APPENDIX A:

Technical Support Document (TSD)

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A1 Introduction

On May, 2001, the National Energy Policy Development Group (NEPD Group) reported a National Energy Policy to the President. One of the recommendations called for the President to direct the Secretary of Energy to take steps to improve the energy efficiency of appliances. The recommendation included supporting the existing appliance standards program, setting higher standards where technologically feasible and economically justified, and expanding the scope of the program to include additional consumer products and commercial and industrial equipment where technically feasible and economically justified.

In response, the Department of Energy (DOE or Department) extended the scope of its annual (2002) priority-setting activities and held two informal public meetings. These meetings provided a forum for the Department and stakeholders to discuss the priorities of the existing program and any possible expansion of the scope of the program to include additional consumer products and commercial and industrial equipment. The Department received suggestions on the criteria it should use to reach decisions on these issues and on the factors, data and analysis methods that might be used by DOE in its decision making process.

With stakeholder guidance, the Department identified several products with substantial energy savings potential that warranted further analysis. (see Table A1-1).

Table A1-1: List of Products Selected for Further Consideration

Commercial Products	Residential Products
High Intensity Discharge (HID) Lamps	Televisions
Monitors	Incandescent General Service Lamps
Personal Computers	Residential Clothes Dryers
Incandescent Reflector Lamps	Ceiling Fans (including Lighting)
Fluorescent Lamps	Set-Top Boxes
Gas Unit Heaters and Gas Duct Furnaces	Torchiere Lamps
Commercial Refrigeration	Dishwashers
	Home Audio (Compact and RACK/Component)

The primary goal of this report is to describe the derivation of energy consumption and savings estimates for all products listed in Table A1-1[1]. In addition, this document provides product-specific information relating to the prioritization criteria shown in Table A1-2.

[1] Spreadsheets containing the assumptions and calculations for equipment under consideration were posted on the DOE website at: http://www.eren.doe.gov/buildings/codes_standards/notices/notc0044/index.html .

Table A1-2: Product Prioritization Criteria.

Prioritization Criteria
Energy savings potential
Potential economic benefits
Potential environmental or energy security benefits
Applicable deadlines for rulemakings
Incremental DOE resources required to complete rulemaking process
Evidence of energy efficiency gains in the market absent new or revised standards
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

.

The following two sub-sections provide an in-depth explanation of the general energy consumption and savings methodology used for all products. Sections 2 through 16 each provide product-specific information for one of the products from Table A1-1.

A1.1 Methodology for Energy Consumption and Savings Estimate

Development of the energy consumption and savings estimates for the aforementioned products consisted of three steps: data collection, critical evaluation of data, and the development of energy consumption and savings estimates (Figure A1-1).

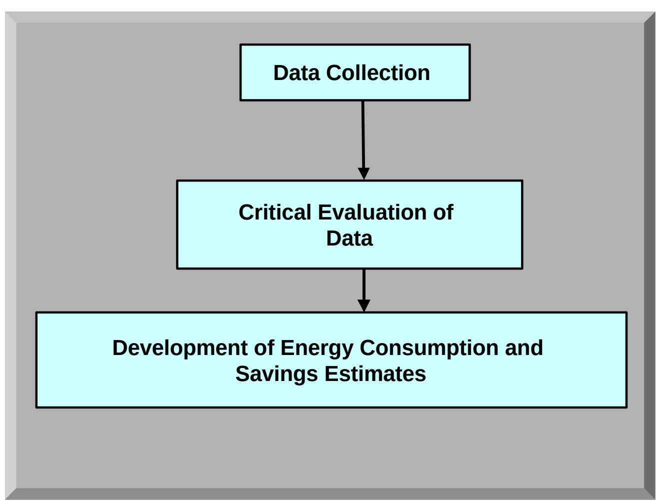

Figure A1-1: Overview of the Development of Product energy Consumption and Energy Savings Estimates

As noted earlier, DOE made a concerted effort to access the most complete and up-to-date information for each product while still achieving reasonable coverage for 35 different products. Whenever possible, the product Annual Energy Consumption (AEC) and Energy Savings Potential calculations leveraged data from previous detailed studies of the product under consideration. "Bottom-up" engineering analyses proved particularly valuable in this process, as they tend to provide a detailed breakdown of energy consumption (e.g., by usage mode), which enhances the quality of the energy savings calculations. When device-specific, detailed studies could not be found, the energy estimates were developed from a range of prior reports on building energy consumption, industry data sources, and industry contacts.

In many instances, energy consumption and/or savings values differed between sources. Based on industry knowledge, the data were critically evaluated to identify the most relevant studies and highest-equality data to obtain the best energy-saving estimates possible.

Future AEC and energy savings calculations do *not* address several issues that could impact future energy consumption or savings estimates (see Table A1-3).

Table A1-3: Issues not Considered for AEC and Energy Savings Potential Calculations

Variable	Example
Future increases or decreases in device installed base	Growth in number of set-top boxes
Future market penetration of technologies without standards actions	LCD monitors displacing CRT monitors
Future evolution of products, including additional product features	Set-top boxes managing information flow into a household

Instead, these issues are discussed in appropriate sub-sections for each device type selected for further consideration.

The following sub-section outlines the basic methodology used to calculate AEC and energy savings potential for different products.

A1.2 Energy Consumption and Savings Calculation Methodology

A1.2.1 Device Annual Energy Consumption (AEC) Estimates

Figure A1-2 explains the basic methodology used to develop the annual energy consumption (AEC) estimates for a device. Any deviation from the process that follows is clearly explained in the product-specific sections. The unit energy (or electricity) consumption (UEC) denotes the energy consumed by an average device (say, a laptop PC) over the course of an entire year. The UEC equals the sum of the products of the approximate number of hours that each device operates in a commercial building setting in each of the t power modes, T_t and the power draw in each mode, P_t :

$$UEC_t = T_t \cdot P_t$$
$$UEC = \sum U_t \quad .$$

For example, as shown in Figure A1-2, laptop PCs have four power modes, namely active, standby, suspended or sleep and off.

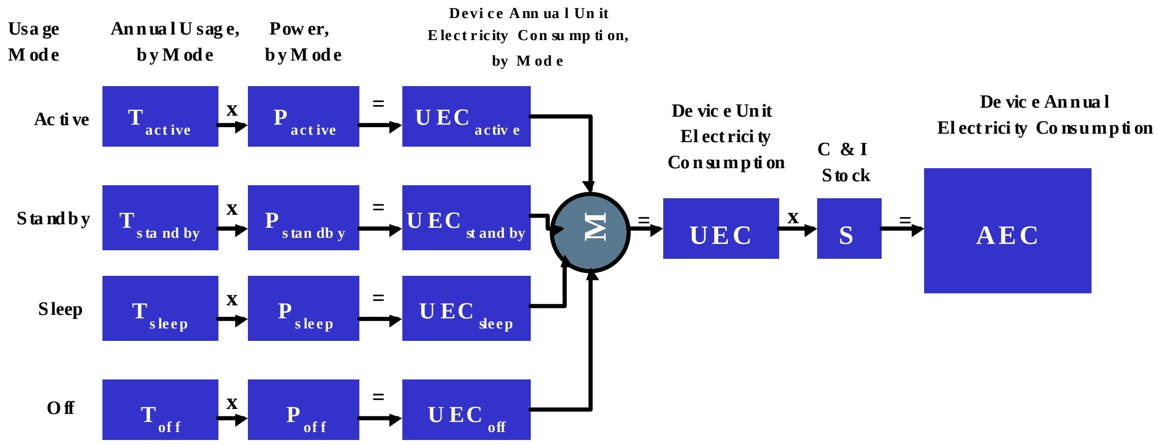

Figure A1-2: AEC Calculation Methodology (from ADL, 2002)

It should be noted that the estimates attempt to reflect values that best represent the average power draw of each equipment segment. For example, television sets have a broad range of power draw levels and also different usage patterns in different homes. In this case, the power draw and usage data came from a study focusing on television electricity consumption that includes values that approximate the *average* usage and power draw (by mode) of the entire installed base of televisions.

Next, an estimate of the device stock (i.e., installed base) of the device, *S*, was obtained or developed. Finally, the product of the stock and the device UEC yields the total annual energy consumption, AEC, for that equipment type:

$$AEC = UEC \cdot S$$

For devices powered by electricity, electric energy is converted to primary energy via the factor of 10,958 Btu/kW-h (BTS, 2000).

The following sections describe the general approach used to develop values for different components of the AEC calculations.

A1.2.1.1 Equipment Stock, S

The equipment stock, *S* of a device simply 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 sales data and equipment lifetimes, simply by summing the sales data over the past *y* years (where *y* represents the equipment lifetime) to develop a stock estimate:

$$S = \sum_{i=1}^{y} Sales_i \ .$$

A1.2.1.2 Usage Pattern

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 used up to four typical usage modes (see Table A1-4) and different devices may have different combination of these modes. For example, most televisions have two modes, active and standby, while copiers typically operate in all four usage modes. 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	Monitor displays image Copier copying images
Stand-by	Device ready to, but not, carrying out intended operation	Monitor displays screen saver Copier ready to print
Suspended	Device not ready to carry out intended operation, but on	Monitor powered down but on Copier powered down but on
Off	Device not turned on but plugged in	Monitor off, plugged in Copier off, plugged in

In many instances, usage data come from results of usage study 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 Power draw by mode, P

Energy consumption estimates incorporates power draw data for different equipment types and segments for each mode of operation. As explained earlier, implicit in the power draw by mode data is the assumption that all of the different devices folded into a single equipment type or segment consume the same amount of energy in a given mode. For example, the model assumes that an IBM ThinkPad 560 laptop and a Compaq Armada E5000 laptop both draw 15 W in 'active' mode and 3 W in 'suspended' mode. Clearly, this simplification is not true; however, in general, the error introduced by this assumption is on the order of or less than the errors in the usage patterns and commercial stock estimates. When available, the power draw estimates consider as many values as possible to give insight into the potential range of power draw values by mode for each equipment type and segment.

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. Consequently, using rated power draws to estimate energy consumption most often leads to gross over-estimation of energy consumption.

A1.2.2 Energy Savings Estimates

Using the above methodology the "current new", "typical new" and the "best available" AEC estimates are made as explained 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)	Desktop PC with a Pentium 2 CPU
Typical new	Based on the product most representative of new products purchased in Y2001.	Desktop PC with a Pentium 3 CPU
Best Available	Based on the device that consumes the least amount of energy in the market.	Desktop PC using a Laptop PC or low-power (e.g., Transmeta Crusoe) chipset

This analysis assumes that the installed base of each product type in 2008 does not increase from its current levels, i.e., that it equals the current installed base. For some devices with short lifetimes, such as PCs, it may be impractical to predict the future stocks due to the unpredictability of future trends. On the other hand, for devices with longer equipment life times (e.g., gas unit heaters), the installed base will likely not change significantly by 2008.

The total energy savings from 2008 to 2030 are calculated based on the assumption that the new technology/standard diffuses into the stock linearly over the lifetime of the device (as illustrated in Figure A1-3). The area under the shaded portion in the graph corresponds to the total actual savings and equals:

$$Savings = 22 \cdot Annual\ Energy\ Savings - \frac{1}{2} \cdot (lifetime \cdot Annual\ Energy\ Savings).$$

The annual energy savings level represents the annual energy saved by replacing the entire installed base of that product - which consumes energy at the "typical new" level – with product consuming energy at the new technology/standard level.

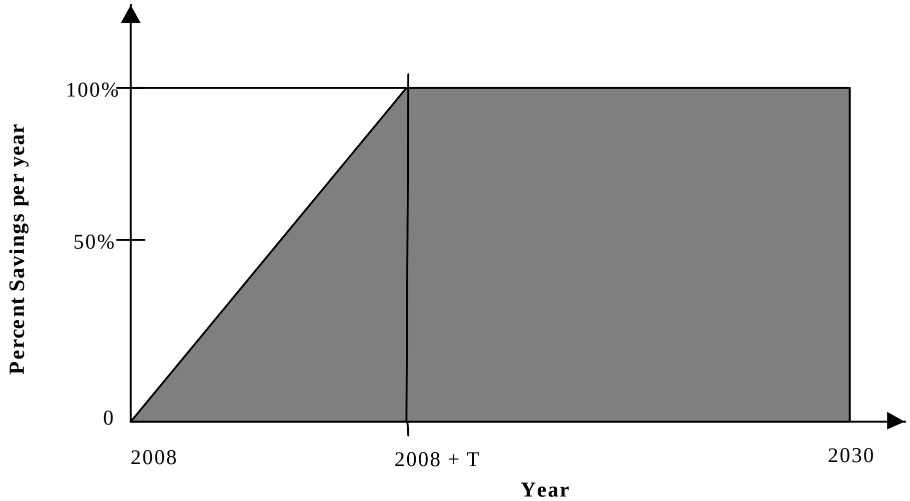

Figure A1-3: Energy Savings Potential Model for 2008-2030

All the energy savings estimates are calculated relative to the ‘typical new’ AEC estimates, i.e., assuming that the entire stock absent an efficiency standard and has the same efficiency level as the “typical new” product

A2 Energy Consumption and Saving Estimates for Televisions

A2.1 Background

Televisions are ubiquitous in the American home, with an average of about two TVs per household, i.e., about 212 million TVs total (see Table A2-1). All together, televisions consumed ~0.35 quads in 1998.

