814-96 (CAN/CSA C814-96) Energy Performance of Ceiling Fans,
- American National Standards Institute and Air Movement and Control Association Standard 230-99 (ANSI/AMCA 230-99) Laboratory Method of Testing Air Circulator Fans for Rating, and
- Hunter Fan Company Solid State Test Method.

The test procedures listed above were all considered during the development of the EPA's ENERGY STAR® Program for Residential Ceiling Fans. During EPA's discussions with industry stakeholders, stakeholders concluded that the Hunter Fan Company's Solid State Test Method was the preferred test procedure for several important reasons:

- the test method includes a specific set of standard test conditions,
- the results using this method are reproducible,
- test conditions represent "real life" conditions,
- testing costs and turnaround time were reasonable, and
- test equipment is widely accessible.

The Solid State Test Method was therefore recommended by stakeholders to be used as the official metric for cfm determination in the ENERGY STAR® Program.

The NEMA FM1-51 test procedure utilizes a mechanical anemometer instrument along with manual readings of air velocity along three-inch centers in a standard room. The equipment and instrumentation used for this test procedure are inexpensive. However, because of the way the measurements are taken, the test is time-consuming and the readings are non-repetitive within a reasonable tolerance. This test procedure has been used by the Hunter Fan Company and Air Cool.

The IEC 60879-86 test procedure is similar to the NEMA FM1-51 test procedure but utilizes controlled airflow in a standard room. The limitations for IEC 60879-86 are the same as NEMA

FM1-51 with regard to the time needed to run the tests and lack of repeatability for the measured results. The test procedure was developed in Europe and is used extensively outside the U.S. Within the U.S., it is used by Home Depot (for its Hampton Bay ceiling fan products), Air Cool, King of Fans, Minka and CEI.

The CAN/CSA C814-96 test procedure is similar to the IEC 60879-86 test procedure but uses hot wire velocity measurements and a different room configuration. The time needed to run the tests is slightly lower than the NEMA FM1-51 and the IEC 60879-86 test procedures. This test procedure is not widely used.

The ANSI/AMCA 230-99 test procedure uses a load cell to measure the downward thrust of the fan's air movement in an axial direction and specific room geometry. The thrust is used to calculate the amount of air movement. The test is inexpensive to conduct but it is very sensitive to ceiling fan wobble, vibrations, and the design of the ceiling fan blades, which contribute to inaccuracies in the test results. Because the load cell is set up to measure airflow in the axial direction, any airflow in the lateral direction is not accounted for.

Because of the limitations with existing test procedures, the Hunter Fan Company internally developed an improved and refined method of measuring ceiling fan air delivery based on the IEC 60879-86 test method called the Solid State Test Method. The Solid State Test Method improves upon the IEC 60879-86 test method by incorporating solid state hot-wire thermister anemometers that are mounted on a sensor arm and allows for simultaneous, multi-point velocity measurements. This improved method allows for greatly reduced testing time and much greater accuracy. According to Hunter Fan Company, the measurements using this test method are typically within 3% of each other.

The distinguishing feature of this test method is that it uses the latest developments in air velocity measurements to improve upon accuracy along with automated measurements to reduce the testing time.

One major limitation of the Solid State Test Method is its inability to report accurate airflow values for hugger type ceiling fans. Hugger fans are installed flush mounted to the ceiling as opposed to hanging from a down-rod pendant style, and subsequently move much less air because of the limited amount of space behind the fan blades. Airflow values from hugger fans tested with the Solid State Test Method are higher than normal because the hugger fans are mounted on a down-rod during the test, thus move more air than they would when installed flush to a ceiling.

The Solid State Test Method is currently used as the test procedure for certifying ENERGY STAR® compliant ceiling fans. Currently, the ENERGY STAR® Ceiling Fan program does not certify hugger fans because of the limitations of the method of testing.

Because of the superiority of the Solid State Test Method over the other various test methods in terms of accuracy, repeatability, and short test duration, it is recommend as the basis for a uniform test method for measuring the energy efficiency of ceiling fans. The Solid State Test Method correlates well with ceiling fan motor energy consumption, energy savings potential, and peak demand impact because it directly measures power draw in all air-moving modes and most fans are expected to operate during (hot) peak demand periods.

To address the problem in measuring hugger type ceiling fans, modifications would have to be made to the Solid State Test Method by either rearranging the configuration of the test setup to be more applicable to hugger fans, applying a correction factor to hugger fan test data (this could be empirically determined), or developing a completely different test method to measure hugger fan performance.

A11.4 Energy Savings Estimates and Calculations

The best available technology standard level (aerodynamic fan blades and high efficiency motor combination) has an energy savings potential of 1.22 quads, while the future technology standard level (future technology with aerodynamic fan blades and improved motor efficiency) can realize 1.93 quads of savings (see Table A11-4). The ENERGY STAR® air moving efficacy level energy savings potential equals 0.57 quad.

Table A11-4: Ceiling Fan UEC and Energy Savings Potential (Fan Energy Only)

Technology/ Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010-2035), (quads)	Source
Typical Device (current stock)	164	NA	NA	Calwell and Horowitz (updated 2003)
'Typical New'	164	NA	NA	Assumed same as Stock
Best Available Technology	100	0.067	1.22	UEC from Calwell and Horowitz (updated 2003)
ENERGY STAR(R), Fan Efficacy Only[25]	134.5	0.031	0.57	UEC from Calwell and Horowitz (updated 2003)
Future Technology (maximum technology)	62.3	0.104	1.93	UEC from Calwell and Horowitz (updated 2003)

Due to a lack of data differentiating energy consumption of fans by vintage, both the fan motor and lighting energy consumption analyses assume the same energy consumption levels for the installed base and typical new equipment.

ENERGY STAR® lighting standard levels, future technology lighting standard levels (maximum technology), and best available lighting technology standard levels assume the use of pin-based compact fluorescent fixtures, which could save 4.22 quads of energy each over the 2010-2035 period (see Table A11-5).

[25] http://yosemite1.epa.gov/ESTAR/consumers.nsf/content/ceilingfans.htm .

Table A11-5: Ceiling Fan UEC and Energy Saving Potential (Lighting Only)

Technology/ Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quad)	Energy Saving Potential (2008-2030) (quads)	Source
Current stock	383	NA	NA	Calwell and Horowitz (updated 2003)
Typical new	383	NA	NA	Assumed same as stock
Best Available	84.3	0.228	4.22	UEC from Calwell and Horowitz (updated 2003)
ENERGY STAR(R) Lighting	84.3	0.228	4.22	UEC from Calwell and Horowitz (updated 2003)
Future Technology (maximum technology)	84.3	0.228	4.22	UEC from Calwell and Horowitz (updated 2003)

The installed base of all ceiling fans has grown dramatically over the past quarter century, from roughly 10 million units in 1976 (Sanchez, 1997) to more than 190 million units in 2001. It is unclear if the trend will continue in the future; continued strong growth will increase both the energy consumption and savings potential over the 2010-2035 period.

A11.5 Regulatory Actions and Cumulative Burden

Ceiling fans have not been subject to regulation for energy efficiency. The extent to which other regulations impact ceiling fans, such as safety regulations, was not determined.

A11.6 Issues Impacting Potential Energy Efficiency Standards

Ceiling fans improve occupant comfort by generating an indoor breeze, which decreases the perceived indoor air temperature. As a result, ceiling fans can enable higher indoor air temperature settings, displacing a portion of an air conditioning load and saving cooling energy. Thus, the cooling energy savings realized by ceiling fans may well exceed their own energy consumption. Potential energy efficiency standards need to ensure that the incremental cost of an efficiency standard (if any) does not deter the purchase of ceiling fans and potentially create a net increase in energy consumption.

References

ADL, 1999, “Opportunities for Energy Savings in the Residential and Commercial Sectors with High-Efficiency Electric Motors”, Final Report to US Department of Energy, Office of Building Technology, State and Community Programs, December.

ANSI/AMCA, 1999. “Laboratory Method of Testing Air Circulator Fans for Rating”, American National Standards Institute and Air Movement and Control Association Standard 230-1999.

Appliance Magazine, 2000, “23rd Annual Portrait of the U.S. Appliance Industry”, *Appliance Magazine*, September, pp. 87-89.

Callwell, C. and Horowitz, N., 2000, "Residential Ceiling Fan - A Look at Their Energy Use and Opportunities for Energy Savings," June 2000 (updated by author in April 2003)

Calwell, C. and Horowitz, N., 2001, “Ceiling Fans: Fulfilling the Energy Efficiency Promise”, *Home Energy*, Jan./Feb., pp. 24-29.

CAN /CSA, 1996. “Energy Performance of Ceiling Fans”, Canadian Standards Association C814-1996.

Energy Information Administration, 1997, “Residential Energy Consumption Survey (RECS)”. Available at: http://www.eia.doe.gov/emeu/recs/pubs.html

Energy Information Administration, 2001, “Residential Energy Consumption Survey (RECS)”. Available at: http://www.eia.doe.gov/emeu/recs/pubs.html

Environmental Protection Agency, 2002, “Energy Star® Testing Facility Guidance Manual: Building a Testing Facility and Performing the Solid State Test Method for Energy Star® Qualified Ceiling Fans”, Version 1.1, December.

IEC, 1986. “Performance and Construction of Electric Circulating Fans and Regulators”, International Electrotechnical Commission Standard 60879.

NEMA, 1951. National Electrical Manufacturers Association Standard Publication No. FM1-1951.

Parker, D., Callahan, M., and Sonne, J., 1999, “Development of a high efficiency ceiling fan”, Florida Solar Energy Center.FSEC-CR-1059-99* Available at: http://www.fsec.ucf.edu/~bdac/pubs/CR1059/CR1059.html .

Sanchez, M., 1997, "Miscellaneous Electricity Use in U.S. Residences", M.S Thesis in the Energy and Resources Group, University of California at Berkeley.

A12 Commercial Reach-In Refrigerators, Freezers, and Refrigerator-Freezers

The commercial refrigeration equipment category consists of reach-in refrigerators, freezers, and refrigerator-freezers, beverage vending machines, and beverage merchandisers. These products all use a vapor compression refrigeration cycle to remove heat from beverage items or food products and reject the heat to ambient air. The three energy-consuming components of a vapor compressor refrigeration cycle are:

- The compressor: moves the refrigerant through the refrigeration cycle;
- The evaporator air fan: blows air to be cooled over the cold evaporator;
- The condenser air fan: blows ambient air over hot condenser to remove heat from the refrigeration system. Some equipment rejects heat from the condenser via natural convection eliminating the condenser fan.

Therefore, the energy consumption and savings potential of commercial refrigeration equipment depend on the efficiency of these three components, the effectiveness of the condenser and evaporator heat exchangers, and the refrigeration system heat gain from insulation, air leaks, door openings, etc. In addition, auxiliary devices such as lighting or a door frame heater also consume electrical power.

Some of the equipment installed base estimates are about 10 years old, creating the theoretical potential for uncertainties in the current installed base. Since commercial refrigeration equipment has been in the marketplace for decades and the primary venues using refrigeration equipment have not increased dramatically over the past 15 years, the older installed base data should provide reasonable estimates of the current installed base of commercial refrigeration equipment.

A12.1 Background

Reach-in refrigerators, reach-in freezers, and reach-in refrigerator-freezers are upright, refrigerated cases with solid or glass doors that hold frozen or refrigerated food products respectively. The freezers maintain the temperature of the food product below freezing, usually around 0°F, and the refrigerators typically maintain food product temperatures between 35°F and 40°F.

Besides the normal complement of power-consuming devices for the refrigeration system, a frame heater is required to prevent condensation on the outside of the case. In addition, lighting inside the case illuminates the inside of the case when the door is open.

Table A12-1 shows that the installed bases of reach-in freezers, refrigerators and refrigerator-freezers in 1994 were 800,000, 1.3 million, and 200,000, respectively. Reach-in freezers, refrigerators and refrigerator-freezers have an average lifetime of 8 to 10 years, and freezers, refrigerators and refrigerator-freezers annually consume 0.066 quad, 0.054 quad, and 0.012 quad, respectively. Despite the larger installed base of refrigerators, the annual energy consumption of all reach-in freezers exceeds that of refrigerators because of freezers' greater power draw levels.

Table A12-1: Installed Base Data for Reach-In Freezers and Reach-In Refrigerators

Equipment type	Data type	Value	Source
Reach-In Freezers	Installed Base, thousands (1994)	800	ADL(1996); Appliance Magazine (2002)
	Annual Sales, thousands (2001)	47	
	Equipment Lifetime, years (1994)	8 to 10	
	AEC, quad	0.066	
Reach-In Refrigerators	Installed Base, thousands (1994)	1,300	ADL(1996); Appliance Magazine (2002)
	Annual Sales, thousands (2001)	260	
	Equipment Lifetime, years (1994)	8 to 10	
	Primary AEC, quad	0.054	
Reach-In Refrigerator-Freezers	Installed Base, thousands (2003)	200	ADL (1996); Personal communication with PG&E FSTC
	Annual Sales, thousands	-	
	Equipment Lifetime, years (1994)	8 to 10	
	AEC, quad	0.012	

A12.2 Test Procedure Status

A DOE test procedure does not exist for reach-in freezers, reach-in refrigerators, or reach-in refrigerator-freezers; however, several organizations have test procedures for reach-in refrigeration.

Measures of energy use or efficiency for commercial refrigeration typically consist of an amount of energy the product uses (per unit volume per unit time). For reach-in refrigerators, freezers, and refrigerator-freezers, energy use is typically expressed in terms of daily energy consumption (kWh/day) per internal volume of the refrigerated space (ft^3). There are a number of existing test procedures that have been developed for rating commercial refrigeration equipment. These include the following:

- National Sanitation Foundation/American National Standards Institute Standard 7-2001 (NSF/ANSI 7-01) Commercial Refrigerators and Freezers;

- Air-Conditioning and Refrigeration Institute Standard 1200-2002 (ARI 1200-02) Commercial Refrigerated Display Cases; and

- American Society of Heating, Refrigeration, and Air-Conditioning Engineers Standard 117-2002 (ASHRAE 117-02) Method of Testing Closed Refrigerators.

The NSF/ANSI 7-01 test procedure was developed with food safety as an objective, and therefore does not include measurements of energy consumption. However, the ARI 1200-02 and the ASHRAE 117-02 test procedures were developed to allow comparisons of commercial refrigeration equipment, and therefore include measurements of energy consumption.

The NSF/ANSI 7-01 test procedure is a performance test for reach-in refrigerators and freezers used to store and/or display cold food. This test procedure is used to ensure that the refrigeration equipment can maintain temperatures safe for food preservation by requiring a case temperature of less than 40° F for refrigerators and less than 0° F for freezers, while the surrounding ambient temperature is maintained at 100° F and the compressor duty cycle is no more that 70% during the test. The 100° F ambient rating condition is appropriately conservative for food safety purposes but may not represent real-world conditions for commercial refrigeration. The test procedure by itself is not sufficient to be used for energy efficiency standards because it lacks an electrical consumption test.