Table A2-1: Television Background Data

Description	Value	Comments/Source
Installed Base (millions, 1998)	212	Rosen and Meier, 1999a
Annual Shipments (millions, 2000)	31.4	Appliance Magazine (2001)
Product Lifetime (years)	9	Appliance Magazine (2000)
Total Energy Use (quads, 1998)	0.35	Average based on UEC and installed base.

A2.2 Product Technology Descriptions and Market Presence

Cathode ray tube (CRT) displays account for over 95% of the market by volume, with projection, liquid crystal display (LCD), and plasma display panels accounting for the remaining market share. Even though 20-inch and smaller TVs represent a majority of the TV stock, the 25- to 27-inch CRT TV best represent the "typical new" because they occupy the largest market share of TVs sold (about 40 % in 1998; Rosen and Meier, 1999a). Consequently, the "typical new" UEC exceeds that of the current stock UEC because the smaller TVs draw less power than the larger TVs.

On average, the "active" mode accounts for about 75% of TV unit energy consumption (based on television usage data from Rosen and Meier, 1999a), while the "standby" (i.e., the TV is off but can be switched to active with a remote control) accounts for the remaining 25%. Nonetheless, most efficiency levels focused upon reducing the standby power draw (see Table A2-2).

Table A2-2: Television Technology Levels and UEC Values

Description	Value	Comments
Stock UEC (kWh)	150	Average of several different TV sizes; from Rosen and Meier, 1999a
Typical New UEC (kWh)	166	25- and 27-inch CRT
Minimum Efficiency Standard	N/A	No minimum efficiency standard
Best Available Efficiency	125	0.1 W standby power draw, 25- to 27-inch CRT
Current ENERGY STAR® Efficiency	146	3W standby power
Proposed ENERGY STAR® Efficiency	131	1W standby power
LCD Television	138	Digital ready LCD, 27-inch display

Televisions do not have a minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program. Presently, the ENERGY STAR(R) threshold for TVs stands at 3W standby power draw; the program has proposed reducing this to 1W standby power[2], effective July, 2002. In terms of standby power, the "best available" TV consumes 0.1W in standby mode (the Panasonic CT-36HX41). Unfortunately, the active power draw of this TV model was not available. LCD TVs have come to market and the UEC values reflect only the gains from reductions in active power draw, i.e., in the UEC calculation, the standby power draw equaled the "typical new" standby power draw.

No data were obtained that indicated the economic impact of the standby power draw thresholds upon the price of the television, if any. LCD TV prices came from the web and suggest that, at present, LCD TVs cost roughly ten times more than CRT TVs[3].

The current market share of ENERGY STAR® TVs is not known; however, the program has a 40% market penetration (sales) target for Y2000 (Webber et al., 2000) and more than 900 TVs have qualified for ENERGY STAR(R) status[4]. In the fall of 2001, the ENERGY STAR® website listed more than 50 televisions that meet the 1W standby power criterion. Several major TV manufacturers (e.g., Sharp, Zenith, Samsung, Panasonic) make LCD TVs, in sizes ranging from at least 10-inches to 40-inches. Based on distributor unit sales, LCD TVs had a 2.7% market share in Y2000 (Appliance Magazine, 2001).

A2.3 Test Procedure Status

Televisions have a DOE test procedure, 10 CFR, Part 430, Subpart B, Appendix A-VIII, entitled "Uniform Test Method for Measuring the Energy Consumption of Television Sets", which references the American National Standard C.16.13-1961, Method of Testing Monochrome Television Broadcast Receivers. The DOE test procedure calls for measurement of both the "active" and "standby" power draw of the TV. To measure the active power draw, the TV is turned on for at least five minutes under controlled conditions. Subsequently, a wattmeter measures power under two conditions, a "standard white" pattern (p_w) and a "standard black" pattern (p_b). The active power, P_a depends upon both two measurements:

$$P_a = \frac{p_b}{2} + p_w .$$

For TVs without a "remote control defeat switch[5]" or a "vacation switch[6]", the standby power draw is measured two minutes after the unit has been turned off. On the other hand, for televisions with a "remote control defeat switch" or a "vacation switch", evaluation of the standby power draw requires two measurements. Specifically, p_{max} is

[2] For analog TVs; 3W for digital TVs and 4W for combination TV/VCRs.
[3] A web search found a Sharp LC-28HD1 28-inch TV priced at 768,000 yen, or roughly $7,000. The 20-inch TV, the Sharp LC-20C1, had a suggested retail price of 220,000 yen, or ~$2,000, in December, 2000.
[4] As of 30 January, 2002; see: http://yosemite1.epa.gov/estar/consumers.nsf/attachments/TVVCRPROD.pdf/$File/TVVCRPROD.pdf?OpenElement .
[5] As explained in 10 CFR, a "remote control defeat switch" denotes "a switch which permits the user to disconnect all standby power to a television set".
[6] As explained in 10 CFR, a "vacation switch" (or master on-off switch) denotes "an optional energy saving feature incorporated into the design of a television set that permits the user to disconnect the filament keep-warm circuit(s)."

measured with the television set power switch off and the vacation switch and remote control defeat switch in the highest energy consuming position, while p_{min} measured with the television set power switch off and the vacation switch and remote control defeat switch in the lowest energy consuming position. The overall standby power draw, P_s, equals:

$$P_s = \left[\frac{p_{max} - p_{min}}{2} \right] + p_{min} \quad .$$

The DOE estimates annual TV energy consumption as:

$$\mathrm{AEC_{TV}} = 2.2 p_a + 6.5 p_s \, ,$$

where the AEC takes the units of kW-h, and p_a and p_s have the units of Watts.

At present, the industry does not use the DOE test procedure and its relevance is unclear. In particular, it is possible that the 1961 American National Standard, which was created in 1961 for evaluating monochrome televisions, may be out-dated.

TVs also have an ENERGY STAR® test procedure to measure standby power draw; the procedure does not call for measurement of active power draw (currently under revision. Under controlled climatic and power quality conditions specified in the test procedure, the TV is plugged in and operated in standby mode until the unit stabilizes, i.e., about 90 minutes. The tester then measures the true standby power of the device, taking care to average the measurement over a sufficiently long time period to obtain an accurate value.

As noted earlier, the “active” mode accounts for more than 75% of the AEC of an average TV. Consequently, the ENERGY STAR® test procedure does not correlate well with TV AEC. Similarly, although detailed usage break-down by time of day could not be obtained, many televisions likely operate during peak demand periods, which would indicate a weak correlation between the test procedure and peak demand impact. In sum, a television test procedure that measures (and puts an emphasis) on active power draw would correlate much more closely to actual TV energy consumption.

A2.4 Energy Savings Estimates and Calculations

All energy savings calculations assume that the average TV over the 2008-2030 period will have a screen size of 25- to 27-inches, i.e., the same size as a “typical new” TV circa Y2000. Table A2-3 presents the energy savings potential for the different standby power levels and the LCD technology.

Table A2-3: Television Energy Savings Potentials

Technology/Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)
Typical Device (current stock)	150	NA	NA
'Typical New'	166	NA	NA
CRT, 3 W standby	146	0.010	0.80
CRT, 1 W stand by	131	0.080	1.4
CRT, 0.1 W standby	125	0.095	1.7
LCD (Digital TV capable)	138	0.064	1.1

All cases, excepting the 3W standby level, have energy savings potentials in excess of one quad, notably 1.4 and 1.7 quads for 1 Watt and 0.1 Watt maximum standby power levels, respectively and 1.1 for LCD-based televisions. Notably, the LCD case only includes savings based upon the active mode and does not include additional potential savings from reducing standby power draw. Appendix A-I contains calculation details.

Three factors create large uncertainties in the LCD UEC and savings estimates. First, due to the dearth of actual LCD TV power measurements, the LCD saving estimates relied upon comparing the two maximum power draw data points (for 20-inch and 28-inch TVs) to the average active power draw of similarly-sized CRT TVs. The average active power draw reduction, calculated as a percentage of an average TV in that size range, was then applied to a "typical new" screen size to estimate the LCD active power draw (see Table A-2). Second, only sources for LCD TV power draw were found and both are stated as maximum power draw values, suggesting that the device may draw less during operation. Overall, the LCD UEC was then evaluated based on the estimated active draw and the same standby draw data as of a 'typical new' TV in order to isolate the effect of the LCD screen. Thus, the LCD UEC only reflects decreases in active power draw; in reality, LCD TVs may also impact standby power draw. Third, the 28-inch LCD TVs for which active power draw information was found includes HDTV functionality (and higher resolution), which tends to increase active power draw relative to conventional CRT-based TVs.

A2.5 Regulatory Actions and Cumulative Burden

Televisions and related consumer electronic products have not been subject to regulation for energy efficiency. The extent to which regulation impact set-top boxes, including health and safety, was not determined.

A2.6 Issues Impacting Potential Energy Efficiency Standards

Several issues impact the establishment of an energy standard for televisions. First, Rosen and Meier (1999a) note that digital television will likely have a major impact on the future of the television. A federal mandate to convert all television programming to digital signals by 2007 will require either the purchase of new TVs with a built-in digital receiver box or deployment of digital receivers (set-top boxes) to enable digital signals to function with existing analog TVs. Either adaptation will strongly impact television energy consumption, as current digital TV receivers operate around the clock and consume ~16 Watts (Rosen and Meier, 1999a). Second, high-definition TVs (HDTV), which offer much higher resolution than conventional analog TVs, exist in the marketplace and are expected to capture a significant market share in the future. HDTV will likely impact the active (and possibly the standby) power draw of TVs. Third, the quantity of multi-function TVs (TV/VCR, TV/DVD, TV/Monitor, electronic programming guide functions, etc.) could increase in the future, impacting overall device UEC. Fourth, other display technologies besides CRTs and LCDs, namely plasma displays and organic light-emitting diodes, may become important for TVs in the future. Finally, as noted by Rosen and Meier (1999a), the market for televisions has a distinctly international flavor and TV energy efficiency regulations enacted in the European Union or, in particular, in Japan, will impact the power consumption of devices sold in the U.S.

A3 Energy Consumption and Saving Estimates for RACK/Component Audio and Compact Audio Devices

A3.1 Background

Audio systems read and analyze a media source (e.g., a radio signal, CD, or magnetic cassette tape), then send an electric output signal through an amplifier and on to the speakers where the electric signal is converted to sound. Compact audio systems and rack/component audio systems are stationary residential systems that owners typically place on a shelf or in an entertainment center.

Compact audio systems are sold as a single unit that includes the amplifier and any components (CD player, cassette-tape player, radio tuner, etc.) all packaged in a single main body, and come with two speakers that are separate from the main body. Portable stereos ("boom-boxes") are not included in the "compact audio" class even though they sometimes have removable speakers.

Each component of a "component audio system" is individually packaged, has its own electric power source, and is usually sold separately. Rack audio systems are a small subset (less than 10% of the market) of component audio system where the components are sold together by a single manufacturer (though each component is still physically separate). Every rack/component audio system comprises one or more speakers, a receiver (the "brains" of the system that the speakers and other components plug into), and at least one component (radio tuner, CD player, cassette tape player, etc.).

In 1997, approximately 47-million compact audio systems consumed about 0.057 quads of energy, while approximately 74-million rack/component audio systems consumed about 0.11 quads of energy (see Table A3-1).

Table A3-1: Audio Background Data

Audio Type	Data type	Value	Source
Rack/Component Audio	Installed Base, millions (1997)	74	Rosen and Meier (1999b)
	Equipment Lifetime, years (1997)	7	
	AEC, quads	0.105	
Compact Audio	Installed Base, millions (1997)	47	
	Equipment Lifetime, years (1997)	7	
	AEC, quads	0.057	

A3.2 Product Technology Descriptions and Market Presence

The different technology levels examined for each product are classified by the standby power draw (see Table A3-2 and Table A3-3).

Table A3-2: Rack/Component Audio Technology Levels and UEC Values

Technology/Standard Level	UEC (kWh/yr)	Comments/Source
Stock (3W Standby)	129	Usage and play power from Rosen and Meier (1999b).
'Typical New' (3W Standby)	129	Usage and play power from Rosen and Meier (1999b); assumed same as stock UEC.
Minimum Efficiency Level	N/A	No minimum efficiency standard.
Best Available (0.26W Standby)	111	Usage and play power from Rosen and Meier (1999b); standby power from www.energystar.gov .
Current ENERGY STAR® (2W Standby)	123	Usage and play power from Rosen and Meier (1999b).
Y2003 ENERGY STAR® (1 W Standby)	116	Usage and play power from Rosen and Meier (1999b).

Table A3-3: Compact Audio Technology Levels and UEC Values

Technology/Standard Level	UEC (kWh/yr)	Comments/Source
Stock (10W Standby)	109	Usage and play power from Rosen and Meier (1999b).
'Typical New' (10W Standby)	109	Usage and play power from Rosen and Meier (1999b); assumed same as stock UEC.
Minimum Efficiency Level	N/A	No minimum efficiency standard.
Best Available (0.25W Standby)	46	Usage and play power from Rosen and Meier (1999b); standby power from www.energystar.gov .
Current ENERGY STAR® (2W Standby)	58	Usage and play power from Rosen and Meier (1999b).
Y2003 ENERGY STAR® (1 W Standby)	51	Usage and play power from Rosen and Meier (1999b).

Audio systems do not have a minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program, which currently calls for a maximum standby power draw of 2-watts, a threshold that will decrease to 1-watt at the beginning of Y2003. For Y2000, the ENERGY STAR® program had a target of 54% market share (of sales) for audio products and, as of October, 2001, the ENERGY STAR® website listed about 50 compact audio models and more than 25 rack/component models that draw 1-Watt or less in standby mode.

A3.3 Test Procedure Status

Audio equipment does not have a DOE test procedure, but does have an ENERGY STAR® test procedure to measure standby power draw. Under controlled climatic and power quality conditions specified in the test procedure, the audio equipment is plugged in and operated in standby mode until the unit stabilizes (about 90 minutes). The tester then measures the power consumed by the device, taking care to average the measurement over a sufficiently long time period to obtain an accurate value.

With compact audio systems, the lack of "play" mode power measurement does not make a significant difference in evaluating energy consumption (UEC), as compact audio systems consume over 50% of their total energy each year in standby mode (with the remaining 50% split between "play" and "idle" modes). If future standby power levels do decrease, the ENERGY STAR® test procedure correlation with device UEC would weaken, as the "play" and "idle" modes would account for a greater portion of device UEC.

In contrast, rack/component audio systems consume only about 10% of their total energy each year in standby mode because, on average, they only draw 3-watts in standby mode (the current ENERGY STAR® level is 2-watts). Therefore, "play" and "idle" mode power draws are important to device UEC for rack/component audio systems and the lack of a "play" and "idle" mode testing standard creates the opportunity for inconsistencies when evaluating energy consumption.

Any potential testing standard for "play" and "idle" modes of audio equipment, however, is complicated by the relationship of power consumption to sound volume and sound quality. An audio system uses exponentially more electric power as the sound output (decibel level) increases, and practice dictates that higher quality sound (less distortion, etc.) is achieved by using a more powerful amplifier (specified as watts per channel – the power output for each speaker). Similar to lighting standards, audio equipment may warrant consideration of an efficacy-type standard that dictates a minimum sound energy output (watts) for a given electric power input.

In terms of peak electricity demand impact, many users likely operate their audio systems in "play" mode during the mid- to late-afternoon peak electricity demand period. Because of the relatively moderate difference between play and standby power draw[7], the current ENERGY STAR® test procedure also should correlate well with device peak load impact for compact audio systems. For rack/component systems (and for compact systems if future standby power levels do decrease), the ENERGY STAR® test procedure correlation with peak load impact is weaker, as many users likely operate their audio systems in "play" mode during the mid- to late-afternoon peak electricity demand period.

A3.4 Energy Savings Estimates and Calculations

Table A3-4 and Table A3-5 present the energy savings potentials for the three standby power thresholds analyzed (see Table AII-1 and Table AII-2 in Appendix A-II for calculation details). Without more specific data available, the "stock" UEC values are assumed to be the same as "typical new" UEC values.

[7] According to Rosen and Meier (1999b), the average compact audio device draws 22W in play, 20W in idle, and 9.8W in standby mode. The ~2-to-1 ratio of play-to-standby power draw contrasts strongly to the ~18:1 ratio (53W to 3W) for rack/component audio.

Table A3-4: Rack/Component Audio Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (kWh/yr)	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Stock (3W Standby)	129	NA	NA
'Typical New' (3W Standby)	129	NA	NA
Best Available (0.26W Standby)	111	0.015	0.27
Current ENERGY STAR® (2W Standby)	123	0.011	0.20
Y2003 ENERGY STAR® (1 W Standby)	116	0.005	0.10

Table A3-5: Compact Audio Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (kW-h)	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Stock (10W Standby)	109	NA	NA
'Typical New' (10W Standby)	109	NA	NA
Best Available (0.25W Standby)	47	0.033	0.60
Current ENERGY STAR® (2W Standby)	58	0.027	0.49
Y2003 ENERGY STAR® (1 W Standby)	52	0.030	0.55

Audio systems typically have three operating modes: "play" (when the unit is on and playing music/sound); "idle" mode (when the unit is on, but not playing); and "standby" mode (when the unit is turned off but still plugged in). Rosen and Meier (1999b) estimate that users operate compact audio systems and rack/component audio systems in a similar manner, with about 65%-70% of the time spent in "standby" mode, with the remaining time split evenly between "play" and "idle". However, rack/component audio systems use significantly less power (3 Watts) in "standby" mode than compact audio systems (10 Watts), so the UEC of compact audio systems exhibits a greater sensitivity to reductions in standby power draw.

The current ENERGY STAR® maximum standby power draw threshold decreases compact audio system UEC by almost 50%, but only reduces rack/component audio system UEC by about 10%. Thus, even though the two audio device types have similar UEC values and usage patterns, standby power draw standards have a much greater impact on compact audio systems UEC than the rack/component audio systems because the average compact audio system has a much higher standby power draw. As a result, the annual energy savings potential of maximum standby power draw levels for compact audio systems is about twice that of rack/component audio systems - despite the fact that rack/component audio consumes about twice as much energy as compact audio systems (0.06 quads versus 0.10 quads).

Three assumptions embodied in the audio system energy UEC calculations have significant uncertainties that affect the AEC and energy savings potential values. First, the time spent in "play" and "idle" modes depends heavily on whether the audio system is used to enhance television sound, which significantly increases the time spent in "play" mode. Rosen and Meier (1999b) used survey to estimate the number of audio systems connected to TVs, but the percentage could grow in the future as more households elect to install “home theatres”. Second, the power draw in “play” mode for both audio systems comes from measurements made using a non-standard test method (no standard is available). Rosen and Meier (1999b) measured audio device play power draw at volume level that seemed most “pleasant” (corresponding to about 50% of maximum volume), but it is not clear how well this represents average listening behavior. Crucially, those authors found that component audio system power draw begins to increase dramatically above the volume threshold used for measurements, indicating the potential for substantially higher “play” mode power draw levels[8]. Third, the AEC estimates embody assumptions about how end-users actually install and operate the different components of rack/component audio systems, which each have distinct energy consumption levels. In practice, the variations between installations and users are likely great, impacting the usage and standby power draw assumptions, as well as the AEC and energy savings potential values.

A3.5 Regulatory Actions and Cumulative Burden

Audio systems and related consumer electronics products have not been subject to regulation for energy efficiency. The extent to which regulation impacts compact audio systems and rack/component audio systems, including health and safety, was not determined.

A3.6 Issues Impacting Potential Energy Efficiency Standards

For rack/component audio systems establishing device UEC standards is difficult because there are large variations within the product category, especially when components from different manufacturers are combined in one system. If a trend develops towards rack audio systems (currently less than 10% of the market according to Rosen and Meier - 1999b), an efficiency standard would be easier to adopt because the standard could address whole-system energy consumption (rather than a component).

[8] For example, operation at the sound level identified as “painful” would approximately double the “play” mode power draw of a component audio system (Rosen and Meier, 1999b).

A4 Energy Consumption and Saving Estimates for Set-Top Boxes

A4.1 Background

Set-top boxes, so named because many units reside on top of the TV set, are consumer electronics products that provide output to a television set. Cable TV boxes, both analog and digital, receive and interpret cable TV signals and act as tuners for analog and digital TV programming, respectively. Wireless set-top boxes serve dish antennas to receive and interpret wireless TV programming. All together, the approximately 59 million set-top boxes in the U.S. consume about 0.075 quads of energy per year (see Table A4-1), with digital and analog cable TV boxes accounting for almost 80% of the set-top box installed base and more than 70% of total set-top box annual energy consumption. Analog boxes made up more than 90% of the cable TV stock in 1999.

Table A4-1: Set-Top Box Background Data

Type	Data type	Value	Source
Wireless	Installed Base, millions (1999)	13	Rosen et al. (2001); annual shipments based on installed base divided by lifetime.
	Annual Shipments, millions (1999)	1.3	
	Equipment Lifetime, years (1999)	10	
	AEC, quads	0.020	
Cable, Analog	Installed Base, millions (1999)	45	
	Annual Shipments, millions (1999)	4.5	
	Equipment Lifetime, years (1999)	10	
	AEC, quads	0.047	
Cable, Digital	Installed base, millions (1999)	3.8	
	Annual Shipments, millions (1999)	0.4	
	Equipment Lifetime, years (1999)	10	
	AEC, quads	0.008	

A4.2 Product Technology Descriptions and Market Presence

Cable set-top boxes either interpret analog or digital signals. In 1999, analog models accounted for more than 90% of the cable set-top box installed base. However, the federal government has mandated that all television broadcasting will transition to digital signals by 2007. To interpret these digital signals, TVs will require a digital receiver, either installed directly in a digital television set or in the form of a set-top box for existing analog television. Consequently, digital set-top boxes are expected to displace all analog cable set-top boxes before 2008 and subsequent discussion and analysis of cable set-top boxes assumes that the entire Y1999 population of cable set-top boxes will become digital devices in the Y2008-2030 period.

Rosen et al. (2001) estimate that the "standby" mode, i.e., the box appears off but still draws power to download information, accounts for about 78% of cable and wireless set-top box unit energy consumption (UEC). As a result, the different technology levels examined focused upon the standby power draw levels (see

Table A4- 2).

Table A4- 2: Set-Top Box Technology Levels and UEC Values

Technology Level	Value		Comments/Source
	Digital	Wireless	
Stock UEC (kWh/yr)	197	140	Usage and Active power from Rosen et al., 2001
Typical New UEC (kWh) or Power	197	140	Usage and Active power from Rosen et al., 2001; assumed same as stock UEC
Minimum Efficiency Standard	N/A	N/A	No minimum efficiency standard.
Best Available UEC (kWh), 14.1/8.8W Standby Power	140	78	www.EnergyStar.gov; Usage, Active power, and wireless standby power from Rosen et al., 2001
ENERGY STAR® Level, 15W Standby Power	147	135	www.EnergyStar.gov; Usage and Active power from Rosen et al., 2001
UEC, 7W Standby Power (kWh)	92	80	Proposed level for 2004 ENERGY STAR® (www.energystar.gov); Usage and Active power from Rosen et al., 2001
UEC, 1W Standby Power (kWh)	51	39	Usage and Active power from Rosen et al., 2001

Set-top boxes do not have a minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program. Presently, the ENERGY STAR® threshold for digital cable and wireless set-top boxes stands at 15W standby power draw; the program has proposed amending this value to 7W for Y2004. The "best available" digital cable device certified by the ENERGY STAR® program (as of October, 2001) draws 14.1W in standby mode and, for Table 4-2, was assumed to have the same active power, 23W, as the average value reported by Rosen et al. (2001) for digital cable set-top boxes. The "best available" wireless set-top box reflects the active (9.1W) and standby (8.8W) power draws of the Sony DRD503RBC.1, the device with the lowest UEC of the thirty wireless set-top boxes measured by Rosen et al. (2001). No data were obtained for the economic impact of standards set at any of these levels.