The ARI 1200-02 test procedure for commercial refrigerated display cases provides test and rating requirements for self-contained or remote, open or closed, and service and self-service commercial refrigerated display cases. It was developed to provide guidance to the commercial refrigeration industry and allows comparison of energy consumption among remote commercial refrigerated display cases or comparison of energy consumption among self-contained commercial refrigerated display cases. The rating conditions for the open type display cases are based on the ASHRAE Standard 72 test procedure, and the rating conditions for the closed type display cases are based on the ASHRAE Standard 117 test procedure. However, two different ambient temperature conditions are used for each type of display case, depending on the environment in which the equipment is installed. Type I display cases are intended to be used in areas where the ambient temperatures do not exceed 75° F and are therefore rated at an ambient dry-bulb temperature of 75° F +/- 2°F. Type II display cases are intended to be used in areas where the ambient temperatures do not exceed 80° F and are therefore rated at an ambient dry-bulb temperature of 80° F +/- 2°F.

The ASHRAE 117-02 test procedure is used as the basic test method by many organizations, including the Canadian Standards Association in the CSA C827-88 Standard, the California Energy Commission (CEC) as the test method for their commercial refrigeration standards, and the EPA certification of commercial refrigeration products for their ENERGY STAR® program. The ASHRAE 117 standard is used for all types of closed refrigerators and freezers that hold or display food, and it applies to both remote and self-contained products.

In the ASHRAE 117 test, the refrigerated case is filled to capacity with a combination of simulated food and space fillers. The doors are opened for specific intervals during an 8-hour period, in order to simulate typical operation. The energy consumption is measured over a 24-hour period, while the ambient conditions are fixed at a dry-bulb temperature of 75° F +/- 2° F and a wet bulb temperature of 64˚ F +/- 2° F.

There are several potential limitations of the ASHRAE 117 test procedure. First, the ambient temperature rating condition may not represent the typical real-world conditions found in active commercial kitchens. These temperatures can be well above the 75° F ambient rating condition and may even reach 100° F at times. Furthermore, ASHRAE 117 does not include a recovery test where the energy consumption required to cool down warm food is measured. This could be particularly important for beverage merchandisers if DOE decides that rapid “pull down” of product temperature is an important feature of beverage merchandisers and accounts for significant energy use. Finally, the ASHRAE 117 test procedure does not specify a case temperature or a food temperature and is thus inadequate by itself for energy efficiency standards, because a valid comparative evaluation of energy consumption among products would require equal food or case temperatures to be maintained during the tests. The ASHRAE 117 test procedure is fairly difficult to carry out and is generally performed by test labs, not manufacturers. In current testing for the CEC, not all units made by a manufacturer are tested. Instead, representative units are tested, and performance estimates are extrapolated to other units.

The ASHRAE 117 test procedure is, however, widely used and has been revised several times since it was originally developed in 1983. It is currently undergoing a revision under ASHRAE's continuous maintenance program, which will combine ASHRAE 117 with ASHRAE 72 for open type refrigerators and freezers. In the CSA C827-88 standard, the ASHRAE 117 test procedure is modified to include a cabinet air temperature of 38° F for refrigerators and 0° F for freezers. For the CEC, the ASHRAE 117 test procedure is modified to include an integrated average product temperature of 38° +/- 2°F for refrigerators. For freezers, an integrated average product temperature of 0° +/- 2°F is specified. The EPA's program for commercial reach-in refrigerators and freezers takes the same approach as the CEC by specifying the same integrated average product temperatures.

Because the ASHRAE 117 test procedure is widely used, has been improved and is being improved through several revisions since 1983, serves as the basis for performance ratings for many organizations and is applicable to many types of commercial refrigeration equipment, it is a good basis for measuring the energy efficiency of commercial refrigeration equipment. To overcome the limitations identified, modifications to the rating conditions may be considered, possibly including: ambient temperature ratings more closely representative of those typically encountered by the equipment, a recovery test that measures the energy consumption required to cool warm products introduced into the cabinet, and an integrated average product temperature rating condition.

A12.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

Table A12-2 presents the potential energy saving estimates for reach-in freezers.

Table A12-2: Potential Energy Saving Estimates for Reach-In Freezers

Technology/Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010-2035) (quad)	Source
Combination	35	0.023	0.47	% Energy Savings potential from ADL (1996)
<2 Years Payback (High Efficiency Compressor, and Non-Electric Anti Sweat Heating)	30	0.020	0.40	% Energy Savings potential from ADL (1996)
<5 Years Payback (ECM Motor for Evaporator Fans, Hot Gas Defrost, and Defrost Controls	44	0.029	0.59	% Energy Savings potential from ADL (1996)
CEC Tier 1	8	0.005	0.11	% Energy Savings potential from CEC Database of Energy Efficient Appliances[26]
CEC Tier 2	13	0.008	0.17	% Energy Savings potential from CEC Database of Energy Efficient Appliances[27]
ENERGY STAR®	20	0.013	0.27	% Energy Savings potential from ENERGY STAR® website[28]

The first combination employs several technologies to save energy:

- hot gas antisweat;
- high efficiency compressor;
- brushless DC evaporator and condenser fan motors.

[26] Available at: http://www.energy.ca.gov/appliances/appliance/ .
[27] Available at: http://www.energy.ca.gov/appliances/appliance/ .
[28] Available at: http://yosemite1.epa.gov/estar/consumers.nsf/content/refrigerator.htm .

The annual energy savings potential if all reach-in freezers employed these technologies equals 35%, which translates into 0.47 quad over the 2010-2035 period. All features have a simple payback period of less than three years.

These energy savings estimates assume a 70°F ambient temperature and a 75% duty cycle. Manufacturers provided these conditions and, given the high duty cycle, probably imply door openings. The baseline energy consumption is 14.2 kWh/day, an estimate that represents the average consumption for units of all sizes (ADL, 1996).

The California Energy Commission (CEC) has proposed two tiers of energy efficiency standards. The first tier took effect on March 1, 2003; the second tier is scheduled for August 1, 2004. The CEC database of appliances produces an average daily energy consumption for solid door reach-in freezers between 19 and 21 ft^3 of 11.74 kWh/day. This is lower than the 14.24 kWh/day baseline used by ADL (1996), because it only considers the smaller-sized units. For units in the 19 to 21 ft^3 size range, assuming all new units consume 11.74 kWh/day, the energy savings of CEC's tier 1 standards would equal 8%[29]. The energy savings of CEC's tier 2 standards are 13%. Subsequently, it is assumed the 8% and 13% energy savings can be applied across the entire volume range of reach-in freezers.

The ENERGY STAR® efficiency level for reach-in freezers is slightly more stringent than the CEC's but only applies to solid-door units, i.e,. glass door units are not in the program. The ENERGY STAR® level for a 20 cubic foot solid door freezer equals 9.36 kWh/day which represents a 20% savings from the baseline of 11.74 kWh/day. Similarly, it is assumed the 20% energy savings can be applied across the entire volume range of reach-in freezers.

Table A12-3 shows two different combinations of technologies to reduce energy consumption in reach-in refrigerators, as well as the energy savings for reach-in refrigerators that qualify for ENERGY STAR® certification.

[29] That is, the CEC Tier 1 standard requires that a unit in the same range consume no more than 10.79 kWh/day; the Tier 2 level caps energy consumption at 10.24kWh/day.

Table A12-3: Potential Energy Saving Estimates for Reach-In Refrigerators

Technology / Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010-2035), (quad)	Source
Combination 1	44	0.024	0.49	% Energy Savings potential from ADL(1996)
Combination 2	67	0.036	0.74	% Energy Savings potential from ADL (2001 and 2002b)
Combination 3	80	0.043	0.89	% Energy Savings potential from ADL (2002b)
<2 Years Payback (ECM Motors for Evaporator Fans, High Efficiency Compressor, and Non-Electric Anti Sweat Heating)	35	0.019	0.39	% Energy Savings potential from ADL (1996)
<5 Years Payback (ECM Motor for Condenser Fan)	45	0.024	0.50	% Energy Savings potential from ADL (1996)
CEC Tier 1	0	0	0	% Energy Savings potential from CEC (2002)[30]
CEC Tier 2	9	0.005	0.10	% Energy Savings potential from CEC (2002)[31]
ENERGY STAR®	29	0.016	0.32	% Energy Savings potential from Energy Star, See Footnote[32]

Combination 1 is a short but effective list of improvements:

- Hot gas antisweat;
- High efficiency compressor;
- Brushless DC evaporator and condenser fan motors.

The 44% energy savings potential translates into 0.49 quad over the 2010-2035 period. The last two technologies, a high efficiency compressor and brushless DC fan motors, are relatively easy to implement while the first, hot gas antisweat, requires product redesign and retooling for a new case. All features have a simple payback period of less than three years.

[30]No reduction in ASHRAE 117 Energy use from 9kWh/day (ADL(current)) to 9.65kWh/day for 43.5 cuft unit.
[31]Reduction in ASHRAE 117 Energy use from 9kWh/day (ADL(current)) to 8.20kWh/day for 43.5 cuft unit
[32] Reduction in ASHRAE 117 Energy use from 9 kWh/day (ADL(current)) to 6.39 kWh/day for 43.5 cubic ft. unit.

These projected savings assume a 70°F ambient temperature and a 65% duty cycle for the baseline refrigeration system. Such a high duty cycle of the baseline refrigerator at 70°F ambient temperature means that it may fail the NSF7 test at the higher ambient temperature of 100°F. Since refrigerators cannot be sold without NSF approval, it is likely that the 65% duty cycle includes door openings, suggesting that the energy savings estimate is based on reasonably realistic operating conditions.

Combination 2 is a more aggressive application of energy saving features, incorporating:

- Improved face frame design;
- Improved gasket;
- Reduced antisweat heater wattage (done in conjunction with improvements to face frame design and gasket);
- Condensate line trap;
- Brushless DC evaporator fan motor;
- PSC condenser fan motor;
- Evaporator fan shutdown; and
- Refrigeration system optimization.

The same operating condition assumptions apply as for the "Combination 1" approach. The final energy savings analysis results in 67% annual energy savings potential or 0.74 quad over the 2010-2035 period. Simple payback periods were not calculated for this option.

Combination 3 includes the following design modifications:

- Improved Face Frame Design;
- Improved Gasket;
- Reduced Antisweat Heat Input;
- Condensate Line Trap;
- Brushless DC Evaporator and Condenser Fan Motors;
- Variable-Speed Refrigeration System; and
- Hot Gas Antisweat Heating.

The same operating condition assumptions apply as for the "Combination 1" approach. The final energy savings analysis results in 80% annual energy savings potential or 0.89 quad over the 2010-2035 period. Simple payback periods were not calculated for this option.

All of the options considered in the three "combinations" – with the possible exception of the variable-speed refrigeration systems – are presently feasible and the components needed to implement the options commercially available. Variable-speed refrigeration systems may not be available in sizes (and with refrigerants) compatible with all sizes of reach-in refrigerators in the market.

The California Energy Commission (CEC) includes two tiers of energy efficiency standards for all reach-in refrigerators. Analysis of a two-door solid reach-in refrigerator with an interior volume of 43.5 ft^3 indicates that the first tier will not realize measurable energy savings. However, the second tier will achieve 9% energy savings. On the other hand, if the CEC standards apply to glass door reach-in refrigerators, which have inherently higher energy consumption levels, the energy savings potential will exceed the aforementioned values.

If all reach-in refrigerators attained ENERGY STAR® certification, then the annual energy savings potential would be 29%.

Table A12-4 shows one combination of technologies to reduce energy consumption in reach-in refrigerator-freezers.

Table A12-4: Potential Energy Saving Estimates for Reach-In Refrigerator-Freezers

Technology / Standard Level	% Energy Savings Potential	Primary Annual Energy Savings Potential(quad)	Energy Saving Potential (2010-2035), (quad)	Source
Combination 1	35	0.0041	0.08	% Energy Savings potential from ADL(1996)

Combination 1 is the same list of improvements as the reach-in freezer:

- Hot gas antisweat;
- High efficiency compressor;
- Brushless DC evaporator and condenser fan motors.

The 35% energy savings potential is from the data for reach-in freezers. This combination was chosen because it has a lower energy savings potential than that of the reach-in refrigerator. The energy savings potential translates into 0.08 quad over 2010-2035. The last two technologies, a high efficiency compressor and brushless DC fan motors, are relatively easy to implement while the first, hot gas antisweat, requires product redesign and retooling for a new case. All features have a simple payback period of less than three years.

Differences in test conditions complicate direct comparison of the ADL (1996) cases with the other energy savings approaches, as the ADL (1996) savings assume a 70° F ambient temperature, as well as a 65% duty cycle. The other approaches base their savings calculation on the ASHRAE 117 test conditions, which assume a slightly higher (i.e., 75° F) ambient temperature and specifies a certain quantity and duration of door openings. In turn, this likely leads to a lower duty cycle than used for the ADL (1996) energy consumption and savings potential. In sum, these differences require further study, but because the ambient temperatures assumed are similar, the energy savings potential calculations should be broadly comparable.

Table A12-5 summarizes the information presented in this sub-section.

Table A12-5: Total Savings Potential for Reach-in Freezers, Reach-in Refrigerators, and Reach-in Refrigerator-Freezers

Technology / Standard Level	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010 – 2035) (quads)
Combination 1	0.051	1.04
Combination 2 [33]	0.036	0.74
Combination 3 [34]	0.043	0.89
CEC Tier 1 [35]	0.005	0.11
CEC Tier 2 [36]	0.013	0.27
ENERGY STAR® [37]	0.029	0.59

A12.4 Regulatory Action

Reach-in freezers, refrigerators, and refrigerator-freezers do not currently have a minimum energy efficiency standard in the United States, but do fall under the voluntary ENERGY STAR® program. The ENERGY STAR® program began qualifying reach-in refrigerators, freezers, and refrigerator-freezers on 1 September, 2001. In addition, the California Energy Commission (CEC) has promulgated energy efficiency standards for all reach-in freezers and refrigerators sold in California. The Canadian Standards Association also has energy efficiency standards for reach-in freezers, refrigerators, and refrigerator-freezers.

The ENERGY STAR® program only qualifies *solid* door refrigerators, freezers, and refrigerator-freezers. The energy efficiency level depends on the internal volume of the case and on the reach-in type, i.e. freezing or refrigerating temperatures.

Since all reach-in refrigerators and freezers use a vapor compression cycle, most manufacturers have contended with the elimination of ozone-depleting CFC refrigerants from new products imposed by the Montreal Protocol. If the U.S. ratifies the Kyoto Protocol or adopts other legislation to reduce emissions of greenhouse gases, then the makers of commercial refrigeration equipment may also have to convert to refrigerants with reduced global warming potential. Most manufacturers produce more than one type of commercial refrigeration equipment, so that regulation of refrigeration equipment as an equipment class would impact a broad range of products for many manufacturers. In addition, some commercial refrigeration manufacturers have other divisions that manufacture other types of equipment that have come under energy efficiency regulations, e.g., unitary air-conditioners. Hence, most manufacturers of reach-in refrigerators and freezers have already borne the cumulative burden of CFC elimination and

[33] Reach-in refrigerators only.
[34] Reach-in refrigerators only.
[35] Reach-in refrigerators and reach-in freezers only.
[36] Reach-in refrigerators and reach-in freezers only.
[37] Reach-in refrigerators and reach-in freezers only.

previous energy efficiency standards, and face the possible elimination of global warming refrigerants.