To date, most of the wireless set-top boxes do not achieve any of the technology levels outlined above. As of October, 2001, the ENERGY STAR® program had certified two set-top box models, both digital cable boxes made by Pace Micro Technology that became available in June, 2001. No wireless or analog cable set-top boxes have qualified for ENERGY STAR® status. Similarly, no set-top boxes have approached the 1 Watt maximum standby power level case examined in the energy savings analysis.

A4.3 Test Procedure Status

Set-top boxes lack a DOE test procedure, but do have an ENERGY STAR® test procedure to measure only standby power draw. Under controlled climatic and power quality conditions specified in the test procedure, the set-top box is plugged in and operated in standby mode until the unit stabilizes, i.e., about 90 minutes. The tester then measures the true standby power of the device, taking care to average the measurement over a sufficiently long time period to obtain an accurate value.

With most set-top boxes in use today, the lack of active mode testing does not make a significant difference in evaluating set-top box energy consumption, as analog and digital boxes consume more than three times more energy annually in standby mode than in active mode. Furthermore, current active mode power draws do not differ much relative to standby power draw; specifically, measurements by Rosen et al. (2001) find that, on average, analog boxes require an average of 1.4W (13%) more to operate in the active mode, digital boxes 0.7W (3%). In essence, current standby power draw serves as a reasonable proxy for active mode power draw. If future standby power levels do decrease, the ENERGY STAR® test procedure correlation with device UEC would weaken, as the active mode would account for a greater portion of device UEC.

Because of the small differences between active and standby power draw, the current ENERGY STAR® test procedure also should correlate well with device peak load impact. If future standby power levels do decrease, the ENERGY STAR® test procedure correlation with peak load impact would likely weaken, as many TV users probably operate their set-top boxes in active mode during the mid- to late-afternoon peak electricity demand period.

A4.4 Energy Savings Estimates and Calculations

The energy savings calculations assume that digital cable set-top boxes will replace all analog cable set-top boxes by 2008, due both to current growth in the quantity of digital units and the mandated conversion from analog to digital TV signals by 2007 (Rosen et al., 2001. Table A4-3 and

Table A4-4 present the energy consumption and saving estimates for the wireless and digital set top boxes, based upon 15W (current ENERGY STAR®), 7W (future ENERGY STAR®) and 1W standby power levels. As noted in section A4.2, the analyses did not consider standards impacting active power consumption levels because standby mode currently accounts for more than 75% of annual energy consumption.

Table A4-3:Wireless Set-top Box Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Typical Device (current stock)	143	NA	NA
‘Typical New’	143	NA	NA
15 W Standby Power	135	0.001	0.02
7 W Standby Power	80	0.009	0.15
1 W Standby Power	39	0.014	0.25

Table A4-4: Digital Cable Set-top Boxes Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Typical Device (current stock)	197	NA	NA
'Typical New'	197	NA	NA
15 W Standby Power	147	0.027	0.45
7 W Standby Power	92	0.056	0.95
1 W Standby Power	51	0.078	1.3

The usage and power draw assumptions for the UEC calculations come from Rosen et al. (2001) (see Table AIII-1 and Table AIII-2, Appendix A-III, for calculation details). The total energy consumption of set-top boxes equals the sum of the wireless and digital set-top boxes (see Table A4-5).

Table A4-5: Total Set-top Box Energy Savings Potential Estimates

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)
15 W Standby Power	0.028	0.47
7 W Standby Power	0.067	1.1
1 W Standby Power	0.092	1.55

At least two major uncertainties exist around the energy savings calculations. Rosen et al. (2001) develop an estimate of active mod usage only taking into account the amount of time spent with the television operating. However, they note that many people likely leave their set-top box on when the television is turned off, suggesting that the actual number of "active" hours may be higher. Because current digital cable boxes and wireless boxes draw similar power levels in the active and standby modes, an increase in the number of active hours would not result in a large change in "typical new" device AEC. On the other hand, fewer standby hours per year would decrease the magnitude of energy savings realized by lower standby power levels.

The current energy savings analysis also assumes that the installed base of cable TV and wireless set-top boxes will remain constant over a thirty-year period. It is very probably that the set-top box installed base, particularly for cable TV devices, will increase dramatically by 2008 due to the federally-mandated transition to digital TV signals by 2007. All of the existing analog TV sets –as well as most of the digital TV sets sold – will require a set-top box to receive the digital signals (Rosen et al., 2001). Assuming that each household has only one set-top box (currently, each household has just over two TVs), the installed base of set-top boxes will almost certainly exceed 100 million units by 2010. Both the annual energy consumption and all energy savings potentials would increase dramatically.

A4.5 Regulatory Actions and Cumulative Burden

Set-top boxes and related consumer electronic products have not been subject to regulation for energy efficiency. The extent to which regulation impact set-top boxes, including health and safety, was not determined.

A4.6 Issues Impacting Potential Energy Efficiency Standards

Several issues impact the establishment of an energy standard for set-top boxes. First, although presently consisting of cable and wireless boxes, the set-top box category may grow in the future to include a wide range of products, including digital TV, personal VCF, video game consoles, Internet access devices, videophone, and multifunction devices. Second, the functionality of future set-top boxes may grow to encompass several different tasks, e.g., receiving and recording TV content, computer network access, telephony, etc. All product evolutions will impact the feasibility of different standards levels. Third, cable TV companies typically purchase set-top boxes and rent or sell their selected model to subscribers, with the subscribers paying for the energy consumed by the device. Because the party selecting the device does not pay for its energy consumption, the cable TV company has little incentive to purchase a set-top box that consumes energy.

A5 Energy Consumption and Saving Estimates for Ceiling Fans

A5.1 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 158 million ceiling fans is weighted toward the Southern portion of the country. The vast majority (about 95%) of ceiling fan installations include associated lighting, and the energy consumption and savings for the fan motor and lighting are analyzed separately (Table A5-1).

Table A5-1: Ceiling Fan Background Data

Type	Data type	Value	Source
Ceiling Fans Motors	Installed Base, millions (1997)	159[9]	Calwell and Horowitz (2001); Appliance (2000)
	Equipment Lifetime, years (1997)	13	
	AEC, quads	0.14	
Ceiling fans (lighting only)	Installed Base, millions (1997)	151[10]	Calwell and Horowitz (2001); Appliance (2000)
	Equipment Lifetime, years (1997)	13	
	AEC, quads	0.36	

Overall, ceiling fans consume about one-half a quad of energy per year, with associated lighting accounting for about 70% of the total.

A5.2 Product Technology Description and Market Presence

All ceiling fans use blades driven by a motor to move air, but the efficiency of different blade-motor combinations varies substantially. For example, data collected in support of the ceiling fan ENERGY STAR® program showed that fan air-moving efficiency (quantified using a cfm/kW metric) varied by more than a factor of two between models. Table 5-2 presents the lighting UEC values for the different lighting options, while Table 5-3 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 A5-2: Ceiling Fan Lighting UEC

Description	Value	Comments
Stock UEC (kWh)	217	Three 60W incandescent bulbs
Typical New UEC (kWh)	217	Assumed same as stock
Minimum Efficiency Standard	N/A	No minimum efficiency standard
Best Available Efficiency	72	Approximate ENERGY STAR® pin-based lighting level – one 60W pin-based fluorescent lamp

[9] Calwell and Horowitz (2001) estimate an average of 1.5 ceiling fans per household, multiplied by the U.S. Census Bureau (2001) Y2000 estimate of ~106 million occupied households in Y2000.

[10] The 150 million ceiling fan lighting units reflects an estimate by Calwell and Horowitz (2001) that 95% of all ceiling fans have associated lighting.

Table A5-3: Ceiling Fan Motor UEC

Description	Value	Comments
Stock UEC (kWh)	78	
Typical New UEC (kWh)	78	Assumed same as stock
Minimum Efficiency Standard	N/A	No minimum efficiency standard
Best Available Efficiency	40	Aerodynamic fan blade
Current ENERGY STAR® Efficiency	61	3W standby power
Higher efficiency motor	40	Permanent split capacitor or permanent magnet motor
High-efficiency motor *and* Aerodynamic Fan Blade	21	Permanent split capacitor or permanent magnet motor

Ceiling fans do not have minimum efficiency standard 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 consume about 22% less air moving efficiency than typical motors. As of January, 2002, more than 100 fan models (without lighting) have met the ENERGY STAR® aerodynamic efficiency threshold[11]. The ENERGY STAR® program also requires that the ceiling fan either incorporate ENERGY STAR® lighting fixtures (pin-based approach) or the inclusion of ENERGY STAR®-qualified screw-based bulbs (screw-based approach). The 60W level reflects the approximate wattage of a pin-based fluorescent lamp (Calwell and Horowitz, 2001). In practice, the actual wattage level for compact fluorescent-based ceiling fan lighting would likely be less, e.g., all of the twelve (12) models that meet the lighting and aerodynamic fan efficiency requirements use screw-based CFLs, with a total power draw of 14 to 23 Watts. 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"[12] 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[13], 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, upon motor feasibility has yet to be studied and it is not known whether or not 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

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[11] Information about ceiling fans meeting the ENERGY STAR® requirements is available at: http://yosemite1.epa.gov/estar/consumers.nsf/attachments/CeilFanProdList.pdf/$File/CeilFanProdList.pdf?OpenElement . The ENERGY STAR® program also includes requirements for "readily accessible" controls.

[12] Based on the / Aeroenvironments CF-1 design; more information available at: http://www.fsec.ucf.edu/~bdac/PROTOTYPE/CFAN.htm .

[13] Also known as an electronically commutated permanent magnet (ECPM) motor.

high-efficiency motor options. To date, no commercially-available fans offer this technology combination.

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.

A5.3 Test Procedure Status

Ceiling fans lack a DOE test procedure for a lighting or air moving efficiency, but do have an ENERGY STAR® test procedure for air moving efficiency, based on the industry-developed Hunter Solid State Test Method, to measure active power draw at High, Medium and Low speed settings. In each case, the ENERGY STAR® program specifies a minimum amount of air moved per Watt of power draw, i.e., cfm/Watt. For the ENERGY STAR(R) test procedure, the fan is hung in a temperature and humidity controlled room above a tunnel or large diameter tube that is slightly larger than the outer diameter of the fan blades. Air directed from fan during operation passes through the tunnel, with airflow measurements taken at various points simultaneously and instantaneously. The average of the recorded velocity measurements forms the basis for airflow calculations (cfm), which is divided by the fan motor power consumption measurements to generate the air moving efficiency metric. The ENERGY STAR® test procedure does not measure lighting energy consumption per se; instead, it prescribes the design of ENERGY STAR® lighting fixtures (pin-based approach) or the inclusion of ENERGY STAR®-qualified screw-based bulbs (screw-based approach).

There are no known plans to develop a new test procedure for ceiling fans.

Overall, the ENERGY STAR® test procedure 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.   As noted, the ENERGY STAR® test procedure prescribes a minimum lighting efficacy but does not measure lighting power draw, so it cannot correlate with energy consumption or savings.

A5.4 Energy Savings Estimates and Calculations

Currently-available aerodynamic fan blade technology has an energy savings potential of 1.1 quads, while fans with aerodynamic fan blades *and* improved motor efficiency can realize 1.6 quads of savings (see Table A5-4). The ENERGY STAR® air moving efficacy level energy savings potential equals 0.47 quads.

Table A5-4: Ceiling Fan UEC and Energy Savings Potential (Fan Energy Only)

Technology/ Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)	Source
Typical Device (current stock)[1]	78	NA	NA	Calwell and Horowitz (2001)
'Typical New'	78	NA	NA	Assumed same as Stock
Aerodynamic Blade *and* More Efficient Motor	21	0.10	1.6	Parker et al. (1999); ADL (1999)
ENERGY STAR(R), Fan Efficacy Only[2]	61	0.03	0.47	www.energystar.gov [2]
Aerodynamic blade design[3]	40	0.07	1.1	Parker et al. (1999)

Due to a lack of data differentiating energy consumption of fans by vintage, both the fan motor (and also lighting energy consumption analyses) assumed the same energy consumption levels for the installed base and typical new equipment. In addition, usage information could not be found for the relative time of operation broken down by speed. Instead, the UEC and energy savings potentials use a model that assumes that the technology efficacy gain equals the average of the high and low speed efficacy gains. The motor efficiency gains estimated above represent a rather rough estimate, with further study needed to understand how effectively different motor technologies can be applied to ceiling fans. Appendix A-IV presents the data used to generate the above estimates and explains the calculations in greater detail.

ENERGY STAR® lighting for ceiling fans could save 3.7 quads of energy over the 2008-2030 period (see Table A5-5).