A12.5 Issues Impacting Potential Energy Efficiency Standards

The ASHRAE 117 test is a time-consuming (24-hour) and meticulous test standard. As a matter of fact, the California Energy Commission has only qualified two laboratories to perform ASHRAE 117 tests. Therefore, the burden on manufacturers in adopting energy efficiency standards may be high if ASHRAE 117 continues to be the basis of test procedures.

References

ADL, 1996, "Energy Savings Potential for Commercial Refrigeration Equipment", Final Report to US Department of Energy, Office of Building Technology, State and Community Programs, June.

ADL, 2001, "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume I: Chillers, Refrigerant Compressors, and Heating Systems," Final Report to US Department of Energy, Office of Building Technology, April.

ADL, 2002a, "Energy Consumption by Commercial Office and Telecommunications Equipment in Commercial Buildings – Volume I: Energy Consumption Baseline", Final Report to US Department of Energy, Office of Building Technology, State and Community Programs, January.

ADL, 2002b, "Application of Best Industry Practices to the Design of Commercial Refrigerators – Development of a High Efficiency Reach-In Refrigerator," Arthur D. Little, Inc., Final Report, June 2002.

ARI, 2002. "Commercial Refrigerated Display Cases", Air-Conditioning and Refrigeration Institute Standard 1200-2002.

ASHRAE, 2002. "Method of Testing Closed Refrigerators", American Society of Heating, Refrigeration, and Air-Conditioning Engineers Standard 117-2002.

Appliance Magazine, 2002, "49th Annual Report", *Appliance Magazine*, May.

California Energy Commission, "Database of Energy Efficient Appliances". Available at: http://www.energy.ca.gov/appliances/appliance/.

ENERGY STAR® website, "Energy Star Qualified Products". Available at: http://yosemite1.epa.gov/estar/consumers.nsf/content/refrigerator.htm.

NSF/ANSI, 2001. "Commercial Refrigerators and Freezers", National Sanitation Foundation/American National Standards Institute Standard 7-2001.

Zabrowski, David, 2003, Personal Communication, PG&E Food Service Technology Center.

A13 Gas Unit Heaters / Gas Duct Furnaces

A13.1 Background

Gas unit heaters and gas duct furnaces both burn natural gas for space heating, typically in commercial and industrial buildings. Unit heaters usually hang from the ceiling and use a fan or blower to circulate room air through a heat exchanger (which transfers heat from the combustion gases), heating the air and distributing it to the room/space. Duct furnaces are installed in a ventilation duct system to heat moving air (a duct furnace does not have its own fan or blower). The approximately 3.9 million gas unit heaters in use in the United States in 2001 consume about 0.65 quad of energy each year, while approximately 0.25 million gas duct furnaces consume about 0.10 quad (Table A13-1).

Table A13-1: Gas Unit Heater and Duct Furnace Data

Type	Data type	Value	Source
Gas unit heaters	Installed Base, millions (2001)	3.9	GAMA (2003) and calculation
	Equipment Lifetime, years	21.5[38]	GRI (1997)
	AEC, quad	0.65	ADL (2001b) and calculation
Gas duct furnaces	Installed Base, millions (2001)	0.25	GAMA (2003) and calculation
	Equipment Lifetime, years	16.5[39]	GRI (1997)
	AEC, quad	0.10	Calculation

The installed base and Annual Energy Consumption (AEC) estimates were derived from GAMA (2003), GRI (1997) and ADL (2001b) (see the Sub-Appendix for calculation details).

A13.2 Product Technology Descriptions and Market Information

A13.2.1 Gas Unit Heaters

Gas unit heaters are self-contained units that usually hang from the ceiling of a space, but can also be installed on floors or walls. A gas supply line feeds fuel to the burner and combustion chamber where the gas is burned to release heat. The hot combustion gas then travels through the inside of a metal heat exchanger and passes out through the vent where it is exhausted outdoors. A fan blows indoor air over the hot outer surface of the heat exchanger and distributes the heated air throughout the space.

Power vented units use a separate fan to draw combustion products through the combustion chamber. This configuration can improve combustion efficiency and reduce off-cycle flue losses. Power vented units with separated combustion bring in combustion air from the outside of the heated space. This configuration further reduces losses and improves the seasonal efficiency of these designs. At one time, pulse combustion unit heaters, that utilize combustion pulses to enhance heat transfer, were offered to improve efficiency but are no longer on the market. Condensing units (currently with very limited commercial availability) are designed to extract more energy from the combustion products to improve efficiency. Water vapor in the exhaust gas condenses on the walls of the heat exchanger, improving efficiency by extracting latent heat.

[38] average of lifetimes (ranges between 17-26 years depending on type, capacity, and location).
[39] average of lifetimes (ranges between 15-20 years depending on type, capacity, and location).

Table A13-2 displays the steady-state efficiency and estimated Annual Fuel Utilization Efficiency (AFUE) values for currently available gas unit heater technologies. AFUE considers cycling and other seasonal effects on efficiency while steady-state efficiency is a measurement at full-load operation. Minimum efficiencies for gas unit heaters and gas duct furnaces as prescribed by ASHRAE Standard 90.1 (as of October 29, 2001) are set at 80% combustion efficiency. These levels have not been changed in subsequent versions of ASHRAE 90.1 to date. In previous versions of ASHRAE 90.1, a thermal efficiency requirement was prescribed. However, for products of this type, thermal and combustion efficiency are virtually identical. A review of current product literature reveals that nearly all unit heaters and duct furnaces on the market today meet ASHRAE 90.1. This reflects the situation that ASHRAE 90.1 requirements have been adopted by many building codes throughout the U.S. Seasonal efficiency values, used in this analysis to calculate unit energy consumption and design option savings potential, are not currently prescribed in ASHRAE 90.1 and therefore are estimated.

Table A13-2: Gas Unit Heater Efficiency

Technology/Standard Level	Steady-State Efficiency	AFUE Efficiency	Comments/Source
Stock Efficiency	78%	72%	ADL (2001b) and estimates
Typical New Efficiency	80%	74%	Product catalogs and estimates
Minimum Efficiency ASHRAE 90.1-1999 (as of 10/29/2001)	80%	--	Standard only specifies steady-state combustion efficiency.
Power Vented - Separated Combustion	82%	80%	Product catalogs and estimates
Best Available (condensing)	93%	93%	Product catalogs and estimates

In 1995, the majority of gas unit heaters sold (~85%) were simple gravity vented units. Power-vented units claimed the rest of the market (~15%). Data are not available to estimate the current share of power vent or power vent-separated combustion unit heaters. Condensing units were introduced in 1999 and are available in the U.S. but apparently have not gained significant market share. A product search identified one condensing model, the Reznor SHE condensing unit heater.

A13.2.2 Gas Duct Furnaces

Gas duct furnaces are heating system components that are installed as a section in the supply ductwork of a ventilation system (they do not have fans or blowers of their own). A gas supply line feeds fuel to the burner and combustion chamber where the gas is burned to release heat. The hot combustion gas then travels through the inside of a metal heat exchanger and passes out through the vent where it is exhausted to the outdoors. The ventilation system fan or blower blows air over the hot outer surface of the heat exchanger and distributes the heated air throughout the space.

Power-vented units use a separate fan in the venting system to draw combustion products through the combustion chamber to improve combustion efficiency and reduce flue losses (by restricting the flow of warm air out the vent when the unit is off). Separated combustion units are also available that further reduce seasonal losses by using outside air for combustion. Pulse combustion is no longer viewed as a viable design option to improve efficiency. Condensing units are designed to extract more heat from the combustion gases to the point where the water vapor in the combustion products condenses on the walls of the heat exchanger (improving efficiency by extracting latent heat). ASHRAE 90.1 minimum efficiency requirements are the same for duct furnaces as for unit heaters (see earlier discussion). Table A13-3 displays the steady-state efficiency and estimated Annual Fuel Utilization Efficiency (AFUE) values for gas duct furnace technologies.

Table A13-3: Gas Duct Furnace Efficiency

Technology/Standard Level	Steady-state Efficiency	AFUE Efficiency	Comments/Source
Stock Efficiency	78%	72%	ADL (2001b) and estimates
Typical New Efficiency	80%	74%	Product catalogs and estimates
Minimum Efficiency ASHRAE 90.1-1999 (as of 10/29/2001)	80%	--	Standard only specifies steady-state combustion efficiency.
Power Vented-Separated Combustion	82%	80%	Product catalogs and estimates
Best Possible (condensing)	93%	93%	Product catalogs and estimates

While the exact numbers are not known, in 1995 the majority of gas duct furnaces sold and installed were simple gravity vented units. Power-vented units claimed the rest of the market. No condensing duct furnaces are currently available in the U.S. market, but several U.S. manufacturers market condensing warm air furnaces, indicating that condensing duct furnaces are technologically feasible.

A13.3 Test Procedure Status

Gas unit heaters and duct furnaces, primarily commercial/industrial products, do not have a DOE test procedure, but do follow an ANSI test procedure. Specifically, ASHRAE Standard 90.1 establishes minimum steady-state combustion efficiency levels for gas unit heaters and duct furnaces based on the ANSI Z83.8 (CSA 2.6) test procedure. The ANSI test procedure establishes a uniform experimental setup and procedure (at maximum steady-state operation) to measure the heating value of the natural gas burned and the heat lost through the vent in the form of hot combustion gases and water vapor (flue losses). The combustion efficiency calculation equals 100% minus the flue losses. The test standard and efficiency determination do not include the electricity consumed.

Steady-state efficiency may not be the most accurate way to calculate annual energy consumption because it does not account for losses due to equipment on-off cycling. Instead, a seasonal efficiency value such as Annual Fuel Utilization Efficiency (AFUE) can better predict how much fuel the equipment consumes on a yearly basis by taking into account cycling losses (attributed to warm-up and cool-down) and when a standing pilot is used, pilot losses (gas consumed by the pilot burner when the unit is not operating). Existing DOE test procedures for NAECA covered heating products, such as residential furnaces and boilers, describe the test procedure for determining AFUE, but an AFUE has not been prescribed by ASHRAE for unit heaters or duct furnaces.

A13.4 Energy Savings Estimates and Calculations

Table A13-4 and Table A13-5 present the Unit Energy Consumption (UEC) and the potential national energy saving estimates for the different technologies available for gas unit heaters and duct furnaces. All energy savings calculations use estimated AFUE values to better reflect expected annual energy consumption.

Table A13-4: Gas Unit Heater UEC and Potential Saving Estimates

Technology/Standard Level	UEC (MM-Btu)	Annual Energy Savings Potential (quad)	Energy Saving Potential (2010-2035, quads)
Typical Device (current stock)	167	NA	NA
Typical New	162	NA	NA
Condensing	129	0.13	1.8
Power Vent-Separated Combustion	150	0.047	0.67

Table A13-5: Gas Duct Furnace UEC and Potential Saving Estimates

Technology/Standard Level	UEC (MM-Btu)	Annual Energy Savings Potential(quad)	Energy Saving Potential (2010-2035), (quad)
Typical Device (current stock)	419	NA	NA
Typical New	408	NA	NA
Condensing	324	0.021	0.34
Power Vent-Separated Combustion	377	0.008	0.13

Condensing technology has over twice the energy savings potential of power vent-separated combustion because it offers both much higher steady-state and seasonal efficiencies.

Some uncertainty exists in the calculation of national energy savings potential for gas unit heaters because assumptions were necessary when deriving the AEC estimate for the installed base. ADL (2001b) provided an estimate of the AEC of gas unit heaters in the commercial building sector, but no data could be found for the AEC in industrial buildings. Instead, based on the widespread application of the unit heater in the industrial sector, it was assumed that gas unit heaters consume 85% of the natural gas heating energy consumption in the industrial sector. The UEC calculation assumed that shipments for the years before 1992 equaled the mean of shipments during the 1992 to 2001 period. Depending on actual sales figures before this period, the gas unit heater installed base could be either higher or lower. This treatment of shipment data could also affect energy estimates for duct furnaces (see the Sub-Appendix for more information).

A13.5 Regulatory Actions and Cumulative Burden

The DOE has not regulated gas unit heaters or gas duct furnaces for energy efficiency. A provision in the new National Energy Bill would require, if passed, that unit heaters have an intermittent ignition device and either power venting or an automatic flue damper. As discussed above, unit heaters and duct furnaces are covered by ASHRAE Standard 90.1, which has been adopted as part of many municipal and regional building codes and which sets a minimum efficiency requirement. Some manufacturers of gas unit heaters and gas duct furnaces also manufacture air-conditioning equipment and furnaces for which the DOE has established minimum efficiency levels.

The extent to which other regulations impact gas unit heaters and duct furnaces, including health and safety, was not determined.

A13.6 Issues Impacting Potential Energy Efficiency Standards

Commercial furnaces have been subjected to efficiency standards (by ASHRAE 90.1 and DOE standards published in the Federal Register – January 2001), which, if similarly promulgated for gas unit and/or duct heaters, could force manufacturers to abandon certain designs and/or technologies. Examples of possible prescriptive standards (such as being considered in the National Energy Bill) include requiring vent dampers and banning pilots. The current ASHRAE 90.1 standard for gas unit heaters and duct furnaces is a performance-based standard that sets the minimum steady-state efficiency level and allows the manufacturer flexibility in execution. An AFUE efficiency level standard is also performance based, and prescribing a minimum AFUE level (rather than steady-state efficiency) for these products would further impact equipment design. A new test procedure would also be necessary to measure AFUE. In addition, the electricity consumed by this equipment could be regulated by future efficiency standards (e.g., electricity consumed by the fan or blower of unit heaters or the power venting system of duct furnaces).

A broader issue when setting efficiency standards for heating equipment is quantifying how effectively heaters deliver warm air to building occupants. For example, many unit heaters are installed near the ceiling of tall spaces; in which case, a portion of the heat generated may not reach the occupants at floor level. Duct furnaces could be impacted by ventilation system distribution inefficiencies, such as duct leakage. It is not clear how to best address such “system” effects and whether future equipment efficiency standards can effectively address installation issues.

References

ADL, 2001, "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume I: Chillers, Refrigerant Compressors, and Heating Systems", Final Report by Arthur D. Little, Inc.to US Department of Energy, Office of Building Technology, State and Community Programs, April. Available at: http://www.eren.doe.gov/buildings/documents/pdfs/hvacvolume1finalreport.pdf .

ANSI/CGA, 1996, *Standard for Gas Unit Heater and Gas-Fired Duct Furnaces,* American National Standard Institute / Canadian Gas Association Standard, Z83.8-1996/CGA2.6-M96.

ASHRAE, 1999, *ASHRAE/IESNA Standard 90.1 – 1999, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, ASHRAE Press: Atlanta, GA.

GAMA, 2003, Statistical Highlights, Gas Appliance Manufacturers Association, Arlington, VA, March 4.

GRI, 1995, *Baseline Projection Data Book, 1995 Edition***,** Gas Research Institute.

GRI, 1997, "Commercial Space Heating Equipment Market," Gas Research Institute Report, GRI-97/0100.

Sub-Appendix. Gas Unit Heaters and Duct Furnaces Calculation Details

Installed Base Calculations

A literature search did not yield gas unit heater and duct furnace installed base estimates, nor shipment data spanning the entire lifetime of the devices. Instead, the installed base estimates utilize shipment data from GAMA (2003) for the period of 1992-2001 (Table A13-A1). The average annual shipment volume for that period and the device lifetime were used to estimate installed base.

Table A13-A1: Gas Unit Heaters and Duct Furnaces Annual Shipments (Source: GAMA 2003)

Year	Gas Unit heaters	Gas Duct Furnaces
1992	130,884	15,114
1993	147,338	15,378
1994	167,187	15,718
1995	171,256	16,812
1996	184,670	16,201
1997	202,350	16,692
1998	206,185	15,845
1999	209,195	14,033
2000	216,141	12,908
2001	166,137	11,049
Average, 1992 to 2001	180,134	14,978

Thus, the installed base estimate equals the product of the average lifetime and the average annual shipments from 1992 to 2001. The drawback of this approach is that the backward extrapolations may not capture sales trends.

AEC Calculations

The AEC estimate for unit heaters was based on an earlier study performed by ADL in 2001 using shipment data from 1991 through 1995. To account for the increase in the installed base from 3.2 million in 1995 to 3.9 million in 2001, the AEC estimate was increased proportionally to the increase in installed base, approximately 20%. The result is a change from the 1995 AEC of 0.54 quad to an AEC based on 2001 data of 0.65 quad. The following three paragraphs describe the analyses performed to produce the original 0.54 quad estimate.

The AEC includes energy consumed by devices in both the commercial sector and industrial building sectors. ADL (2001b) provides an estimate of commercial sector unit heater AEC; however, no estimate for the AEC of unit heaters in the industrial sector could be found. Instead, the gas unit heater AEC estimate was derived from gas space heating energy consumption data for buildings in the manufacturing sector (see Table A13-A2).

Table A13-A2: Gas Unit Heaters AEC Calculation

Type	Data	Source
Commercial sector gas unit heater consumption (quad)	0.20	ADL (2001b)
Total Manufacturing sector total gas consumption (quad)	0.40	MECS (1998)
% in Manufacturing sector consumed by gas unit heaters	85 %	ADL Estimate
Manufacturing sector gas unit heater consumption (quad)	0.34	Calculation
Total sector gas unit heater consumption (quad)	0.54	Sum of Commercial and Manufacturing sector

Because the stock split of commercial-size unit heaters between the two building sectors was unknown, the industrial/manufacturing sector energy consumption was estimated assuming that gas unit heaters account for a large percentage (85%) of gas heating in the manufacturing sector. This yields an estimate that gas unit heaters consume about 0.54 quad of primary energy per year.

As a check, another gas unit heater AEC was developed, using the same procedure as used for the duct furnaces, i.e., based on the average unit heater output, the installed base, average duty cycle and the seasonal efficiency data. Using this method yields an AEC of ~1.0 quad, a value that is clearly too high. The 1998 MECS (EIA) survey estimates that industrial space heating consumed a *total* of about 0.4 quad of gas. Even if unit heaters consume all of this heat, the total gas consumption estimate would be 0.6 quad (0.2 for the commercial consumption plus 0.4 for the industrial consumption), much less than the above estimate of ~1 quad. The high estimation may occur for a variety of reasons, including widespread equipment over-sizing and unutilized equipment. The above estimate of 0.54 quad seems to be a more accurate estimate.

The gas duct furnace AEC estimate is derived by estimating the total installed capacity of duct furnaces and multiplying it by the average annual duty cycle for duct furnaces:

$$AEC = \frac{Average\ unit\ size(output)}{seasonal\ efficiency\ (typical\ new)} \cdot 8760 \cdot installed\ base \cdot average\ duty\ cycle\ ,$$

where the duty cycle equals the ratio of the annual heating load to the peak-heating load:

$$average\ duty\ cycle = \frac{Average\ heating\ load}{Peak\ heating\ load}\ .$$

Warehouse duty cycle data from DOE-2 computer model runs (see Table A13-A3) performed for representative warehouses in two climates(LBL, 1990) were used to model duct furnace duty cycles, as these products are often deployed in buildings similar to warehouses.

Table A13-A3: Gas Duct Furnaces Load Data

Type	Annual Heating Load (Btu/ft^2)	Peak Heating Load (Btu/hr–sq. ft)	Approximate Duty Cycle (%)
Warehouse, Fort Worth, TX	7902	13	6.8
Warehouse, New York City	28,226	22	14.6
Average	NA	NA	10.7

The average gas duct furnace size (output in kBtu/hour), is assumed equal to the approximate shipment-weighted aveage over the years 1991 to 1995. Table A13-A4 presents the data used in the calculations, resulting in an AEC estimate of 0.10 quad.

Table A13-A4: Gas Duct Furnace AEC Calculation

Type	Data	Source
Average unit size (output, kBtu/hr)	321	Calculation based on data from GRI (1997)
Seasonal efficiency (average installed)	72%	GRI 1995
Average duty cycle	10.7%	Calculation , Table A13-A4
AEC(quad)	0.1	Calculation

Energy Savings Potential Calculations

For a given heating load, energy consumption is proportional to the inverse of the seasonal efficiency, in this case AFUE. Thus, the energy savings potential of an advanced technology equals one minus the ratio of the 'typical new' AFUE to that of the technology:

$$Savings\ Potential = 1 - \frac{AFUE\left(Typical\ New\right)}{AFUE\left(Tech.Level\right)}$$

This yields the savings potentials displayed below (Table A13-A5).

Table A13-A5: Gas Unit Heaters and Duct Furnaces Savings Potential

Type	Seasonal Efficiencies (%, AFUE)	Savings Potential (%)	AFUE Source
Current Stock	72	NA	GRI (1995)
Typical new	74	NA	ADL (2001b)
Condensing	93	20%	Product Literature and Estimates
Power vent	80	8%	

A14 Illuminated Exit Signs

A14.1 Background

An exit sign is an internally illuminated sign that is permanently fixed in place and used to identify the exit from a building. An internal light source illuminates the sign or letters spelling "EXIT". The sign is connected to only one source of power at a time (normal or emergency), and is designed to remain illuminated via an emergency power source upon failure of the normal power supply (EPA, 2004a).

Exit signs in the U.S. consume 0.0282 quad of energy per year (see Table A14-1). The total installed base of exit signs is approximately 33 million units, with LED, compact fluorescent and incandescent representing 26.4, 5.0 and 1.6 million units respectively (NCI, 2003).

Table A14-1: Exit Signs Background Data

Data type	Value	Source
Installed Base, million (2002)	33.0	NCI, 2003.
Equipment Lifetime, years	11	Calculated, based on NEMA, 2003 and the estimated installed base.
AEC, quad	0.0282	NCI, 2003; Calculation

A14.2 Product Technology Descriptions and Market Presence

Table A14-2 presents the technology level and wattage levels for several types of exit signs (incandescent, CFL, and LED).

Table A14-2: Exit Sign Technology Levels and Wattage Values

Technology Level	Wattage	Comments/Source
Stock Efficiency	8.9	Weighted average wattage from installed base and product class average wattages. NCI, 2003.
Typical New (LED)	6	Estimated average. NCI, 2003.
Minimum Efficiency	NA	No national energy standard, however California has passed standards that are consistent with ENERGY STAR® (CEC, 2003).
Incandescent	32	Weighted average wattage. NCI, 2003.
Compact Fluorescent	17	Weighted average wattage. NCI, 2003.
Light Emitting Diode	6	Weighted average wattage. NCI, 2003.
Best Available Efficiency (LED light source)	< 1	Some ENERGY STAR® Exit Signs are listed that consume less than one watt. EPA, 2004b.
ENERGY STAR® Efficiency	5 W per face	ENERGY STAR® Program Requirements for Exit Signs. Eligibility Criteria. EPA, 2004a.
Maximum Efficiency (Future Technology)	< 1	Electroluminescent and some LED panels already use 1 W or less.

LED exit signs have considerably lower operating costs than other types of signs and last much longer. According to E-Source, LED signs typically cost less than \$5 a year to operate, depending on the model and local utility costs (E Source, 2002). Total costs over a ten-year period, including first cost, energy, and maintenance will be approximately \$380 for incandescent signs and about \$65 for LED signs. Even on a first cost basis, which can be an important purchasing determinant, LEDs have become competitive. While incandescent signs without battery backup are still marginally less expensive than LED signs, the price for both types of signs with battery backup is about the same because the incandescent system requires a much larger battery. LED first costs have fallen in part due to the red LED being a relatively mature and well-understood technology (NCI, 2003).

Currently, exit signs do not have a national minimum efficiency standard, but they do fall under the voluntary ENERGY STAR® program (see Table A14-3). The ENERGY STAR® requirement for exit signs requires 5 watts or less per face. In addition, certain luminance specifications that are consistent with National Fire Protection Association requirements must be met (EPA, 2004a). Some key performance characteristics are presented in Table A14-3.

Table A14-3: ENERGY STAR® Requirements for Exit Signs

Selected Performance Characteristics	ENERGY STAR® Specification (summarized)
Input power demand	≤ 5 W per face
Luminance contrast	Greater than 0.8
Average Luminance	Greater than 15 candelas/meter^2 (cd/m^2) measured at normal (0^o) and 45^o viewing angles
Minimum Luminance	Greater than 8.6 cd/m^2 measured at normal (0^o) and 45^o viewing angles
Maximum to Minimum Luminance	Less than 20:1 measured at normal (0^o) and 45^o viewing angles

Due to favorable economics, better performance, enhanced safety capabilities, and marketing programs such as ENERGY STAR® Exit Signs, LED exit signs have already captured a significant share of this market. With an 80% market share, the installed base of LED exit signs is already more than 26 million compared to about 1.6 million for incandescent signs (NCI, 2003).

A14.3 Test Procedure Status

The Department of Energy does not have a test procedure for Exit Signs.

The draft Energy Bill states that the "Test procedures for illuminated exit signs shall be based on the test method used under Version 2.0 of the ENERGY STAR® program of the Environmental Protection Agency for illuminated exit signs." This test procedure draws on several industry standards and methods, including the National Fire Protection Association document 101 *Life Safety Code* and the Underwriters Laboratory 924 *Standard for Safety: Emergency Lighting and Power Equipment*.

The input power of the exit sign model is measured with an appropriate true root-mean square watt meter at the input voltage representing normal operation. For an exit sign model that includes a battery, the battery circuit shall be connected and the battery fully charged before any measurements are made.

The luminance measurement positions are to be measured in accordance with NFPA 101, *Life Safety Code*, figure A-7-10.6.3. The positions where the luminances are to be measured are detailed in figure 40.9 of UL 924, *Standard for Safety: Emergency Lighting and Power Equipment*.

A14.4 Energy Savings Estimates and Calculations

The energy savings calculation for exit signs assumes an installed base of 33 million units nation-wide, which operate 24 hours per day (NCI, 2003). The energy savings scenario is based on the standard level included in the draft Energy Bill, requiring all new exit signs to be ENERGY STAR® compliant products. Table A14-4 presents data for the baseline scenario, including installed base, wattage, and usage data for exit signs in 2002. The proportions of technologies shown in the table for the baseline scenario were held constant over the analysis period. This was done to be consistent with the methodologies followed in other priority setting analyses, and because even though more than 90% of exit signs sold today are based on LED technology, incandescent and CFL units are still being sold (NCI, 2003).

Table A14-4: Exit Sign Installed Base, Wattage, and Usage Data

Exit Sign Type	Installed Base/Stock	Wattage	Hours of use/day	References
Light Emitting Diode	26.5 million	6	24	NCI, 2003.
Compact Fluorescent Lamp	4.9 million	17	24	NCI, 2003.
Incandescent	1.6 million	32	24	NCI, 2003.

As discussed earlier, approximately eighty percent of the installed base of exit signs have already converted to ENERGY STAR® compliant technology. Thus, the energy savings estimate is based on converting the remaining 20% of exit signs, which includes both compact fluorescent and incandescent technology signs. For this analysis, it was assumed that half of the replacement incandescent and compact fluorescent exit signs have two faces and that half have one face, meaning the average energy consumption is reduced to 7.5 watts per unit, based on the threshold for ENERGY STAR® certification (less than 5 watts per face). The annual energy savings that would result from this conversion is approximately 0.008 quad. On a cumulative basis over the analysis time period of 2010-2035, the energy savings totals 0.16 quad (see Table A14-5).

Table A14-5: Exit Sign AEC and Potential Energy Saving Estimates

Technology/ Standard Level	AEC (quad)	Annual Energy Savings Potential (quad)	% Energy Savings	Energy Saving Potential (2010-2035), (quad)
Baseline	0.0282	NA	NA	NA
Scenario 1 (ENERGY STAR®)	0.0200	0.008	29%	0.16

A14.5 Regulatory Actions and Cumulative Burden

Exit signs are not subject to regulatory action on energy consumption, however there are considerable regulations associated with dimensions and visibility, operating hours and other safety-related attributes. Indicative of this is the fact that the ENERGY STAR® test method for qualification includes not just a method for measuring the energy consumption, but also the safety, battery life operating hours, and other non-energy related aspects that are critical to the safe operation of exit signs (EPA, 2004a).

The State of California adopted energy standards for exit signs such that input power, luminance contrast, minimum luminance, average luminance and maximum to minimum luminance ratio of illuminated exit signs manufactured on or after March 1, 2003 must meet the requirements of the ENERGY STAR® program.

A14.6 Issues Impacting Potential Energy Efficiency Standards

There is good availability of ENERGY STAR® compliant products on the market already, and the trend is toward LED-based technology due to its savings on both energy and maintenance.

References

CEC, 2003.California Energy Commission, *Appliance Efficiency Regulations*. P400-03-016, Sacramento, California.

EPA, 2004a. ENERGY STAR® Program Requirements for Exit Signs, Eligibility Criteria; PDF posted on the EPA website, available at: http://www.energystar.gov/ia/partners/product_specs/eligibility/exit_signs_elig.pdf

EPA, 2004b. Exit Signs Product List, Current as of Feb. 27, 2004. PDF posted on the EPA website, available at: http://www.energystar.gov/ia/products/prod_lists/exit_signs_prod_list.pdf

NCI, 2003. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*, prepared for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program by Navigant Consulting, November 2003.

NEMA, 2003. Email from Kyle Pitsor, Lighting Division Manager, National Electrical Manufacturers Association, Roslynn, Virginia. June 2, 2003.

A15 Lamps, Incandescent Reflector – ER/BR

A15.1 Background

The Energy Policy Act of 1992 (EPACT 92) established minimum average lamp efficacy standards (LPW) for incandescent reflector lamps, although ellipsoidal reflector (ER) and bulge reflector (BR) shaped lamps were exempted.

EPACT 92 defines an ER incandescent reflector lamp as “a reflector lamp with an elliptical section below the bulb’s major diameter and above its approximate baseline as shown in Figure 1 (RE) on page 7 of ANSI C79.1-1994 (see 10 CFR 430.22) and a finished size and shape as shown in ANSI C78.21-1989 including the referenced reflective characteristics in part 7 of ANSI C78.21-1989.”

EPACT 92 defines an BR incandescent reflector lamp as “a reflector lamp with a bulged section below the bulb’s major diameter and above its approximate base line as shown in Figure 1 (RB) on page 7 of ANSI C79.1-1994 (see 10 CFR 430.22). A BR lamp has a lamp wattage of 85 or less than 66 and a BR40 lamp has a lamp wattage of 120 or less” (10 CFR 430.2(c)(16)).