Table A5-5: Ceiling Fan UEC and Energy Saving Potential (Lighting Only)

Technology/ Standard Level	UEC (kW-h)	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030) (quads)	Source
Current stock	217	NA	NA	Calwell et al. (2001)
Typical new	217	NA	NA	Assumed same as stock
ENERGY STAR(R) Lighting	72	0.24	3.7	www.energystar.gov; Calwell and Horowitz (2001)

The ceiling fan lighting AEC estimate has appreciable uncertainty, as the lighting usage does not come from field measurements of actual usage; instead, it reflects an estimate of usage, assuming that ceiling fan lighting operates just over 3 hours per day[14] (about 25% less than typical socket lighting; [Horowitz, 2002]). 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 150 million units in 2000. It is

[1] Emerson CF-705
[2] http://yosemite1.epa.gov/ESTAR/consumers.nsf/content/ceilingfans.htm .
[3] FSEC/Aerovironment CF-1.
[14] Horowitz (2002) indicated that a study has begun to meter ceiling fan and ceiling fan lighting usage in California.

unclear if the trend will continue in the future; continued strong growth will increase both the energy consumption and savings potential over the 2008-2030 period.

A5.5 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.

A5.6 Issues Impacting Potential Energy Efficiency Standards

Ceiling fans to 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 than 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.

A6 Energy Consumption and Saving Estimates for Gas Unit Heaters and Gas Duct Furnaces

A6.1 Background

Gas unit heaters and gas duct furnaces both burn natural gas to heat spaces in buildings. Unit heaters typically hang from the ceiling and use a fan to blow air over a heat exchanger (which contains the combustion gases), transferring heat to the air and distributing the heated air in the room/space. Duct furnaces are installed in a ventilation duct system to heat the air before it is delivered to the space (it does not have its own fan or blower). The approximately 3.25 million gas unit heaters installed in the United States consume about 0.54 quads of energy each year, while approximately 0.24 million installed gas duct furnaces consume 0.10 quads (Table A6-1).

Table A6-1: Gas unit Heater and Duct Furnace Data

Type	Data type	Value	Source
Gas unit heaters	Installed Base, millions (1997)	3.25	GRI (1997) and calculation
	Equipment Lifetime, years (1997)	21.5[1]	GRI (1997)
	AEC, quads	0.54	ADL (2001b) and calculation
Gas duct furnaces	Installed Base, millions (1997)	0.24	GRI (1997) and calculation
	Equipment Lifetime, years (1997)	16.5[2]	GRI (1997)
	AEC, quads	0.10	Calculation

The installed base and AEC data were derived information from and GRI (1997) and ADL (2001b) from (see Appendix A-V for calculation details).

A6.2 Product Technology Descriptions and Market Presence

Gas unit heaters are self-contained units that typically hang from the ceiling of a space, but can also be installed on floors or walls. A natural gas supply line feeds fuel to the 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 outdoor air. At the same time, a fan 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 vent pipe to suck air through the combustion chamber to improve combustion efficiency. Pulse combustion units modulate the fuel supply in pulses to enhance heat transfer in the heat exchanger and improve efficiency. Condensing units are designed to extract more heat from the combustion gas to the point where the water vapor condenses on the walls of the heat exchanger (greatly improving efficiency by extracting latent heat in addition to sensible heat from the combustion gas). Table A6-2 displays the steady-state efficiency and Annual Fuel Utilization Efficiency (AFUE) values for each gas unit heater technology (AFUE considers cycling and other seasonal effects on efficiency while steady-state efficiency only considers full-load operational efficiency, i.e. “combustion efficiency”).

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

Table A6-2: Gas Unit Heater Efficiency

Technology/Standard Level	Steady-State Efficiency	AFUE Efficiency	Comments/Source
Stock Efficiency	78%	70%	ADL (2001b) and GRI (1995)
Typical New Efficiency	78%	72%	ADL (2001b)
Minimum Efficiency ASHRAE 90.1-1999 (prior to 10/29/2001)	78%	--	Standard only specifies steady-state efficiency.
Minimum Efficiency ASHRAE 90.1-1999 (as of 10/29/2001)	80%	--	Standard only specifies steady-state efficiency.
Power Vented	82%	80%	GRI (1997) and ASHRAE (1996)
Pulse Combustion	90%	82%	GRI (1997) and ASHRAE (1996)
Best Available (condensing)	93%	93%	GRI (1997)

In 1995 the majority of gas unit heaters sold and installed (~85%) were simple gravity vented units without any “frills.” Power-vented units claimed the rest of the market at ~15%. Condensing units were recently introduced in 1999 and are available in the U.S. but primarily marketed in Europe; a brief search identified one condensing model, the Reznor SHE condensing unit heaters. Unfortunately, the source for technology market shares (GRI, 1997) is several years old; more recently information was not found.

Gas duct furnaces are component units 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 natural gas supply line feeds fuel to the 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 outdoor air. At the same time, the ventilation system blows air (from a central fan or blower) 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 vent pipe to suck air through the combustion chamber to improve combustion efficiency and reduce “flue losses” (by blocking the flow of warm air out the vent pipe when the unit is off). Pulse combustion units modulate the fuel supply in pulses to create better heat transfer in the heat exchanger and improve efficiency. Condensing units are designed to extract more heat from the combustion gas to the point where the water vapor condenses on the walls of the heat exchanger (greatly improving efficiency by extracting latent heat in addition to sensible heat from the combustion gas). Table A6-3 gives thermal efficiency and UEC values for each gas duct furnace technology.

Table A6-3: Gas Duct Furnace Efficiency

Technology/Standard Level	Steady-state Efficiency	AFUE Efficiency	Comments/Source
Stock Efficiency	80%	70%	ADL (2001b) and GRI (1995)
Typical New Efficiency	80%	72%	ADL (2001b)
Minimum Efficiency ASHRAE 90.1-1999 (prior to 10/29/2001)	78%	--	Standard only specifies steady-state efficiency.
Minimum Efficiency ASHRAE 90.1-1999 (as of 10/29/2001)	80%	--	Standard only specifies steady-state efficiency.
Power Vented	82%	80%	GRI (1997) and ASHRAE (1996)
Pulse Combustion	90%	82%	GRI (1997) and ASHRAE (1996)
Best Available (condensing)	93%	93%	ASHRAE (1996)

While the exact numbers are not known, in 1995 the majority of gas duct furnaces sold and installed were simple gravity vented units without any "frills." Power-vented units, where a smaller fan drives the exhaust gas out the vent to improve combustion efficiency claimed the rest of the market[15]. No condensing duct furnaces were found in the U.S. market, but several manufacturers market conventional condensing furnaces, indicating that condensing duct furnaces are technologically feasible.

Minimum efficiencies for gas unit heaters and gas duct furnaces are prescribed by ASHRAE Standard 90.1 (1999) as 78% (prior to October 29, 2001) and 80% (as of October 29, 2001), and have been adopted by many building codes throughout the U.S. The efficiency standard does not force a new technology on unit heaters or duct furnaces (such as power venting, pulse combustion, or condensing), but simply sets a minimum efficiency that all "typical" units must meet. If the minimum efficiency level were increased beyond 80%, manufacturers would likely need to introduce power venting or pulse combustion to their standard products. The "best available" units are condensing units that extract the latent heat in the water vapor from the combustion gas and require added design complexity and cost to handle the condensed gases (e.g., stainless steel construction to resist corrosion by the condensed combustion gases). Power vented units cost approximately 30% more than standard (gravity vented) units, while pulse combustion and condensing units cost nearly twice as much as standard units (GRI 1997 and product catalogs).

A6.3 Test Procedure Status

Gas unit heaters and duct furnaces do not have a DOE test procedure, but do have an ANSI test procedure. Specifically, ASHRAE Standard 90.1 establishes minimum steady-state efficiency levels for gas unit heaters and duct furnaces based on ANSI test procedure ANSI Standard Z83.8-1996 (also CGA Standard 2.6-M96). The ANSI test standard dictates 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 gasses and water vapor ("flue losses"). The "appliance thermal efficiency" calculation equals 100% minus the "percent flue

[15] Two major manufacturers, **Reznor and Sterling, each make a power vented duct furnace product.**

loss" ("percent flue loss" is determined graphically as a function of flue gas temperature, room temperature, and percent of CO_2 in the flue gas). However, the testing standard and efficiency values do not include electricity consumed by the units (e.g., by the air fan in gas unit heaters).

Steady-state efficiency is not the most accurate way to calculate annual energy consumption because it does not account for thermal losses due to equipment on-off cycling. Instead, an annual efficiency value such as Annual Fuel Utilization Efficiency (AFUE) better describes how much fuel the equipment consumes by taking into account cycling losses (attributed to warm-up and cool-down) and pilot light losses (gas consumed to keep the pilot light on when the unit is not operating). Existing test standards, such as ANSI/ASHRAE 103 (for residential furnaces and boilers), describe the test procedure for AFUE, and could be easily adapted to cover gas unit heaters and duct furnaces.

Peak electric loads will not be impacted by increased efficiency standards for gas heating equipment. While unit heaters and duct furnaces do consume some electricity (for fans and controls, etc.) they do not normally operate during warm summer months when peak electric loads normally occur.

A6.4 Energy Savings Estimates and Calculations

Table A6-4 and Table A6-5 present the gas unit heaters and duct furnaces energy consumption data and the potential energy saving estimates for the different technologies considered. All energy savings potential calculations used AFUE values to best reflect actual energy consumption usage and efficiency. The current stock UEC came from the AEC and the installed base data (refer to Table F-2 and Table F-3 for AEC calculation details, for the unit heater and duct furnace respectively).

Table A6-4: Gas Unit Heaters UEC and Potential Saving Estimates

Technology/Standard Level	UEC (MM- Btu)	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030, quads)
Typical Device (current stock)	167	NA	NA
'Typical New'	162	NA	NA
Condensing	125	0.12	1.3
Pulse combustion	142	0.064	0.72
Power vent	146	0.053	0.59

Table A6-5: Gas Duct Furnaces UEC and Potential Saving Estimates

Technology/Standard Level	UEC (MM-Btu)	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Typical Device (current stock)	419	NA	NA
'Typical New'	408	NA	NA
Condensing	316	0.022	0.30
Pulse Combustion	358	0.012	0.16
Power vent	367	0.010	0.13

Table A6-6: Total Gas Unit Heaters and Gas Duct Furnaces Energy Savings Potential

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Savings Potential (2008 – 2030) (quads)
Typical Device (current stock)	N/A	N/A
'Typical New'	N/A	N/A
Condensing	0.142	1.6
Pulse Combustion	0.076	0.88
Power vent	0.063	0.72

Condensing technology has about twice the energy savings potential of the other approaches because it offers a higher steady-state efficiency, while also providing superior cyclical efficiency, in both cases because the condensing design more completely extracts heat from the combustion gases.

A major uncertainty exists in the calculation of energy savings potential for gas unit heaters because the distribution of unit heaters between the commercial building sector and the industrial building sector is unclear. 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 or unit heat installed base in industrial buildings. Instead, based on the widespread application of unit heater in the industrial sector, the unit heater AEC includes the assumption that gas unit heaters consume 85% of the natural gas heating energy consumption in the industrial sector (see Appendix A-V for more information).

The calculation also assumed that shipments for the years before 1991 and after 1995 equaled the mean of shipments during the 1991 to 1995 period. Depending on actual sales figures before and after this period, the gas unit heater and duct furnace installed bases and AECs could be either higher or lower. Finally, if power-vented units or condensing units constitute a larger portion of the market (since 1995), then the energy savings estimates will be high.

A6.5 Regulatory Actions and Cumulative Burden

The DOE has not regulated gas unit heaters or gas duct furnaces for energy efficiency. Nonetheless, gas unit heaters and duct furnaces do fall under the auspices of ASHRAE

Standard 90.1, which has been adopted as part of many municipal and regional building codes. Some manufacturers of gas unit heaters and gas duct furnaces also manufacture unitary air-conditioning units, 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.

A6.6 Issues Impacting Potential Energy Efficiency Standards

Commercial furnaces have recently been subject to prescriptive standards (by ASHRAE 90.1-1999 and the new DOE standards published in the Federal Register – January 2001) which, if promulgated for gas unit and/or duct heaters, could force manufacturers to abandon certain designs and/or technologies. Examples of possible prescriptive standards include requiring vent dampers to block "flue losses" when the heater is off and banning pilot lights. The current standard for gas unit heaters and duct furnaces (ASHRAE 90.1-1999) is a performance-based standard that sets the minimum steady-state efficiency level. An AFUE efficiency level is also performance based, and prescribing a minimum AFUE level (rather than steady-state efficiency) would give more room (i.e. more design options such as vent dampers) to improve energy efficiency levels without forcing major changes in equipment design (such as going to a condensing design). Additionally, the electricity consumed by the equipment could be considered by efficiency standards (e.g., electricity consumed by the fan of gas unit heaters), as this energy increases the quantity of energy required to deliver a given amount of heat. Unfortunately, the annual electricity consumption by gas unit heaters and duct furnaces is not known.

A broader issue when setting efficiency standards for heating equipment is quantifying how effectively heaters distribute warm air to building occupants. For example, many unit heaters are installed near the ceiling of tall spaces, in which case much of the heat may not reach the occupants at floor level. Other heating equipment also suffers from distribution inefficiencies, such as duct leakage, and it is not clear how to best address such "system" effects.

A7 Energy Consumption and Saving Estimates for Torchieres

A7.1 Background

Torchieres, lighting fixtures that operate a halogen, incandescent or compact fluorescent light (CFL) source, are a subcategory of residential lighting. In particular, halogen torchieres in particular are very popular consumer products, owing to their crisp white light, dimming capabilities, low glare, and low cost (BTS, 2000). The approximately 40 million torchieres in the U.S. consume 0.19 quads of energy per year (see Table A7-1). Total annual shipments of torchieres are approximately 14 million units, with halogen, incandescent, and compact fluorescent accounting for 9, 4.5, and 0.65 million units respectively (Calwell and Granda, 1999).

Table A7-1: Torchiere Background Data

Data type	Value	Source
Installed Base, millions (1997)	40	BTS (2000)
Annual Shipments, millions (1999)	14	Calwell and Granda (1999)
Equipment Lifetime, years	20[16]	DOE & EPA (2001)
AEC, quads	0.19	Calculation

DOE began working with Lawrence Berkeley National Laboratory in 1995 to research and develop suitable CFL alternatives with similar features to the halogen torchiere, but with the advantage of a more efficient light source that also could eliminate fire hazard (BTS, 2000).

A7.2 Product Technology Descriptions and Market Presence

The efficiency levels for torchieres examined included one lower incandescent wattage level and different levels of CFL technology (see Table 7-2). Only wattage levels were considered; dimming capability or usage was not considered.

Table A7-2: Torchiere Technology Levels and Wattage Values

Technology Level	Wattage	Comments/Source
Stock Efficiency	300	Halogen bulb; BTS, 2000.
Typical New	300	Halogen bulb; BTS, 2000.
Minimum Efficiency	N/A	No minimum efficiency standard for torchiere lamps
Incandescent	190	CEC (2001)
Best Available Efficiency (CFL light source)	50	BTS (2000)
ENERGY STAR® Efficiency	~67	EPA 2001. Calculated using 60 LPW ENERGY STAR® specification and 4,000 lumen output (typical 300W Halogen).
Maximum Efficiency (Future Technology)	~40	Assume efficacy will improve to highest linear florescent tube (100 LPW) and 4000 lumen demand.

Halogen torchieres accounted for about 65% of torchiere sales in Y1999, while lower-wattage (~190W) incandescent torchieres captured 31% of the market. The CFL torchiere was originally developed by a DOE initiative with Lawrence Berkeley

[16] CEC (2001) assumes a 12-year lifetime, which would result in somewhat larger energy savings potentials.

Laboratory (LBNL) in 1995 in which they worked with lamp manufacturers to develop and commercialize CFL torchieres (BTS, 2000). In 1999, CFL torchieres had just under a 5% market share. Retail homegoods stores typically sell all types of torchieres, with CFL torchieres priced at $10-30 more than typical $20 halogen or incandescent torchieres (CWEB, 2000). To promote the use of CFL torchieres, several utilities and university campuses have sponsored trade-in programs, where consumers could swap their halogen torchieres for more efficient and safe 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 minimum efficiency standard, but they do fall under the voluntary ENERGY STAR® program (see Table A7-3). The ENERGY STAR® Residential Light Fixture Program requirement of 60 LPW for indoor fixtures 24 inches or shorter that consume 30 or more Watts, and all associated safety and performance standards, applies to torchieres. 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 A7-3: 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

A7.3 Test Procedure Status

Torchieres do not have a DOE test procedure. However, applicable ENERGY STAR® test procedures cover input power, efficacy (LPW), lamp life, color rendering, and other performance characteristics (see

Table A7-4). The ENERGY STAR® test procedures are promulgated by IESNA, ANSI and IEEE (DOE & EPA, 2001).

Table A7-4:ENERGY STAR® Reference Standards for Residential Indoor Lights

Performance Characteristic	Reference Standard for Method of Measurement
Efficacy Light output Input power	 IESNA LM-9; LM-66 IESNA LM-9; LM-66; ANSI C82.2
Power factor	ANSI C82.11-3.3.1
Lamp current crest factor	ANSI C82.11-3.3.3
Lamp start time	ANSI C82.11-5.2
Lamp Life	IESNA LM-40; LM-65
Lamp Color Rendering	IESNA LM-58; LM-16
Lamp Correlated Color Temperature	IESNA LM-58; LM-16
Dimming	Use manufacturer protocol
Warranty	Use manufacturer protocol
Safety – Portable Fixtures	ANSI/UL 153
Safety – Hardwired Fixtures	UL 1598
Safety – Ballasts and "Fluorescent Adapters"	ANSI/UL 935; UL 1993
Ballast Frequency	IESNA LM-28
Transient Protection	IEEE C 62.41

The ENERGY STAR® referenced test procedures cover the two key metrics that represent torchiere energy consumption and potential energy savings - input power (Watts) and light output (lumens). Currently, the torchiere ENERGY STAR® program requirements state that future revisions may change the required test procedures for durability, which include on-off cycling, voltage variations, and current variations among other factors. The proposed California standards do not specify a test procedure for torchieres.

The ENERGY STAR® referenced test procedures cover the two key metrics that represent torchiere energy consumption and potential energy savings - input power (Watts) and light output (lumens). Consequently, the test procedures should correlate well with peak load impact, as lamp dimming is likely to have a small overall effect. For example, a halogen torchiere operating at 50 percent light output draws nearly 75 percent of peak power, and at 20 percent of peak light output, it draws 50 percent of peak power. (Page and Siminovitch, 1997 as reported in Mills *et al*, 1998). Dimming has even less impact on CFL torchieres[17], which produce 25 percent more lumens than the average 300 W halogen torchiere at full power (five-fold efficacy increase), and six (6) times the lumens of the halogen torchiere at half power (13 fold efficacy increase) (Mills *et al*, 1998).

However, many torchieres are not likely operated during peak demand periods (e.g., between noon and 6pm during the summer), and torchieres are expected to have a moderate peak electricity demand impact relative to their "on" power draw levels. One

[17] A 72 W CFL torchiere was used to make the comparison to the 300 W halogen torchiere (LBNL, 1998).

preliminary study found that most lamps are used in the evenings between 5pm and 11pm (LBNL, 2000).

A7.4 Energy Savings Estimates and Calculations

The energy savings calculation for torchieres assumes an installed base of 40 million halogen units at 300 W each (BTS, 2000), which operate an average of 3.9 hours per day (ADL, 1998). Two energy savings scenarios are considered (see Table A7-5). The first scenario assumes a standard of 190 W, which reflects torchieres with incandescent lamps, and the second scenario reflects CFL torchieres, with a standard of 70 W (see Table A7-6).

Table A7-5: Torchiere Wattage and Usage Data

Scenario	Wattage	Hours of use/day	References
Baseline (all halogens)	300	3.9	BTS, 2000; Calwell and Granda, 1999; LBNL, 1999.
Scenario 1 (all incandescent)	190	3.9	CEC, 2001.
Scenario 2 (all CFL)	70	3.9	BTS, 2000; Calwell and Granda, 1999.

Table A7-6: Torchieres AEC and Potential Energy Saving Estimates

Technology/ Standard Level	AEC (quads)	Annual Energy Savings Potential (quads)	% Energy Savings (quads)	Energy Saving Potential (2008-2030), (quads)
Baseline	0.188	NA	NA	NA
190W Limit (Incandescent)	0.119	0.069	37%	0.83
70W Limit (CFL)	0.044	0.14	77%	1.7

One major uncertainty to the energy savings estimate is the assumption that the installed base stays constant at 40 million units. The installed base of torchiere lamps is much smaller than the product of the device lifetime and annual sales (see Table 7-1). This factor, combined with the popularity of torchiere style fixtures and the recent introduction of new lower-wattage products that are considered safer, may result in a much larger installed base of torchiere lamps over the 2008-2030 timeframe, increasing both the AEC and energy savings potentials. On the other hand, a shift to lower-wattage options due to safety concerns and/or non-DOE regulation (e.g., the 190W limit proposed in California [CEC, 2001]), would decrease the energy savings potential of torchiere lamps.

A7.5 Regulatory Actions and Cumulative Burden

Torchieres have yet to be subject to regulation for energy efficiency, but this may change in Y2002. The California Energy Commission reissued a proposed efficiency standard at a proposed maximum wattage of 190W on November 6, 2001, and the adoption hearing will take place in February of 2002 (CEC, 2001).

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).

The extent to which other regulations impact torchieres was not determined.

A7.6 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 limit proposed in California [CEC, 2001]) 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[18].

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

A8 Energy Consumption and Saving Estimates for Commercial Refrigeration Equipment

A8.1 General Background for All Commercial Refrigeration Equipment

The commercial refrigeration equipment category consists of water coolers, ice makers, reach-in freezers and refrigerators, beverage vending machines, and beverage merchandisers, as well as supermarket refrigeration systems and walk-in refrigerators and freezers. At the November 6 prioritization meeting, supermarket refrigeration systems and walk-in refrigerators/freezers were eliminated from further consideration because both product classes encompass a very wide range of system types and sizes. Furthermore, many walk-in refrigerators/freezers and most supermarket refrigeration systems are assembled on-site and do not constitute a finished product.

The remaining products, water coolers, ice makers, reach-in freezers and refrigerators, beverage vending machines, and beverage merchandisers, all use a vapor compression refrigeration cycle to remove heat from water[19] or food products (which often have similar thermal characteristics as water) 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. Water coolers and ice makers do not use air as a heat transfer medium, so they dispense with the evaporator air fan;
- 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 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.

The equipment installed base estimates are at least five years old, creating the theoretical potential for uncertainties in the current installed base. In reality, commercial refrigeration equipment has been in the marketplace for decades and the primary venues using refrigeration equipment have not increased dramatically over the past ten years. Thus, the older installed base data should provide reasonable estimates of the current installed base of commercial refrigeration equipment.

[19] A small number of water coolers use a thermoelectric cooler instead of a vapor compression cycle.

A8.2 Water Coolers

A8.2.1 Background

A water cooler is a self-contained assembly with the primary function of cooling potable water and providing a means for dispensing such water. The American Refrigeration Institute defines the following types of water coolers:

- Pressure water cooler: cooler that is supplied with potable water under pressure;
- Bottle-type water cooler: cooler that employs a bottle or reservoir for its water supply;
- Compartment-type water cooler: cooler that includes a compartment for ice making;
- Hot and cold-type water cooler: cooler that dispenses hot and cold water;
- Remote-type water cooler: cooler that cools water and delivers water to remove dispensing site.

In 1990 there were approximately six million water coolers installed in the United States, consuming 0.043 quads annually (see Table A8-1).

Table A8-1: Water Coolers Data

Data type	Value	Source
Installed Base, thousands (1990)	6,030	ADL(1993)
Annual Shipments, thousands (1998)	1,000	U.S. Census (1999)
Equipment Lifetime, years (1990)	10	ADL(1993)
AEC, quads	0.043	

A8.2.2 Test Procedure Status

Water coolers do not have a DOE test procedure; however, several other organizations have test procedures for water coolers. The basic test procedure, ASHRAE 18, originated with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The Air-Conditioning and Refrigeration Institute (ARI) is the national trade association representing manufacturers of commercial refrigeration equipment; their ARI 1010-94 standard is based on the ASHRAE 18 test procedure. The Canadian Standards Association (CSA) has a test procedure, C815-99, which is also based on the ASHRAE 18 test procedure. There is an ENERGY STAR® program for water coolers, and the ENERGY STAR(R) test is based on the ASHRAE 18 standard.

The ASHRAE 18 test standard focuses on the cooling capacity rather than the energy consumption of water coolers. In particular, ASHRAE 18 does not specify a particular ambient temperature, water inlet temperature, or water outlet temperature. All of these conditions significantly affect the amount of time the refrigeration system compressor runs. For instance, if the water coming into the cooler is almost as cold as the desired temperature for consumption then the refrigeration system will rarely run. The ASHRAE 18 test sets testing methods and tolerances but leaves it to other associations and organizations to determine the operating conditions, so the ASHRAE 18 test by itself is ill-suited for an energy efficiency rulemaking.