At the time ER/BR lamps were exempted, they constituted a very small percentage of total reflector lamp shipments. However, since that time, market forces have expanded the proportion of ER/BR lamps so that they now represent more than 50% of all reflector lamp sales in the United States. ER/BR lamps have a lower first-cost than regulated reflector lamps, but they have higher operating costs because of their lower relative efficacy.

There are approximately 165 million ER/BR lamps in service in the United States. This estimate was prepared by looking at national shipments supplied by the National Electrical Manufacturers Association (NEMA), and then deriving a national installed base using estimates of operating hours and lamp lifetimes. These reflector lamps (ER/BR) consume approximately 0.166 quad per year (see Table A15-1).

Table A15-1: ER/BR Background Data

Data type	Value	Source
Installed Base, millions (2003	165	Calculated estimate, based on NEMA, 2003; NCI, 2002; and Manufacturer Catalogues, 2003.
Annual Shipments, millions (2003)	108	NEMA, 2003.
Equipment Lifetime, years	1.57	Weighted average lifetime of ER/BR lamps in residential and non-residential applications (NCI, 2002).
AEC, quad	0.166	Calculation, all sectors

A15.2 Product Technology Descriptions and Market Presence

Two energy savings scenarios were considered for ER/BR lamps. The first scenario evaluates a lamp efficacy standard in which ER/BR lamps are subject to a halogen standard (approximately

18% increase in lamp efficacy). This first scenario is approximately equivalent to the EPACT 92 standard for reflector lamps (removing the exemption for ER/BR). The second energy savings scenario evaluates a higher efficacy standard in which incandescent reflector lamps shift to the halogen infrared reflector (HIR) technology (54% increase in lamp efficacy). This higher standard level is commercially available, but lamps incorporating HIR technology are only starting to enter the market. Only efficacy levels were used for this energy savings analysis; dimming capability or usage was not considered.

Table A15-2: ER/BR Technology Levels and Efficacy Values

Technology Level	Value	Comments/Source
Stock Power Consumption	71 W	Shipments estimate and average wattages, NEMA, 2003.
Typical New	71 W	Unregulated lamp.
Minimum Efficiency	None	No known standard.
Incandescent Efficiency	12 LPW	Efficacy of a 75-watt reflector lamp.
Halogen Efficiency	14.2 LPW	Halogen reflector lamp of equivalent light output.
Halogen IR Efficiency	18.5 LPW	Halogen infrared reflector lamp of equivalent light output.
Maximum Efficiency (Future Technology)	18.5 LPW	No known method of improving performance of incandescent technology without changing technology (e.g., CFL, LED)

ER/BR lamps are being considered because the volume of these lamps shipped has been increasing since the exemption was made in EPACT 1992. By 2001, 57% of all reflector lamp shipments were ER/BR lamps (NEMA, 2003), and these lamps accounted for an estimated 77% of all reflector lamp shipments to the residential sector (NEMA, 2003 and NRCan, 2002). All major NEMA lamp manufacturers now produce this lamp. Thus, more than half of all reflector lamp sales are now exempt from EPACT.

Shipments of parabolic aluminized reflector (PAR) lamps, which are regulated by and are compliant with EPACT, showed no growth from 1999-2002. In contrast, shipments of BR lamps continue to increase over that same time period at about 6% a year. This trend is primarily due to two factors: 1) an increase in the prevalence of low-cost fixtures that use reflector lamps (e.g., recessed ceiling and track lighting), and 2) BR lamps are the lowest first-cost reflector lamp, although they do have higher life-cycle costs. Recent shipment information on ER lamps do not show an increasing trend like BR, however, the Department is concerned that if standards were promulgated for BR lamps and not ER, the ER-shape lamp may expand its market share, as it may then become the lowest first-cost reflector lamp. For this reason, the Department is considering ER/BR lamps as a group of reflector lamps.

A15.3 Test Procedure Status

The Department of Energy has a test procedure for reflector lamps that already covers ER/BR lamps (10 CFR 430 Subpart B, Appendix R, 4.3). This test procedure applies to all reflector lamps, and incorporates appropriate test methods promulgated by the Illuminating Engineering Society of North America (IESNA) and ANSI.

A15.4 Energy Savings Estimates and Calculations

The energy savings calculation for ER/BR lamps is based on a calculated installed base of 165 million lamps, including ER, BR, and bulged parabolic aluminum reflector (BPAR) units. The estimated installed base of ER, BR, and BPAR lamps is 1.5 million, 157.6 million, and 5.6 million respectively. The shipment-weighted average wattages for ER lamps is 87W, for BR lamps is 68.8W, and for BPAR lamps is 135.9W (NEMA, 2003). Operating hours are 2.4 hours per day in the residential sector and 9.7 hours per day in all other sectors (NCI, 2002).

Two energy savings scenarios are considered (see Table A15-3). The first evaluates a lamp efficacy standard in which incandescent reflector lamps (12 LPW) shift to halogen technology (14.2 LPW). This first energy savings scenario is approximately equivalent to the standard already in place for regulated reflector lamps. The second energy savings scenario evaluates a lamp efficacy standard in which incandescent reflector lamps shift (12 LPW) to the HIR technology (18.5 LPW).

For the first scenario, the annual energy savings potential is 0.0304 quad, a savings of 18.3%. Over the cumulative analysis period 2010-2035, these savings total 0.74 quad. For the second scenario, the annual energy savings potential is 0.09 quad, a savings of 54.2%. Over the cumulative analysis period 2010-2035, these savings total 2.17 quads (see Table A15-4).

Table A15-3: ER/BR Efficacy and Usage Data

Scenario	Efficacy	Hours of use/day Residential	Hours of use/day Commercial Industrial, Outdoor	References
Baseline	12 LPW	2.4	9.7	NCI, 2002.
Scenario 1 (Halogen, EPACT 92)	14.2 LPW	2.4	9.7	NCI, 2002.
Scenario 2 (HIR technology)	18.5 LPW	2.4	9.7	NCI, 2002.

Table A15-4: ER/BR AEC and Potential Energy Saving Estimates

Technology/ Standard Level	AEC (quad)	Annual Energy Savings Potential (quad)	% Energy Savings	Energy Saving Potential (2010-2035) (quads)
Baseline	0.166	NA	NA	NA
Scenario 1 (Halogen, EPACT 92)	0.136	0.030	18.3%	0.74
Scenario 2 (Halogen Infrared)	0.076	0.090	54.2%	2.17

A15.5 Regulatory Actions and Cumulative Burden

Based on the definition of incandescent reflector lamps in EPACT 92, ER/BR lamps were exempted from standards. EPACT 92 states "*Incandescent reflector lamp* (commonly referred to as a reflector lamp) means any lamp in which light is produced by a filament heated to incandescence by an electric current, which is not colored or designed for rough or vibration service applications that contains an inner reflective coating on the outer bulb to direct the light; has an R, PAR, or similar bulb shape (excluding ER or BR) with an E26 medium screw base; has a rated voltage or voltage range that lies at least partially in the range of 115 and 130 votes; has a diameter that exceeds 2.75 inches; and is either low(er)-wattage reflector lamp that has a rated wattage between 40 and 205; or a high(er)-wattage reflector lamp that has a rated wattage above 205." (see 10 CFR 430.2(c)(16)).

The Energy Policy Act of 1992 set the following standard for incandescent reflector lamps:

"Each of the following incandescent reflector lamps manufactured after November 1, 1995 shall meet or exceed lamp efficacy standards shown in the table in this paragraph.

Table A15-5: Incandescent Reflector Lamps

Nominal Lamp Wattage (Watts)	Minimum Average Lamp Efficacy (LPW)
40-50	10.5
51-66	11.0
67-86	12.5
86-115	14.0
116-155	14.5
156-205	15.0

(10 CFR 430.2(n)(2)).

ER/BR lamps are not part of the draft Energy Bill. If the Energy Bill becomes law, the Department must decide whether to continue attempting to cover this product or reprioritize ER/BR lamps for a later date.

A15.6 Issues Impacting Potential Energy Efficiency Standards

One issue that has been raised with respect to the regulation of ER/BR lamps is the consumer demand for low-first-cost reflector lamps. If ER/BR lamps were forced to comply with the EPACT 92 standard for reflector lamps, consumers may start installing general incandescent lamps (A-type) or other shapes of these lamps (e.g., K-type director lamps which do not have aluminized reflectors or optics designed for recessed fixtures) in their fixtures designed for reflector lamps. This type of substitution could be problematic because when installed in a recessed lighting fixture or track-lighting housing, the system efficiency (lamp + fixture) could be lower when compared to the same fixture operating with an ER/BR lamp, which directs light more efficiently.

References

NEMA, 2003, ER/BR Reflector Lamp Shipment and Market Share Data, provided by NEMA in a meeting with the Department of Energy on April 2003.

NRCan, 2002, Reflector Study by Navigant Consulting, Inc. for Natural Resources, Canada, March 2002.

NCI, 2002, "U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate", prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002. Available at: http://www.eere.energy.gov/buildings/documents/pdfs/lmc_vol1_final.pdf.

A16 Large Unitary Air Conditioners (≥ 240 kBtu/hr)

A16.1 Background

Large unitary air conditioners (A/C) (i.e., those with more than 240 kBtu/hr of cooling capacity) heat, cool, and ventilate commercial buildings. This section focuses on cooling performance. The heating function may be provided by a gas-fired warm air furnace section, electric resistance heat, or, less commonly, a heat pump cycle. Electric resistance tends to be used in those areas of the U.S. that have mild winters and low heating degree-days. Gas-fired heat generally has an Annual Fuel Utilization Efficiency (AFUE) within a couple of percentage points of 80%.

The most common large unitary A/C configuration is the single package horizontal roof top configuration (cooling only or so-called year-round with cooling and heating), but split systems are also used in this capacity range. Altogether, the installed base of approximately 421,000 large unitary air conditioners consumes approximately 0.32 quad for cooling (see Table A16-1).

Table A16-1: Large Unitary (≥240kBtu/hour) Background Data for Major Unit Classes

Type	Data type	Value	Source
Single package cooling only	Installed base, units	122,000	U.S. Census Bureau (1988-2002)
	Annual shipments (2002), units	10,950	U.S. Census Bureau (2002)
	Equipment lifetime, years	15	DOE (2003) for Unitary >65kBtu/hour to <240kBtu/hour
	AEC, quad (cooling only)	0.12	ADL (1999), ADL (2001); for 1995
Single package year-round	Installed base, units	182,000	U.S. Census Bureau (1988-2002)
	Annual shipments, units	14,790	U.S. Census Bureau (2002)
	Equipment lifetime, years	15	DOE (2003) for Unitary >65kBtu/hour to <240kBtu/hour
	AEC, quad (cooling only)	0.12	ADL (1999), ADL (2001); for 1995
Split systems	Installed base, units	101,000	U.S. Census Bureau (1988-2002)
	Annual shipments, units	7,140	U.S. Census Bureau (2002)
	Equipment lifetime, years	15	DOE (2003) for Unitary >65kBtu/hour to <240kBtu/hour
	AEC, quad (cooling only)	0.08	ADL (1999), ADL (2001); for 1995
All Large Unitary (above categories)	Installed base, units	406,000	U.S. Census Bureau (1988-2002)
	Annual shipments, units	32,880	U.S. Census Bureau (2002)
	Equipment lifetime, years	15	DOE (2003) for Unitary >65kBtu/hour to <240kBtu/hour
	AEC, quad (cooling only)	0.32	ADL (1999), ADL (2001); for 1995

*All AEC values based on fraction of total shipments tonnage, all units ≥240kBtu/hour

Shipments of all large unitary air conditioners in 2002 totaled 33,265 units. In 1993, what was then a record level of 18,860 large unitary air conditioners, were shipped. Without analyzing the capacity distribution of either 1993 or 2002 shipments, shipments grew over that nine-year period at a compound annual growth rate of 6.5 %. The often-predicted slow-down to a mature industry unit volume growth rate has yet to materialize.

A16.2 Product Technology Descriptions and Market Presence

The majority of large unitary air conditioners are single package systems. Table A16-2 summarizes efficiency levels.

Table A16-2: Large Unitary Air Conditioner Technology levels and UEC Values

Technology Level	EER Btu/Watt-hr		Comments/Source
	240-760 kBtu/hr	>760 kBtu/hr	
Stock	~8.5	~8.2	Meet ASHRAE 90.1-1989
Typical New	~9.5	~9.2	Meet ASHRAE 90.1-1999
Minimum Efficiency Standard ASHRAE 90.1 (1999)	9.5	9.2	ASHRAE (1999)
EnergyStar®	N/A	N/A	ENERGY STAR® (2003)
CEE Tier 2	10.0	10.0	CEE (2003)
Maximum Available	11.0	9.2	Lennox (2003) for 240 to 360 kBtu/hr Carrier (2004) for >760 kBtu/hr. Higher efficiencies achievable with some custom packages

Table A16-3 summarizes current DOE and ASHRAE 90.1 standards and minimum efficiency levels for unitary air conditioners that fall under the voluntary Consortium for Energy Efficiency (CEE) and EnergyStar® programs. Minimum efficiency levels decrease with increasing capacity, which is somewhat counter intuitive, given that the effects of large scale usually favor increased efficiency. Some unique circumstances account for this situation in large unitary. First, space and size constraints become more acute with increasing size of unitary equipment, making it necessary to reduce duct and coil face areas relative to capacity. In the largest sizes, the need to fit a single package on a standard flat bed truck is a size constraint. The ARI 340/360 test procedure also recognizes that larger capacity systems cover more floorspace and require longer duct runs.

Table A16-3: Energy Efficiency Levels - Standards and Voluntary Efficiency Programs for Electrically Operated Air-Cooled Air-Conditioners and Heat-Pumps (in Cooling Mode Only)

Standard	Minimum EER*				
	<65 kBtu/hr	**65 – 135 kBtu/hr**	**135 – 240 kBtu/hr**	**240 – 760 kBtu/hr**	**>760 kBtu/hr**
ASHRAE 90.1 – 1989	10 SEER (split system) 9.7 SEER (single package)**	8.9**	8.5**	8.5	8.2
ASHRAE 90.1 – 1999*** (Baseline level for ongoing rulemaking)	10 SEER (split system) 9.7 SEER (single package)	10.3	9.7	9.5	9.2
EnergyStar®	13 SEER	11.0	10.8	N/A	N/A
CEE Tier 1 (obsolete)	12 SEER	10.3	9.7	9.5	9.5
CEE Tier 2	11.3 (13 SEER)	11.0	10.8	10.0	10.0
LEED	Requires that minimum standard be met, credit points based on ≥20% energy savings relative to minimum efficiency standard				
*Minimum EER: Steady-state energy efficiency ratio, as determined by ARI 210/240 or 340/360 test procedures at ARI Standard Conditions **Current DOE/EPAct, as of January, 1992 ***Deduct 0.2 EER from units with heating other than electric resistance heat.					

The CEE Tier 1 level was discontinued as of 31 December, 2002 “in response to increasing Federal standards” (CEE 2003). In 2001, about 43% of units (presumably for all size ranges) met or exceeded the Tier 1 level, while 16% of units (all size ranges) met the Tier 2 level (CEE 2003).

Table A16-4 shows the external static pressure requirements (accounting for distribution duct pressure loss) for the indoor airside, as specified in the unitary test procedure, ARI-340/360. The increasing external static pressure increases the blower power. Since indoor air moving power typically equals 15 to 20% of unit power draw, a 25% to 40% increase in air moving power decreases EER by 4 to 8%. This accounts for a large part of the difference between the minimum efficiency levels for small and large unitary.

Table A16-4: Minimum External Static Pressure for Testing Unitary Products (from ARI 2000)

Standard Capacity Ratings		Minimum External Resistance [in H_2O]
kBtu/hour	**For Tons**	
135 to 210	11.3 - 17.5	0.35
211 to 280	17.5 - 23.3	0.40
281 to 350	23.2 - 29.2	0.45
351 to 400	29.2 – 33.3	0.55
401 to 500	33.3 – 41.7	0.65
501 +	41.7 and over	0.75

The basic options for increasing the full load, standard conditions EER are to specify more efficient refrigerant compressors, increase condenser and/or evaporator coil face area and heat transfer area, and to specify high efficiency fans, blowers, or motors. Application of one or more efficiency measure is a design-specific cost-benefit tradeoff that is constrained by total unit cost for each manufacturer, including aforementioned unit size.

Some large unitary products may also include one or more technologies that can reduce annual cooling energy consumption and/or improve seasonal energy efficiency. When the unitary AC supplies outdoor ventilation air mandated by ASHRAE Standard 62, energy recovery heat and/or enthalpy exchange between the ventilation make up air and exhaust air can reduce energy consumption by a significant amount (10% or more) under standard test conditions (per ANSI/ARI 340/360). This approach can also reduce seasonal energy consumption. Airside economizers, which are prescribed by ASHRAE 90.1-1999 under several circumstances, can also realize significant reductions in seasonal energy consumption. Variable air volume (VAV) operation of the indoor blower, coupled with compressor capacity modulation (typically through the use of multiple compressors) is another approach that can appreciably reduce seasonal energy consumption. One difficulty in applying VAV is the need to deliver a constant flow of outdoor air to comply with ASHRAE 62. On the other hand, if a separate blower brought in the outdoor air (and another blower recirculated additional air for cooling and heating purposes), varying the recirculated indoor airflow rate would have minimal impact on outdoor air delivery rates. Large unitary AC with demand control ventilation (DCV) allows reductions in outdoor air delivery in response to building occupancy, for which measurements of CO_2 levels in occupied zones serve as a proxy (per ASHRAE Standard 62). Thus, DCV can reduce annual HVAC energy consumption in buildings by decreasing the quantity of outdoor air that requires conditioning; it does not impact unitary equipment efficiency performance (TIAX 2002).

A16.3 Test Procedure Status

A DOE energy efficiency test procedure has not been instituted for commercial unitary air conditioners. Industry (ANSI/ARI) test procedures are used instead.

ASHRAE 90.1 minimum efficiency requirements for large unitary products are specified in terms of EER. The efficiency of large unitary air conditioners is tested according to ANSI/ARI standard 340/360. The standard provides for determining the EER at a standard condition, analogous to the EER at the DOE A test condition in the NAECA test procedure for residential central air conditioners. It also determines Integrated Part Load Value (IPLV) as an approximation of seasonal average performance. In addition, ANSI/ARI 340/360 enables performance evaluation for units that have a separate pre-cooling coil for outdoor ventilation air.

In general, the IPLV procedure in ARI 340/360 does not appear to correlate well with actual seasonal performance (based on discussions with major unitary equipment manufacturers). The ARI 340/360 Engineering Committee is beginning to work on an improved method for determining part-load performance and seasonal energy consumption. Furthermore, ARI 340/360 does not account for the seasonal energy impact of VAV, DCV, or economizers on seasonal energy use. It also does not consider the energy performance of efficient methods of preconditioning outdoor ventilation air (e.g., heat or enthalpy recovery exchange). ASHRAE guideline V, however, addresses this configuration.

A16.4 Energy Savings Estimates and Calculations

All energy savings calculations assume that the entire installed base of large unitary air conditioners operate at the ASHRAE 90.1 – 1999 minimum EER levels. Table A16-5 summarizes the potential energy consumption and energy savings for new technologies, along with anticipated annual energy savings from 2008-2030.

Table A16-5: Energy Savings Potential Associated with Various Efficiency Improvements

Technology/Standard Level	UEC Savings Potential [%]	Energy Savings Potential [2010-2035; quads]
Typical New Device (9.5 EER)	—	—
CEE Tier 2 (10.0 EER)	5%	0.25
Best Available (11.0 EER)	14%	0.7*
Typical New Device with VAV	~30%**	1.1
Typical New Device with ERV	~40%***	1.6

*Calculated as if 11.0 EER is available across the entire capacity range. However, 11.0 EER products are generally not available at the upper end of the capacity range.

**From ADL (1999)

***Includes the savings from VAV. Does not include heating-season savings. Savings can vary, depending on climate, ventilation rates, and other factors. From TIAX (2003).

A16.5 Regulatory Actions and Cumulative Burden

A significant fraction of all large unitary air conditioners are produced by manufacturers who produce smaller commercial unitary and residential central air conditioners. Commercial unitary equipment ≥65 kBtu/hr and <240 kBtu/hr have been subject to minimum EER since the provisions of the Energy Policy Act of 1992 (EPAct) took effect. Residential central air conditioners and heat pumps have been subject to minimum SEER and HSPF standards since 1990. Standard levels were increased in 1993 and in 2004 with the end of the rulemaking litigation on residential central air conditioners and heat pumps.

The Energy Policy Act of 1992 (EPAct) first established minimum efficiency levels for commercial unitary based on the recommended minimum efficiency levels for unitary in ASHRAE 90.1-1989. ASHRAE 90.1-1999 raised the minimum efficiency. An ongoing DOE rulemaking for unitary equipment with capacity ≥65 kBtu/hr and <240kBtu/hr is considering whether to adopt 90.1-1999 efficiency levels or to set more stringent levels.

Several states are considering setting standards at the state level. To avoid having to manage multiple state-level standards, ARI is developing a proposal for a federal performance standard. More information should be available in early April on the status of ARI's proposal.

A16.6 Issues Impacting Potential Energy Efficiency Standards

As discussed in Section A16.2 above, space constraints (for both shipping and installation) become more acute with increasing equipment capacity. Some efficiency improvement measures (such as increasing coil size or adding energy recovery/enthalpy exchange) tend to increase unit physical size, so unit physical size constraints may limit efficiency improvements. Also, the industry faces the phase out of HCFC refrigerants. Switching to HFC alternatives (such as HFC-410a) may impact efficiency.

References

ADL, 1999, "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation", Final Report by Arthur D. Little, Inc. to the U.S. Department of Energy, Office of Building Technology, State and Community Programs, October. Available at: http://www.eren.doe.gov/buildings/documents/pdfs/comhvac.pdf .

ADL, 2001, "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume I: Chillers, Refrigerant Compressors, and Heating Systems", Final Report by Arthur D. Little, Inc.to US Department of Energy, Office of Building Technology, State and Community Programs, April. Available at: http://www.eren.doe.gov/buildings/documents/pdfs/hvacvolume1finalreport.pdf .

ARI, 2000, *ARI Standard 340/360, 2000, Standard for Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*, The Air-Conditioning and Refrigeration Institute: Arlington, VA.

ARI, 2003, "Guideline V: 2003 Guideline for Calculating the Efficiency of Energy Recovery Ventilation and Its Effect on the Efficiency and Sizing of Building HVAC Systems," The Air-Conditioning and Refrigeration Institute: Arlington, VA.

ASHRAE, 1989, *ASHRAE/IES Standard 90.1 – 1989, Energy Efficient Design of New Buildings Except New Low-Rise Residential Buildings*, ASHRAE Press: Atlanta, GA.

ASHRAE, 1989, *ASHRAE/IESNA Standard 90.1 – 1999, Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, ASHRAE Press: Atlanta, GA.

Carrier, 2004, Telephone conversation between Dick Lord of Carrier and Bob Zogg of TIAX, March 15, 2004.

CEE, 2003, "Fact Sheet: High-Efficiency Commercial Air Conditioning and Heat Pumps," Consortium for Energy Efficiency. Available at: http://www.cee1.org/resrc/facts/hecac-fx.php3 .

DOE, 2003, "DOE Rulemaking: Commercial Unitary Air Conditioners and Heat Pumps," Documentation available at: http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html .

ENERGY STAR®, 2004, "EnergyStar® Program Requirements for Light Commercial HVAC – Eligibility Criteria," Downloaded on 9 March, 2004, from: http://www.energystar.gov/ia/partners/product_specs/eligibility/lchvac_elig.pdf .

Lennox, 2003, Engineering Data, L Series® – LCA.C – 60 Hz, 13 to 60 Ton, Packaged Cooling. Available at: http://pirl.lennox.com/C03e7o14l/ehb_lcalcc_13to30_0309.pdf

TIAX, 2002, "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume III: Energy Savings Potential," Final Report by TIAX LLC to US Department of Energy, Office of Building Technology, State and Community Programs, July. Available at: http://www.eren.doe.gov/buildings/documents/pdfs/hvacvolume3finalreport.pdf .

TIAX, 2003, "Energy Efficient Rooftop Air-Conditioner—Design, Development and Field Testing", Final Technical Report by TIAX LLC to US Department of Energy, National Energy Technology Laboratory, DOE Cooperative Agreement Number DE-FC26-99FT40640, June.

U.S. Census Bureau, 2002[40], "Current Industrial Reports – Refrigeration, Air Conditioning, and Warm Air Heating Equipment: 2002," Issued July.

[40] Reports were also used for the years 1988 through 2001, in which case the title changes to reflect the actual year, e.g., for 2001 the title is: "Current Industrial Reports – Refrigeration, Air Conditioning, and Warm Air Heating Equipment: 2001."

A17 Residential Furnace Fans

A17.1 Background

Residential gas-fired furnaces use electricity for the circulating air fan as well as for other electrical components. In many applications, the furnace fan is also the air handler for the air conditioner. The electricity use for non-weatherized furnaces is shown in Table A17-1. Since one circulating air blower is included in every residential furnace, the installed base and equipment lifetime are the same as for residential furnaces.

Table A17-1: Residential Furnace Fan Background Data

Data type	Value[1]	Source/Comments
Installed Base, millions	48.9	Based on historical shipments and equipment lifetime of 20 years
Annual Shipments, millions	3.20 3.38 (year 2006 forecast)	(Kendall 2002) (Appliance 2004)
Equipment Lifetime, years	20	(Appliance 2004)
AEC, quad	0.58	Based on installed based and stock annual energy use

[1] Installed base, annual shipment, and AEC values are for the year 2002 except where noted.

A17.2 Product Technology Description and Market Presence

The baseline design for the furnace circulating-air blower is a centrifugal design with a forward-curved impellor in a sheet metal scroll powered by a permanent split capacitor (PSC) induction motor. The forward-curved impellor is made of stamped sheet metal. The air handlers are sized to move air for the air conditioner with which the furnace is installed.

Nominal motor sizes are less than 1 horsepower (hp) and operate at about 1075 rpm. Usually, ⅓ hp motors are used in furnaces designed for a three-ton air conditioner and ½ hp motors for a four-ton air conditioner. The motors are built with multiple electrical taps, usually three or four, which connect to different windings in the motor for different speed settings. The lower speeds are much less efficient than the higher speeds. The motor is usually set to the highest speed setting when the air conditioner is operating. For furnace operation, a lower motor setting is used. About 95 percent of furnaces are sold with a PSC motor and centrifugal-type blower. The combined efficiency of these motor and blowers is typically 10 to 15 percent.

Another motor technology that is also used in furnaces is the brushless permanent magnet (BPM) motor. This variable speed motor technology is more efficient and more expensive than PSC motors. The variable speed capabilities of these motors are used in as much as 20 percent of condensing furnaces. The primary selling point is the extra consumer utility of being able to operate the furnace air handler at a reduced airflow, thereby improving consumer comfort and reducing noise. This motor is currently used with standard forward-curved centrifugal blowers.

With DOE assistance, General Electric has developed a prototype backward inclined blower with a smaller BPM motor. The different geometry of this blower requires it to operate at a higher speed, but allows the motor to be smaller in size. Improvements to the aerodynamics of the blower inlet cone were also included. This prototype blower has about double the efficiency of the baseline blower and blower-motor design. The impellor is likely to be more expensive, because it is more difficult to make, but the motor will likely be less expensive than current BPM motor designs because it is smaller. Table A17-2 provides the UEC values corresponding to the furnace fans discussed above.

Table A17-2: Residential Furnace Fan Technology Levels and UEC Values

Technology Level	UEC (kWh/yr)	Source/Comments
PSC motor, forward-curved blower	1,085	Based on metered data from condensing furnaces with air conditioners in Wisconsin. (Pigg 2003)
BPM motor, forward-curved blower	645	Based on metered data from condensing furnaces with air conditioners in Wisconsin. (Pigg 2003)
BPM motor, backward-inclined blower	566	Based on laboratory comparison with baseline blower and blower-motor. (Walker et.al. 2003)

Table A17-3 provides the change in retail price for the two BPM designs listed in Table A17-2. The BPM retail price is based on a cost estimate from the Sachs and Smith (Sachs and Smith 2003) multiplied by a manufacturer cost-to-retail price markup estimated by DOE (DOE 2002). The additional price of the backward-inclined blower is based on a DOE estimate for the blower alone (DOE 2002).

Table A17-3: Residential Furnace Fan Retail Prices

Technology Level	Delta Retail Price ($2002)	Source/Comments
PSC motor, forward-curved blower	NA	NA
BPM motor, forward-curved blower	$174	Manufacturer cost estimated by Sachs and Smith multiplied by a retail price markup estimated by DOE (Sachs and Smith 2003; DOE 2002)
BPM motor, backward-inclined blower	$275	Motor same as above. Blower price from DOE (DOE 2002)

A17.3 Test Procedure Status

The current DOE test procedure for furnaces measures Annual Fuel Utilization Efficiency (AFUE), which does not include electricity. The test procedure does specify how to calculate Annual Auxiliary Electricity Use (E_{AE}). However this parameter is not an efficiency descriptor and it includes electricity from other furnace components as well. E_{AE} is measured during furnace testing. It does not measure air-handling performance and it does not include the impact of standby power or air handler operation during air conditioning.

The Air Movement and Control Association International (AMCA) and ASHRAE have developed Laboratory Methods for Testing Fans for Aerodynamic Performance Rating that could be adapted for use as the basis of a test for furnace air handler efficiency (ANSI/AMCA 210-99; ANSI/ASHRAE 51-1999).

A17.4 Energy Savings Estimates and Calculations

Table A17-4 presents the energy savings potential for the efficiency levels specified in Table A17-2. Also provided in Table A17-4 is the economic benefit or burden to consumers for each efficiency level taking into account both utility bill savings and the increased equipment costs. Consumer national utility bill savings for a given year are derived by taking the national annual energy savings and multiplying it by the corresponding electricity price from the DOE-Energy Information Administration's *Annual Energy Outlook 2004* (DOE 2004). Consumer national equipment cost increases are derived by taking the per unit change in equipment cost and multiplying it by the annual shipments. Cumulative bill savings and equipment cost increases are summed over the time period 2010-2035 with the net benefit or burden being the difference between the two values.[41]

.