The ARI Standard 1010-94 builds on the ASHRAE 18 standard by specifying the ambient temperature, inlet water temperature, cooled water temperature, and heated potable water temperature. Those values for bottle type water coolers are as follows:

- Ambient: 90°F;
- Inlet water: 90°F;
- Cooled water: 50°F;
- Heated potable water: 165°F.

Examination of the ambient and inlet water temperatures indicates that the test condition best reflects hot or summer conditions. The conditions are similar for other types of water coolers. The ARI test procedure does not include the additional refrigeration load imposed by water draws. Given the high ambient temperatures, ARI 1010-94 is more appropriate for durability and performance ratings.

The CSA test standard, C815-99, is also based on ASHRAE 18. C815-99 measures standby energy consumption with conditions very similar to the rating conditions of ARI 1010-94. Notably, C815-99 adds to the ARI standard simulated water draws. After measuring the energy consumption at steady state, 3 draws of 6 ounces are made, and the temperature of the water drawn last must be at most 50°F. However, CSA815-99 does not specify the timing of the three water draws. Presumably, the tester draws the water as quickly as possible while meeting the 50°F temperature requirement in order to minimize the time that electrical power consumption is recorded. The CSA standard measures energy consumption due to standby losses *and* water draws.

The ENERGY STAR® test is also based on ASHRAE 18 and only measures standby energy consumption like ARI 1010-94. But, ENERGY STAR® uses the following test conditions:

- Inlet water temperature: 75± 2°F
- Ambient temperature: 75± 2°F;
- Cold water temperature less than 50°F;
- Hot water temperature greater than 165°F.

The ENERGY STAR® test uses temperatures closer to indoor conditions than the ARI rating conditions. However, the dispensed water temperatures for both cooling and heating remain the same as ARI and CSA. Overall, the ENERGY STAR® test is the most accurate for measuring standby energy consumption, but the CSA test with water draws is appropriate for measuring energy consumption needed to pull down the temperature of warm inlet water. A more accurate test procedure suited to energy efficiency standards would use the ENERGY STAR® test conditions to model standby energy consumption in conjunction with the CSA test with water draws. This combination will reflect more likely ambient and inlet water temperatures and include the effect of water draws on energy usage.

The ARI test procedure likely correlates better with peak power demand, as the 90°F ambient air temperature and the 90°F inlet water temperature both correspond to a hot, summer day.

No alternative test procedure is likely to be developed, and all future test procedures will likely be based on the ASHRAE procedure.

A8.2.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

Table A8-1 presents the potential energy saving estimates for a combination of technologies and for the ENERGY STAR® level.

Table A8-2: Water Coolers Potential Energy Saving Estimates

Technology / Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030) (quads)	Source
Combination	35	0.015	0.26	ADL (1993)
ENERGY STAR®®	33	0.014	0.24	ENERGY STAR® Website[20]

The "combination" option consists of the following features:

- high insulation value;
- efficient compressor;
- improved thermal bond between coil and evaporator;
- improved fan motor efficiency;
- storage coil redesign.

The "combination" option is for a theoretical drinking fountain, i.e. pressure type water cooler, and has a 35% energy savings potential with an energy savings potential of 0.26 quads over the period from 2008-2030. These energy savings estimates are based on conditions identical to those in the ARI and CSA standards, and have simple payback periods of 2 to 10 years (depending on the specific feature).

If all bottle type water coolers qualified for ENERGY STAR® certification, then the annual energy savings would be 0.014 quads. The energy saving potential for 2008 to 2030 would be 0.24 quads. At first glance, the ENERGY STAR® result is very similar to the "combination" option, but the "combination" option is evaluated under the higher ambient and inlet water temperatures of the ARI standard. Since the ambient and inlet water temperatures are lower for the ENERGY STAR® test, the ENERGY STAR®-based projections of energy savings will be lower than for the "combination" option. In addition, the ENERGY STAR® test conditions are more likely to be encountered; therefore, the ENERGY STAR® energy savings are likely more accurate. However, both the "combination" option and the ENERGY STAR® level illustrate the potential energy savings available in the water cooler market.

[20] Assumes1.2 kWh per day for hot/cold bottled units, the ENERGY STAR® threshold. See: http://yosemite1.epa.gov/estar/consumers.nsf/content/watercooler.htm .

The actual energy savings could vary substantially from the projected annual energy savings because operating conditions vary so widely. The current test procedures only consider two ambient air temperatures, 75°F and 90°F, and the latter is at the upper range of air temperatures experienced in the United States, and water coolers are normally situated indoors where the ambient air may be air-conditioned. Moreover, the inlet water temperatures (also 75°F and 90°F) both exceed the average water temperature for most regions of the U.S. Consequently, both tests – particularly the ARI test – would result in higher energy consumption estimates than found in practice (assuming the same water draws). In all likelihood, the projected energy savings are somewhat high.

A8.2.4 Regulatory Action

Water coolers do not have a DOE minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program. The ENERGY STAR® program has energy efficiency limits that only apply to bottle type water coolers between four and five gallons in size, and the ENERGY STAR® test procedure only considers standby energy consumption is tested. In contrast, the Canadian Standards Association has energy efficiency limits that depend on water cooler type and capacity.

Since most water coolers utilize 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 water coolers have already borne the cumulative burden of CFC elimination, the possible elimination of global warming refrigerants, and previous energy efficiency standards.

A8.2.5 Issues Impacting Potential Energy Efficiency Standards

The wide range of water cooler types (e.g., ARI categorizes water coolers as: bottle-type, pressure, compartment-type water cooler, hot and cold-type water cooler, and remote-type) complicate the promulgation of a unified standard for water coolers. For instance, the ENERGY STAR® only encompasses bottle-type water coolers.

A8.3 Ice Machines

A8.3.1 Background

Ice machines produce ice for use in the food service, food preservation, hotel, and hospital industries. Ice machines vary in ice making capacity and can have either an air-cooled condenser or a water-cooled condenser. In addition, ice machines produce ice in a range of different shapes.

The 1.2 million ice machines installed in the U.S. consume about 0.10 quads annually (see Table A8-3).

Table A8-3: Ice Machine Data

Data type	Value	Source
Installed Base, thousands (1994)	1,200	ADL(1996)
Annual Sales, thousands (1998)	296	U.S. Census (2000)
Equipment Lifetime, years (1994)	7 to 10	ADL(1996)
AEC, quads	0.10	

A8.3.2 Test Procedure Status

Ice machines do not have a DOE test procedure; however, several other organizations have developed test procedures for ice machines. The basic test procedure, ASHRAE 29, originated with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The Air-Conditioning and Refrigeration Institute (ARI) is the national trade association representing manufacturers of commercial refrigeration equipment, and their ARI 810 standard is based on the ASHRAE 29 test procedure. The Canadian Standards Association also has a test standard based on ASHRAE 29, C742-98.

The ASHRAE 29 standard measures performance (e.g., ice production per unit time) and energy usage by ice machines. However, ASHRAE 29 does not specify ambient temperature, supply water temperature, or cooling water temperature for water-cooled condensers, allowing other organizations to set those parameters for their own purposes.

The ARI Standard, ARI 810, is based on ASHRAE 29 and specifies the following test conditions:

- 90°F ambient temperature;
- 70°F supply water temperature and/or cooling water temperature for water-cooled condensers;
- Ice machine runs at full capacity (i.e., producing the maximum quantity of ice per hour) during test.

In the ARI standard, the ambient temperature and water temperatures are higher than typical values for ice machine applications. Also, the testing of ice machines at full capacity overestimates the duty cycle of the machines. For example, ice cube demand from a hotel ice machine is sporadic throughout the day, so the ice machine does not produce ice continuously for 24 hours a day. Therefore, the unit's refrigeration system does not operate 24 hours per day. Measuring energy usage of an ice machine in full capacity mode is more suitable for peak electrical load estimates than for average electrical energy use.

The Canadian Standards Association also has a test standard, C742-98, which is based on ASHRAE 29, which uses the same rating conditions as ARI 810.

No alternative test procedure is likely to be developed, and all future test procedures will likely be based on the ASHRAE procedure. However, a test procedure with more typical, i.e. lower ambient, supply, and cooling water temperatures would be more representative of actual energy use than the ARI/CSA ratings.

A8.3.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

Table A8-4 presents the energy savings potential for a combination of improvements and a unit recommended by the Federal Energy Management Program (FEMP).

Table A8-4: Potential Energy Saving Estimates for Ice Machines

Technology / Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)	Source
Combination	10	0.010	0.18	ADL(1996)
FEMP Recommended	9	0.0093	0.16	FEMP website[21]
FEMP Best Available	17	0.017	0.31	FEMP website
CSA	0	0.0	0.0	CSA C742-98 standard

The "combination" of technologies includes a high efficiency compressor and reduced evaporator thermal cycling, and has an energy saving potential of 0.18 quads from 2008 to 2030. These energy savings projections are based on ARI test data and have simple payback periods of 1.8 and 1.2 years, for the high efficiency compressor and reduced evaporator thermal cycling, respectively.

FEMP recommends to federal agencies that they procure icemakers ranked in the top 25% energy efficiency levels by ARI. FEMP also identifies the most energy efficient ice machine available, equal to roughly twice the projected savings of the recommended levels. The energy saving potentials from 2008 to 2030 for the FEMP recommended level and the best available are 0.16 and 0.31 quads, respectively.

The Canadian Standards Association's (CSA) energy efficiency standards for ice machines are relatively low. In fact, few ice machines listed in the ARI database do not meet the CSA energy efficiency standards. Therefore, a standard set at the CSA level would realize small energy savings.

[21] Based on ARI average consumption for air-cooled ice makers with 401 to 500 lb/day capacity (7.05 kWh/100lb) and water-cooled ice makers with 301 to 500lb/day capacity (5.62kWh/100lb) compared with FEMP recommended and "best available" data for these ranges. As of January, 2002. See: http://www.eren.doe.gov/femp/procurement/icemkr.html .

A8.3.4 Regulatory Action

Ice machines do not have a DOE minimum energy efficiency standard, but FEMP recommends ice machines that meet their energy efficiency standards to all federal agencies. The Canadian Standards Association does have energy efficiency standards for ice machines.

The FEMP energy efficiency standard for ice machines applies only to ice-cube machines, as opposed to flake or crushed ice. However, the FEMP recommendation does cover air-cooled and water-cooled condenser, several configurations, and capacities.

The CSA energy efficiency standard only applies to automatic ice machines with a capacity between 50 pounds/day and 2200 pounds/day, but does cover a variety of shapes: cube, flake, crushed, or fragmented. It does not apply to blowdown type ice machines.

Since all ice machines utilize 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 ice machines 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 ice machines have already borne the cumulative burden of CFC elimination and previous energy efficiency standards, and face the possible elimination of global warming refrigerants.

A8.3.5 Issues Impacting Potential Energy Efficiency Standards

No additional issues impacting potential energy efficiency standards were identified.

A8.4 Reach-In Freezers and Reach-In Refrigerators

A8.4.1 Background

Reach-in freezers and reach-in refrigerators 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 A8-5 shows that the installed bases of reach-in freezers and refrigerators in 1994 were 800,000 and 1.3 million, respectively. Both reach-in freezers and refrigerators have an average lifetime of 8 to 10 years, and freezers and refrigerators annually consume 0.066 quads and 0.054 quads, 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 A8-5: 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)
	Annual Sales, thousands (1994)	80	
	Equipment Lifetime, years (1994)	8 to 10	
	AEC, quads	0.066	
Reach-In Refrigerators	Installed Base, thousands (1994)	1,300	
	Annual Sales, thousands (1994)	120	
	Equipment Lifetime, years (1994)	8 to 10	
	AEC, quads	0.054	

A8.4.2 Test Procedure Status

A DOE test procedure does not exist for reach-in freezers or reach-in refrigerators; however, several organizations have test procedures for reach-in refrigeration. The basic test procedure, ASHRAE 117, originated with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). In addition, the Canadian standard, CSA C827-88, the California Energy Commission (CEC), and the EPA ENERGY STAR® program all use the ASHRAE 117 test for their programs as well. The National Sanitation Foundation (NSF) has a performance test for reach-in freezers and refrigerators, NSF7.