[41] Economic calculations are performed with a spreadsheet tool which is available on the DOE Building Technologies Program, Appliances and Commercial Equipment Standards web site. http://www.eere.energy.gov/buildings/appliance_standards/docs/fy05_priority_setting_spreadsheets.zip

Table A17-4: Residential Furnace Fan Potential Energy Savings and Economic Impact Estimates

Technology Level	UEC (kWh/yr)	Energy Saving Potential, 2010-2035 (quads)	Potential Economic Benefits/Burdens; Cumulative NPV 2010-2035 (billions of $2002)
PSC motor, forward-curved blower	1,085	NA	NA
BPM motor, forward-curved blower	645	5.02	6.19
BPM motor, backward-inclined blower	566	5.92	5.44

A17.5 Regulatory Actions and Cumulative Burdens

The AFUE of furnaces are regulated for energy efficiency under NAECA. Furnace manufacturers currently measure and publish the airflow performance of furnaces for a range of static pressures. These are guidelines for contractors to use when installing furnaces.

A17.6 Issues Impacting Potential Energy Efficiency Standards

Perhaps the largest issue impacting potential efficiency standards is energy legislation currently being considered by Congress. If approved and enacted, DOE would be allowed to regulate the electricity consumption of furnace fans.

DOE has not adopted a test procedure to rate the efficiency of residential furnace fans. This will have to be done before any standards are adopted. The current test procedure includes, but doesn't require certification of, E_{AE}. However this parameter is not an efficiency descriptor and it includes electricity from other furnace components as well. E_{AE} is measured during furnace testing. It does not measure air-handling performance and it does not include the impact of standby power or air handler operation during air conditioning.

The type of motor-blower combinations used in residential furnaces fans is also used in heat pumps. If DOE decides to pursue the regulation of furnace fan efficiency, the Department will need to determine if heat pump air handlers are also covered under residential furnace fans.

Finally, as noted earlier, the backward-inclined blower is a prototype design. Thus, the energy and cost impacts may change significantly if the blower goes into mass production. The effectiveness of backward-inclined blowers has been confirmed through their use in large commercial equipment. But until backward-inclined blowers have been mass-produced for residential applications, their cost and energy impacts will be to some degree uncertain.

References

Appliance Magazine. 2004. “Healthy Times Ahead.” January, 2004.

Kendall, Mark. 2002. Appendix A - Furnace Shipments; Appendix B - Boiler. Comment # 24 submitted to Docket Number: EE-RM/STD-01-350 Shipments. Arlington, VA: GAMA.

Pigg, Scott. 2003. “Electricity Use by New Furnaces: A Wisconsin Field Study, Appendices.” Madison: Energy Center of Wisconsin.

Sachs, H.M. and S. Smith. 2003. “Saving Energy with Efficient Residential Furnace Air Handlers: A Status Report and Program Recommendations,” American Council for an Energy-Efficient Economy (ACEEE), Washington DC A033, April 2003.

U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, Building Technology Program, "Engineering Analysis, Furnaces and Boilers Standards Rulemaking, Draft Report for Review". September 19, 2002. http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/furnace_engineering_analysis.pdf

U.S. Department of Energy (DOE), Energy Information Administration. 2004. “Annual Energy Outlook 2004 with projections to 2025.” Washington, DC. DOE/EIA-0383(2004). January 2004.

Walker, I.S., M.D. Mingee, and D.E. Brenner. 2003. Improving Air Handler Efficiency in Residential HVAC Applications. LBNL 53606. Berkeley: Lawrence Berkeley National Laboratory.

A18 Torchieres

A18.1 Background

Torchieres, lighting fixtures that operate a halogen, incandescent or compact fluorescent light (CFL) source, are a subcategory of residential lighting. These fixtures are used to illuminate living spaces with indirect, ambient light. Torchieres are popular because of their function – illuminating a large space from one fixture, often with an adjustable lighting level. Newer living spaces typically require more portable (i.e., plug-in-the-wall) lamps because there is a general trend away from 'hard-wired' fixtures, such as chandeliers or decorative wall sconces. Newly constructed homes and apartments tend to be built with switched electrical outlets rather than hard-wired fixtures because builders allocate less than 1% of their construction budget to lighting fixtures (DOE, 2002). This increases the demand for plug-in-the-wall lamps, including torchieres.

There are approximately 69 million torchieres in the U.S. that consume approximately 0.238 quad of energy per year (see Table A18-1). Total annual shipments of torchieres are approximately 12 million units, with halogen, incandescent, and compact fluorescent accounting for 1.3, 10.0, and 0.9 million units respectively (Ecos Consulting, 2003).

Table A18-1: Torchiere Background Data

Data type	Value	Source
Installed Base, millions (2003	69	Ecos Consulting, 2003
Annual Shipments, millions (2003)	12	Ecos Consulting, 2003
Equipment Lifetime, years	4.5	Ecos Consulting, 2003
AEC, quad	0.238	Calculation, installed base

A18.2 Product Technology Descriptions and Market Presence

Two efficiency levels for torchieres were examined – one limiting the wattage to 190 watts per fixture (i.e., the California standard and the level in the pending federal energy bill) and one limiting the wattage to 70 watts per fixture, approximately equivalent to the ENERGY STAR® standard (see Table A18-2). Only wattage levels were considered; dimming capability or usage was not considered.

Table A18-2: Torchiere Technology Levels and Wattage Values

Technology Level	Wattage	Comments/Source
Stock Efficiency	253	Average installed base efficiency; Ecos Consulting, 2003.
Typical New	225	Incandescent torchiere wattage; Ecos Consulting, 2003.
Minimum Efficiency	190	Draft Energy Bill Standard; CEC maximum effective March 1, 2003.
Incandescent	225	Ecos Consulting, 2003.
Best Available Efficiency (CFL light source)	55	Assume light output of energy star light source held constant with 225 W incandescent (3500 lumens)
ENERGY STAR® Efficiency	70	Assume light output of CFL source equivalent to halogen baseline.
Maximum Efficiency (Future Technology)	40	Assume efficacy will improve to highest linear florescent tube (100 LPW) and 4000 lumen output.

Halogen and incandescent torchieres have a broad range in price due to differences in shades and metal fixture surface finishes, but generally the most popular units are the least expensive, ranging between \$10 and \$30. CFL torchieres require a ballast and fluorescent lamp, in addition to aesthetic costs such as shades and finishes. Generally, CFL torchieres cost between \$40 and \$70. Operating costs tend to be about \$18 less per year for operating a CFL torchiere, with a simple payback period of between 1.7 to 2.2 years. However, the majority of the residential torchiere market is first-cost sensitive, favoring the cheaper, but less efficient incandescent and halogen torchieres. Halogen torchieres accounted for about 11% of torchiere sales in 2003, while lower-wattage incandescent torchieres captured 82% of the market. In 2003, CFL torchieres represented approximately 7% of the units shipped (Ecos Consulting, 2003).

To promote the use of CFL torchieres, several utilities and university campuses have sponsored trade-in programs, where people can swap their halogen torchieres for more energy efficient and safer CFL torchieres. Utilities have also sponsored rebate programs for CFL torchieres. The maximum efficiency technology, which assumes that CFL technology efficacy will improve to that of the most efficient linear fluorescent tube currently available, is not commercially available in torchiere form at this time.

Currently, torchieres do not have a national minimum efficiency standard, but they are included in the voluntary ENERGY STAR® program for residential light fixtures (see Table A18-3). The ENERGY STAR® Residential Light Fixture Program requires 60 LPW for indoor fixtures 24 inches or shorter that consume 30 or more watts. The 60 LPW requirement translates to an allowed wattage of approximately 67 W per fixture, assuming a 4,000-lumen output. ENERGY STAR® also specifies that torchiere style portable fixtures shall be dimmable from 100 percent to 30 percent or less of maximum light output, or be switchable to three levels of brightness, not including the off position (DOE & EPA, 2001).

Table A18-3: ENERGY STAR® Requirements for Indoor Lights

Selected Performance Characteristics	ENERGY STAR® Specification (summarized)
System efficacy (LPW) All fixtures ≤24 inches and ≥30W	≥60 LPW
Power factor	≥0.5
Lamp current crest factor	≤1.7 per ANSI C82.11-5.6.1
Lamp color rendering	CRI ≥ 80 for CFLs
Dimming	Torchiere style portable fixtures shall be dimmable from 100% to 30% or less of maximum light output, or be switchable to three levels of brightness, not including the off position.
Safety	Must comply with NFPA 70, NEC Other ANSI and UL standards apply to specific fixture types

Despite concerted marketing efforts and more than 30 different compliant models for consumers to choose from, ENERGY STAR® torchieres still represent just 7% of the units shipped (Ecos Consulting, 2003). In fact, between 2001 and 2003, estimates of torchiere sales increased while the units sold and total shipment percentage of ENERGY STAR® CFL torchieres declined. Generally, consumers have not responded to the marketing efforts, bulk procurements, subsidies and awareness raising initiatives conducted to increase the market share of Energy Star torchieres.

A18.3 Test Procedure Status

The Department does not presently have a test procedure for measuring the energy consumption of torchiere fixtures. However, industry-recognized testing procedures published by IESNA are available which provide standardized test methods by which engineers can measure the energy consumption and light output of a torchiere.

This section is divided into three parts, each summarizing the test method by which torchieres are evaluated in respective programs. The three sections are: (A) the draft Energy Bill; (B) the California Energy Commission standard; and (C) the ENERGY STAR® Torchiere program.

A) Draft Energy Bill

In the event that Congress passes the draft Energy Bill, a national standard will be enacted for torchieres manufactured on or after January 1, 2005 that “(1) Shall consume not more than 190 watts of power; and (2) Shall not be capable of operating with lamps that total more than 190 watts.”

The IESNA has a test method that can be used to measure the power consumption of a fixture (IESNA Guide for the Selection, Care, and Use of Electrical Instruments in the Photometric Laboratory; LM-28-98), addressing the first criterion, i.e., that the torchiere consume not more than 190 watts of power.

The second criterion – that the torchiere shall not be capable of operating with lamps that total more than 190 watts – requires interpretation in order to develop an appropriate test method. There are two possible interpretations of this statement. First, it could be interpreted to mean the luminaire was not originally designed to operate at more than 190 watts. This would require an inspection of the complete torchiere and lamp, as sold, to ascertain that the rated lamp wattage totals 190 watts or less. Second, a stricter interpretation of this clause would mean that the luminaire is not *capable* of operating at more than 190 watts. In order to ascertain whether a luminaire is capable of operating at more than 190 watts, a test method would need to be developed where lamps rated at more than 190 watts are installed into the fixture undergoing testing. In this scenario, the fixture may simply not operate ("not capable of operating"), or could operate, but only consuming 190 watts instead of the rated wattage of the test lamp(s). These issues would need to be resolved in order to develop an acceptable test procedure.

B) The California Energy Commission Standard

The State of California recently passed an energy consumption standard for torchieres. Amending the California Code of Regulations, Title 20: Division 2, Chapter 4, Article 4, Section 1605.3 (n), California mandated that torchieres manufactured on or after March 1, 2003 shall not consume more than 190 watts and shall not be capable of operating with lamps that total more than 190 watts. This standard does not provide or specify a test procedure, as it was not recognized as being necessary. Rated out-of-the-box wattage is the metric by which regulators determine compliance.

C) The ENERGY STAR® Torchiere Program

The ENERGY STAR® program includes torchieres in its portfolio of products. Rather than basing eligibility on a wattage limit, the Energy Star program sets a minimum efficacy (lumens of light produced per watt of energy consumed) requirement. The EPA has developed a test procedure by which manufacturers can demonstrate compliance. This procedure references IESNA standards documents LM-9 and LM-66 as the methods for measuring efficacy and demonstrating compliance.

As presently written, this test procedure pertains to fluorescent-source torchieres, to the exclusion of other light sources that could meet the minimum efficacy such as metal halide high-intensity discharge lamps. Also, the test procedure measures the efficacy of the source rather than overall system (fixture) efficacy. Expanding the test procedure to incorporate fixture optics and thus measure the overall light output and performance of the luminaire may be advantageous.

The IESNA publishes methods for photometric testing of luminaires (rather than simply light sources) that can be used to determine torchiere system performance. For testing indoor luminaires using HID or incandescent filament lamps, the IESNA publishes LM-46-98. For indoor fluorescent luminaires, the IESNA publishes LM-41. These two publications can be applied to torchieres on the market today, and could form the basis of a test procedure that can be applied to all torchieres, irrespective of the light source used by the luminaire.

A18.4 Energy Savings Estimates and Calculations

The energy savings calculation for torchieres assumes an installed base of 69 million torchieres, including halogen, incandescent and compact fluorescent units. The average wattage, weighted by proportion of the installed base, is 253 watts (Ecos Consulting, 2003). Operating hours are 3.4 hours per day (Home Energy, 2001). Two energy savings scenarios are considered (see Table A18-4). The first scenario assumes a standard of 190 W, which assumes that those torchieres that consume more than 190 watts will move to exactly that consumption level. The second scenario approximates an ENERGY STAR® Torchiere standard. Although ENERGY STAR® is an efficacy-based standard, to keep the scenarios in consistent units, this standard has been approximated as an energy consumption limit of 70 watts (see Table A18-4).

In the first scenario, energy savings are calculated under the assumption that all torchieres consume less than 190 watts. Thus, all shipments of torchieres that had been greater than 190 watts would become 190 watts. This first scenario approximates the energy savings potential of the torchiere standard in the draft Energy Bill. In the second scenario, it was assumed that all torchieres must consume less than 70 watts. This assumption approximates the energy consumption standard for ENERGY STAR®, which has a residential fixtures efficacy threshold of 60 lumens per watt for torchieres. The typical source light output of a 225 incandescent torchiere is approximately 3200 lumens. The typical source light output of a 300 watt halogen torchiere is approximately 5400 lumens. Therefore, the Department selected a source light output averaging these two products at 4300 lumens. This level attempts to balance customer utility (light output), while recognizing the market is transitioning to a lower light output torchiere (incandescent). At the ENERGY STAR® standard of 60 lumens per watt, 4300 lumens equates to 71.7 watts, or rounded down to 70 watts.

Table A18-4: Torchiere Wattage and Usage Data

Scenario	Wattage	Hours of use/day	References
Baseline (weighted average installed base, 2003)	253	3.4	Ecos Consulting, 2003; Home Energy Magazine, 2001.
Scenario 1 (190 watt max)	225	3.4	Ecos Consulting, 2003; Home Energy Magazine, 2001.
Scenario 2 (70 watt max)	70	3.4	Home Energy Magazine, 2001.

For the potential energy saving estimate calculation, a slight modification to the baseline torchiere was made. In Table A18-4, the weighted average installed base of torchiere lamps is reported as 253 watts. This represents approximately 50 percent of the installed base being halogen torchieres (300 watts), 44 percent being incandescent torchieres (225 watts) and 6 percent being compact fluorescent torchieres (70 watts). However, it is clear that shipments in 2003 were dominated by incandescent torchieres, and halogen torchieres have been experiencing decreasing proportions of shipments ever since the late 1990's, when several fires caused by the halogen fixtures raised concern among consumers.

In 2003, the proportional breakdown of torchieres shipped was approximately 11 percent halogen (300 watts), 82 percent incandescent (225 watts) and 7 percent compact fluorescent (70 watts). This 2003 shipment-weighted average wattage corresponds to an average baseline wattage torchiere of 222 watts, approximately 12 percent lower than the 253 watts for the installed base weighted average wattage. Due to the relatively short operating lives of these fixtures (3.1 – 6.6 years) and the fact that the market shown a strong preference for incandescent technology, the Department calculated the energy savings potential for this product using the 2003 shipment-weighted average wattage for torchieres. The Department believes that this adjustment to the baseline would give a more accurate estimate of the energy savings potential, as it more accurately reflects the dynamic qualities of today's torchiere market.

Table A18-5: Torchieres AEC and Potential Energy Saving Estimates

Technology/ Standard Level	AEC (quad)	Annual Energy Savings Potential (quad)	% Energy Savings	Energy Saving Potential (2010-2035), (quads)
Baseline	0.238	NA	NA	NA
Scenario 1 (190 watt max)	0.199	0.038	16%	0.87
Scenario 2 (70 watt max)	0.095	0.143	60%	3.25

A18.5 Regulatory Actions and Cumulative Burden

The State of California passed an energy consumption standard for torchieres that took effect recently. Amending the California Code of Regulations, Title 20: Division 2, Chapter 4, Article 4, Section 1605.3 (n), California mandated that torchieres manufactured on or after March 1, 2003 shall not consume more than 190 watts and shall not be capable of operating with lamps that total more than 190 watts.

Safety concerns for halogen torchieres have instigated regulatory attention and consumer demand for halogen torchiere substitutes. Halogen torchiere bulbs operate at extremely high temperatures, (700 to 1,000^{o}F compared to 100 to 200^{o}F for a comparable CFL torchiere) and thus present a fire hazard (DOE & EPA, 2001). Following multiple fires, Underwriters Laboratories banned halogen bulbs above 500W from UL listing in 1996. Many universities have also banned halogen torchieres from dormitories for safety reasons (LBNL, 1999).

A18.6 Issues Impacting Potential Energy Efficiency Standards

Although not mandated, many manufacturers have responded to torchiere safety concerns by installing safety measures such as lower wattage bulbs and protective cages to avoid materials coming into contact with the bulb. Any future efforts made to reduce the bulb temperature and/or wattage (e.g., the 190W standard in California) will impact lighting technology options available to torchiere lamps.

Concern also exists regarding residential consumer acceptance of CFL light sources, specifically with respect to light quality, e.g., color rendering index (CRI). CRI is a measure of the quality of color that a light source renders an object. Whereas incandescent and halogen light sources have a CRI index of 100, CFL light sources score a CRI of approximately 80-88.[42]

In the event that Congress passes the Energy Bill, a national standard will be enacted for torchieres manufactured on or after January 1, 2005 that "(1) Shall consume not more than 190 watts of power; and (2) Shall not be capable of operating with lamps that total more than 190 watts." Issues related to this national standard have been raised, including the consideration of how to interpret and test the second clause of the standard.

[42] The ENERGY STAR® program mandates a minimum CRI of 80 for compact fluorescent lamps.

References

DOE, 2002, "*The FY 2003 Priority-Setting Summary Report and Actions Proposed*," Appliance Standards Program of the Department of Energy, August 22, 2002.

Ecos Consulting, 2003. Estimated Inventory of Torchiere Lamps, prepared for the Department of Energy, Ecos Consulting, March 2003.

DOE & EPA, 2001, "ENERGY STAR Program Requirement for Residential Light Fixtures Eligibility Criteria – Version 3.2," Energy Star, Environmental Protection Agency. Available at: http://www.energystar.gov/ia/partners/product_specs/eligibility/fixtures_elig.pdf.

Home Energy, 2001 ,"CFL Torchiere Top Choice," Home Energy Magazine Online. July/August 2001. Accessed on March 30, 2004 at http://hem.dis.anl.gov/eehem/01/010709.html

LBNL, 1998, "Energy Efficient Torchieres: From the Laboratory to the Marketplace," ACEEE 1998 Summer Study on Energy Efficiency in Buildings, August 23-28, 1998, Pacific Grove, California. Available at: http://eetd.lbl.gov/btp/papers/41648.pdf.

A19 Traffic Signal Modules

A19.1 Background

Traffic signals are illuminated traffic control devices by which people are warned or directed to take a specific action. Traffic modules (or “balls”) typically come in eight- and twelve-inch diameter round signals, consisting of a light source and a lens. These modules communicate movement messages (stop, caution or prepare to stop, and go) to drivers through red, yellow, and green light signals.

Traffic signals are an integral part of the transportation system in the United States, safely regulating the movement of vehicles. In the United States, there are approximately 312,500 signalized intersections (NCI, 2003). At each intersection, up to three types of traffic signals, including the three-colored ball, arrow, and bi-modal arrow, can be found for the purposes of controlling traffic flow. In addition, approximately 75%, or about 234,400 intersections, also have pedestrian crossing signals (NCI, 2003).

Combining the inventories of colored ball, arrow, and pedestrian crossing signals, there are approximately 15.3 million traffic signal modules in the U.S. These modules, including both incandescent and light emitting diode (LED) types, consume approximately 0.0374 quad of energy per year (see Table A19-1).

Table A19-1: Traffic Signals Background Data

Data type	Value	Source
Installed Base, million units (2002	15.3	NCI, 2003
Equipment Lifetime, years	10	Estimate.
AEC, quad	0.0374	NCI, 2003.

A19.2 Product Technology Descriptions and Market Presence

Table A19-2 presents the technology level and wattage levels for two types of traffic signals (incandescent and LED).

Table A19-2: Traffic Signal Technology Levels and Wattage Values

Technology Level	Wattage	Comments/Source
Average energy consumption of installed base (watts)	95.2	Stock weighted average wattage, NCI, 2003.
Typical New (LED)	9.6	Assume LED. Estimated average. NCI, 2003.
Minimum Efficiency	None, CEC: 2003	No national energy standard, however California has passed minimum efficiency standards that are consistent with ENERGY STAR®.
Incandescent	126.9	Average of 8-inch and 12-inch signals. NCI, 2003.
LED	9.6	Estimated average LED. NCI, 2003.
Best Available Efficiency (LED light source)	9.6	Assume LED, installed base weighted average
ENERGY STAR® Efficiency	Variable	See Table A19-3
Maximum Efficiency (Future Technology)	5.0	Assume doubling of LED system efficiency by 2020, relative to today's LED efficiencies (NCI, 2003).

LEDs are emerging as the technology of choice for traffic and pedestrian control signals. Throughout the United States, municipalities are retrofitting and installing LED technology in these applications. These systems have a higher first-cost, however the energy and maintenance savings benefits offset those initial costs in a reasonable time period, justifying the replacements. For example, a red LED traffic signal costs about $75 compared with $3 for an incandescent signal. However, when considering the lower energy consumption, extended operating life and associated maintenance savings, over a seven year period, the cost of ownership of red LED traffic signals is about one-third that of incandescent traffic signal (CEE, 2002).

Currently, traffic signals do not have a national minimum efficiency standard, but they do fall under the voluntary ENERGY STAR® program (see Table A19-3). The ENERGY STAR® LED traffic signal modules include the following: LED vehicular traffic signal modules, including arrow modules and LED pedestrian signal modules. In addition, other (non-LED) technology products may be considered if they meet Institute of Transportation Engineer's (ITE) Vehicle Traffic Control Signal Heads Part 1 or 2 (or other relevant future ITE specification), as well as consuming energy at or below the standards in Table A19-3. (EPA, 2004)

Table A19-3: Energy-Efficiency Criteria for ENERGY STAR® Qualified Traffic Signal Modules

Module Type	Maximum Wattage (at 74°C)	Nominal Wattage (at 25°C)
12 inch Red Ball	17 watts	11 watts
8 inch Red Ball	13 watts	8 watts
12 inch Red Arrow	12 watts	9 watts
12 inch Green Ball	15 watts	15 watts
8 inch Green Ball	12 watts	12 watts
12 inch Green Arrow	11 watts	11 watts
Combination Walking Man/Hand	16 watts	13 watts
Walking Man	12 watts	9 watts
Orange Hand	16 watts	13 watts

Due to their energy saving benefits and reduced maintenance costs of LEDs, as well as market transformation programs highlighting these advantages, approximately 30-33% of the traffic signal market has already moved to LEDs. Red signal heads have seen the highest level of market penetration at 39%, while green signal heads are approximately 29% LED. Because of their low duty-cycle, yellow LED traffic signals have a much longer payback period. This, coupled with the stringent luminosity specifications for yellow LED signals results in a low market penetration, assumed to be around 2% (NCI, 2003).

A19.3 Test Procedure Status

The draft Energy Bill states: "Test procedures for traffic signal modules shall be based on the test method used under the ENERGY STAR® program of the Environmental Protection Agency for traffic signal modules, as in effect on the date of enactment of this paragraph." The ENERGY STAR® program for traffic signals specification states that "The products must meet the minimum performance requirements of the relevant ITE specification, and be tested under the conditions presented in Section 6.4.2 of the Vehicle Traffic Control Signal Heads, Part 2."

A19.4 Energy Savings Estimates and Calculations

The energy savings calculation for traffic signal modules assumes an installed base of 15.3 million units (NCI, 2003). The energy savings estimate is based on the standard contained in the draft Energy Bill, which establishes an ENERGY STAR® efficiency standard. Thus, the remaining stock of non-LED traffic signals convert to ENERGY STAR® compliant LED modules. Although the Energy Star specifications allow for other products that meet certain requirements (see A19-3), only LED technology can currently meet these requirements (EPA, 2004). Table A19-4 presents data for the baseline scenario, including installed base, wattage, and usage data for traffic signals in 2002 (NCI, 2003).

Table A19-4: Traffic Signals Installed Base, Wattage, and Usage Data

Equipment Type		Installed Base/Stock	Stock Average Wattage*	Hours of use/day	References
Three Colored-Ball	Red	3,031,250	78	13.2	NCI, 2003.
	Yellow	3,031,250	120	0.7	NCI, 2003.
	Green	3,031,250	90	10.1	NCI, 2003.
Arrow	Red	937,500	85	2.2	NCI, 2003.
	Green	937,500	91	2.2	NCI, 2003.
Bi-Modal Arrow	Yellow	312,500	90	2.2	NCI, 2003.
	Green	312,500	98	2.2	NCI, 2003.
Walking Man	White	1,875,000	97	7.4	NCI, 2003.
Hand	Orange	1,875,000	97	7.4	NCI, 2003.

*Note: Stock Average Wattage represents the weighted average wattage of the installed base of incandescent and LED traffic and pedestrian control signal heads.

Table A19-5: Traffic Signals Sign AEC and Potential Energy Saving Estimates

Technology/ Standard Level	AEC (quad)	Annual Energy Savings Potential (quad)	% Energy Savings	Energy Saving Potential (2010-2035) (quad)
Baseline	0.0374	NA	NA	NA
Scenario 1 (Energy Star)	0.0086	0.029	77%	0.662

In this scenario, the annual energy consumption is reduced from 0.0374 quad to 0.009 quad, a 77% savings. Over the time period 2010-2035 the cumulative primary energy savings is more than half a quad, 0.66 quad (see Table A19-5).

A19.5 Regulatory Actions and Cumulative Burden

Traffic signals are not been subject to national regulation for energy efficiency. However, traffic signals are included in the draft Energy Bill currently being considered in Congress. If the Energy Bill is passed, the following standard will go into effect: "Traffic signal modules manufactured on or after January 1, 2006, shall meet the performance requirements used under the ENERGY STAR® program of the Environmental Protection Agency for traffic signals, as in effect on the date of enactment of this subsection, and shall be installed with compatible, electrically connected signal control interface devices and conflict monitoring systems."

The State of California considered energy efficiency standards for traffic signals in its proposed revisions to California Code of Regulations (CEC, 2002). In section 1605.3, the following revision is proposed to subsection (m) Traffic Signal Modules and Traffic Signal Lamps:

> (1) Energy Efficiency Standards for Traffic Signal Modules. The power consumption of traffic signal modules manufactured on or after March 1, 2003, shall be not greater than the applicable values shown in [Table A19-6] when tested at the temperatures shown.

Table A19-6: California Energy Efficiency Standards for Traffic Signal Modules

Type	Red		Amber		Green	
	at 25°C (77°F)	at 74°C (165.2°F)	at 25°C (77°F)	at 74°C (165.2°F)	at 25°C (77°F)	at 74°C (165.2°F)
300 mm circular	11 watts	17 watts	22 watts	25 watts	15 watts	15 watts
200 mm circular	8 watts	13 watts	13 watts	16 watts	12 watts	12 watts
300 mm arrow	9 watts	12 watts	10 watts	12 watts	11 watts	11 watts
Lane control (X)	9 watts	12 watts	No requirement	No requirement	No requirement	No requirement
Lane control (Arrow)	No requirement	No requirement	No requirement	No requirement	11 watts	11 watts

(2) Energy Efficiency Standards for Traffic Signal Lamps. The power consumption of traffic signal lamps manufactured on or after March 1, 2003, shall be not greater than 25 watts.

The California standard differs from the ENERGY STAR® standard in two ways – first, it does not include all the product classes and second, it adds some new ones that do not appear in ENERGY STAR®. However, those product classes it does have in common with ENERGY STAR® have identical standard levels.

A19.6 Issues Impacting Potential Energy Efficiency Standards

Commercial products from a range of manufacturers are available, and many municipalities are already switching voluntarily to ENERGY STAR® LED technology because it is more cost-effective.

An issue that may impact the energy savings estimate for this product is the assumption holding the baseline technology mix constant (i.e., incandescent vs. LED). This assumption tends to increase the energy savings that would result from a possible standard, and may not be an accurate representation of today's traffic signal market. In the late 1990's, a few municipalities initiated programs to gradually replace incandescent traffic signals with LEDs as their capital budgets allowed. As LED signal heads became more affordable and the EPA started its ENERGY STAR® awareness program, more and more municipalities launched programs to upgrade their traffic signals. Municipalities are motivated by both the energy and the maintenance and labor savings associated with LED signals. The installed-base-weighted average percentage of LED signal heads in the United States is 27%. If this number were increased to 40%, the energy savings over the 2010-2035 analysis period would be reduced approximately 23%, to 0.50 quad of savings.

References

CEC, 2002. California Energy Commission Express Terms (15-day language) and Notice of Adoption Hearing for Proposed Amendments to California Code of Regulations, Title 20: Division 2, Chapter 4: Energy Conservation, Article 4: Appliance Efficiency Regulatoins, Sections 1601-1608 and California Code of Regulations, Title 24: Part 6, Subchapter 2: Building Standards, Sections 110-111: Docket No. 01-AB970-APSTD, January 22, 2002.

CEE, 2002. Consortium for Energy Efficiency, "LED Traffic Signals Provide Dramatic Energy Saivngs," 2002, PDF file location: http://www.cee1.org/gov/led/led-cost.pdf

EPA, 2004. Accessed EPA website to review PDF document of the eligibility requirements for traffic signal energy star eligibility requirements: http://www.energystar.gov/ia/partners/product_specs/eligibility/traffic_elig.pdf

NCI, 2003. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*, prepared for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program by Navigant Consulting, November 2003.