The ASHRAE 117 test standard is intended for all closed refrigerators, i.e. refrigerators and freezers with a door to access product. During the test, the case is filled to capacity with a combination of simulated food products and wood. In addition, the door(s) are opened at specific intervals for an eight-hour period to simulate the refrigeration load imposed by door openings. Well-defined ambient conditions are maintained as follows:

- Dry bulb temperature of 75°F±2°F;
- Web bulb temperature of 64°F±2°F;
- Minimal external air drafts;
- Lighting to simulate lighted room;
- No excessive radiant heat to or from the case.

The ASHRAE 117 test best simulates a typical 24-hour day usage of a reach-in with normal ambient conditions. It does not attempt to evaluate a unit operating under hot conditions, such as those often encountered in an active kitchen. In addition, the test conditions only consider steady-state conditions, i.e., it does not take into account the energy required to cool down warm food introduced into the unit. The ASHRAE 117 test standard does not specify a case temperature or a food temperature, so the ASHRAE

117 test by itself is inadequate for energy efficiency standards. Other organizations that evaluate the energy efficiency of reach-in units specify a case air temperature and a food temperature.

CSA C827-88 adds the following conditions to the ASHRAE 117 test:

- 38°F air temperature in refrigerator case;
- 0°F air temperature in freezer case.

The product temperatures depend on the tester. In any case, the CSA test does not consider the energy required to “pull-down” warm food to the refrigeration/freezer unit.

The California Energy Commission plans to use the ASHRAE 117 test with the following additions for reach-in refrigerators:

- 38°F initial product temperature;
- 40°F maximum product temperature.

For freezers, the CEC uses the following specifications:

- 0°F initial product temperature;
- 2°F maximum product temperature.

The higher temperatures specified in the CEC test procedure serve to limit product increases during the door opening periods.

The NSF7 test is a performance test to ensure that reach-in freezers and refrigerators can maintain temperatures safe for food preservation. This translates to a case temperature of less than 40°F in a refrigerator and 0°F in a freezer with the surrounding ambient at 100°F. The maximum duty cycle allowed for a reach-in refrigerator during this test equals 70%, ensuring that there is extra refrigeration capacity in the event of more adverse conditions like door openings that could allow food temperatures to become dangerously high. The maximum allowable duty cycle for a reach-in freezer during the NSF7 test is 80%. The NSF7 does not require measurement of electrical power consumption so, by itself, it is insufficient as an energy efficiency test.

None of the existing test procedures are relevant to peak load impact estimates. The ambient temperature in the ASHRAE 117 test is a moderate 75°F, well below the temperatures encountered in active commercial kitchens. Combining the NSF7’s ambient temperature of 100°F with the door openings of the ASHRAE 117 would result in an appropriate test procedure for peak load impact estimates, though. This hybrid test would correspond to a reach-in unit being used during operating hours in a hot commercial kitchen.

In sum, several different organizations use the ASHRAE 117 test with associated food product temperatures to evaluate energy consumption. The inclusion of food packages whether real or simulated also makes the ASHRAE 117 test more realistic. For these reasons, the ASHRAE 117 test will probably remain the basis for any new energy efficiency standards.

A8.4.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

Table A8-6 presents the potential energy saving estimates for reach-in freezers.

Table A8-6: Potential Energy Saving Estimates for Reach-In Freezers

Technology/ Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030) (quads)	Source
Combination	35	0.023	0.40	ADL(1996)
CEC Tier 1	8	0.005	0.09	CEC Database of Energy Efficient Appliances[22]
CEC Tier 2	13	0.009	0.15	CEC Database of Energy Efficient Appliances[23]
ENERGY STAR®	20	0.013	0.23	ENERGY STAR® website[24]

The theoretical reach-in freezer employs a combination of technologies to save energy:

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

The annual energy savings potential if all reach-in freezers employed these technologies equals 35%, which translates into 0.28 quads over the 2008-2030 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 is scheduled to take 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%[25]. 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.

[22] Available at: http://www.energy.ca.gov/appliances/appliance/ .
[23] Available at: http://www.energy.ca.gov/appliances/appliance/ .
[24] Available at: http://yosemite1.epa.gov/estar/consumers.nsf/content/refrigerator.htm .
[25] 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.

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 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 A8-7 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.

Table A8-7: Potential Energy Saving Estimates for Reach-In Refrigerators

Technology / Standard Level	% Energy Savings Potential	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)	Source
Combination 1	44	0.024	0.42	ADL(1996)
Combination 2	67	0.036	0.64	ADL (2001a); ADL (2002b)
Combination 3	80	0.044	0.76	ADL (2001a)
CEC Tier 1	0	0.00	0.00	CEC (2002)[26]
CEC Tier 2	9	0.005	0.09	CEC (2002)[27]
ENERGY STAR®	29	0.016	0.28	See Footnote [4]

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 0.44 quads over 2008-2030. 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.

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;
- Refrigeration system optimization.

[26]No reduction in ASHRAE 117 Energy use from 9kWh/day (ADL(current)) to 9.65kWh/day for 43.5 cuft unit.
[27]Reduction in ASHRAE 117 Energy use from 9kWh/day (ADL(current)) to 8.20kWh/day for 43.5 cuft unit
[4] Reduction in ASHRAE 117 Energy use from 9kWh/day (ADL(current)) to 6.39kWh/day for 43.5 cuft unit

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 0.64 quads over the Y2008-2030 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;
- 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 0.76 quads over the Y2008-2030 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) plans for 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.
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If all reach-in refrigerators attained ENERGY STAR® certification, then the annual energy savings potential would be 29%.

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^o 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^o 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 A8-8: Total Reach-in Freezers and Reach-in Refrigerators Energy Savings Potential

Technology / Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008 – 2030) (quads)
Combination 1	0.047	0.82
Combination 2	0.059	1.04
Combination 3	0.067	1.16
CEC Tier 1	0.005	0.09
CEC Tier 2	0.014	0.24
ENERGY STAR®	0.029	0.51

A8.4.4 Regulatory Action

Reach-in freezers and refrigerators 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 and freezers on 1 September, 2001. In addition, the California Energy Commission (CEC) plans to promulgate 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 and refrigerators.

The ENERGY STAR® program only qualifies *solid* door refrigerators and 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.

The California Energy Commission has proposed to enact energy efficiency standards that will take effect in two tiers. Tier 1 is scheduled to take effect 03/01/03, and Tier 2 is planned for 08/01/04.

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

A8.4.5 Issues Impacting Potential Energy Efficiency Standards

The ASHRAE 117 test is a very 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.

A8.5 Vending Machines and Beverage Merchandisers

A8.5.1 Background

Vending machines and beverage merchandisers are refrigerated cabinets that hold bottled or canned beverages at a cool temperature up until the time or purchase by the consumer. The vending machine is designed as a 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. 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, Coca-Cola, 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 pulldown requirement by Coca-Cola necessitate bigger refrigeration systems for beverage merchandisers than comparably-sized reach-in refrigerators.

Table A8-9 presents the installed base data for vending machines and beverage merchandisers. There are approximately four million beverage vending machines and 800,000 beverage merchandisers installed in the US. The annual energy consumption of the vending machines and beverage merchandisers equals 0.135 and 0.052 quads, respectively.

Table A8-9: Installed Base Data for Vending Machines and Beverage Merchandisers

Equipment type	Data type	Value	Source
Vending Machines	Installed Base, thousands (1994)	4,100	ADL(1996)
	Annual Sales, thousands (1994)	410[28]	
	Equipment Lifetime, years (1994)	7 to 10	
	AEC, quads	0.135	
Beverage Merchandises	Installed Base, thousands (1994)	800	
	Annual Sales, thousands (1994)	60 to 120[29]	
	Equipment Lifetime, years (1994)	7 to 10	
	AEC, quads	0.052	

A8.5.2 Test Procedure Status

Neither vending machines nor beverage merchandisers have a DOE test procedure.

A8.5.2.1 Vending Machines

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) has their ASHRAE 32.1 standard for vending machines. The Coca-Cola corporation, a major consumer of beverage vending machines, has their own proprietary test procedure to evaluate energy use and performance.

The ASHRAE 32.1 standard contains an energy consumption test for a unit in standby mode, i.e. no product is being vended. The standby mode is characterized by:

- Beverage temperatures of 36°F;
- Ambient: 90±2°F with 65% relative humidity.

This corresponds to a vending machine maintaining the beverages at the desired vending temperature in a hot environment. It does not specify a lighting level, but since the test last 24 hours, one can reasonably assume that the test occurs under normal room level lighting (as opposed to the noon sun in southern climates). The ASHRAE 32.1 test most closely approaches conditions encountered in a hot room or hot climate in the shade. It does not take into account the energy required to "pull down" warm product to the vending temperature.

The Canadian Standards Association promulgated CAN/CSA-C804-96 standard for the energy performance of vending machines. The CSA standard has many similarities with the ASHRAE standard, except that the product temperature is two degrees less, i.e., 34°F. As a result, the CSA standard will measure slightly higher energy consumption rates than the ASHRAE standard.

[28] Installed base divided by high-end of equipment lifetime.
[29] Conversations with manufacturers suggest that this range may be low.

The ASHRAE 32.1 and CAN/CSA-C804-96 test standards for vending machines are both well-defined and relatively easy to implement. A lower ambient temperature may better represent actual energy use, though. In sum, because they mandate high ambient temperatures and do not consider "pull down" energy consumption and power draw, both the ASHRAE and CSA test standards are inappropriate for measuring average energy use.

On the other hand, the high ambient temperatures of both standards mean that they correlate better with standby energy consumption during peak electrical demand periods, although they will not capture additional energy required to "pull down" warm beverages during this period. The 90°F ambient air temperature corresponds to a summer day, and many vending machines are located outdoors.

A8.5.2.2 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).

A8.5.3 Energy Savings Estimates and Calculations, and Technology Description and Market Presence

The potential energy saving estimates are shown in Table A8-10

Table A8-10: Vending Machines and Beverage Merchandisers- Energy Saving Potential Estimates

Equipment Type	Technology/ Standard Level	% Energy Savings Potential	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)	Source
Vending Machines	Royal Vendors - Econo-cool Technology	47	0.064	1.13	Royal Vendors Website[30] (2002)
Vending Machines	Combination	28	0.038	0.67	ADL(1996)
Beverage Merchandises	Combination	35	0.018	0.33	

The first 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 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 energy savings potential is 0.064 quads, and the energy savings potential from 2008 to 2030 is 1.13 quads.

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.

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

A8.5.4 Regulatory Action

The California Energy Commission (CEC) is preparing efficiency standards for glass door reach-in refrigerators that encompasses beverage merchandisers (CEC, 2001). In addition, the CEC requires registration of beverage vending machines and will prescribe 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 is in the process of developing voluntary efficiency improvements for beverage vending machines.

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. If the U.S. ratifies the Kyoto Protocol or adopts other legislation to reduce emissions of greenhouse gases, then the makers of beverage merchandisers and vending machines 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 beverage merchandisers and vending machines have already borne the cumulative burden of CFC elimination and previous energy efficiency standards, and face the possible elimination of global warming refrigerants.

A8.5.5 Issues Impacting Potential Energy Efficiency Standards

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.

A9.1 Background

Desktop personal computers (PCs) refer to non-portable (non-laptop) personal computers. The installed base of approximately 110 million units is divided between commercial[31] and residential buildings, with very different usage patterns in each. Consequently, PCs in commercial buildings account for 0.19 of the 0.22 quads consumed by all PCs in Y2000 (see Table A9-1).

Table A9-1: Desktop PC Background Data

Type	Data type	Value	Source
Commercial Desktop PC	Installed Base, (millions)	59	ADL (2002a) (based on shipment data from Akatsu et al., 1999)
	Equipment Lifetime, years	3	National Safety Council (1999)
	AEC, quads	0.19	ADL (2002a)
Residential Desktop PC	Installed Base, (millions)	51	ADL(2002) (based on shipment data from Akatsu et al., 1999)
	Equipment Lifetime, years	3	National Safety Council (1999)
	AEC, quads	0.03	Kawamoto et al. (2001) and Calculation (see Appendix A-VI)

PCs have an average lifetime of about three years due to a rapid evolution of computer performance.

A9.2 Product Technology Descriptions and Market Presence

PCs perform a wide range of functions, ranging from word processing to computation to communication (e-mail, internet access, etc.). In all functions, PCs use a CPU to carry out computations guided by a program to provide the functionality observed by the end user. Similarly, PCs store data in short-term RAM while running programs and more permanently in hard drives to archive data. All of these functions consume energy, with the CPU accounting for the bulk of the power draw while “active”.

Many PCs “power-down” into a lower-power “sleep” mode after a period of inactivity using power management software installed on the computer, usually to comply with the voluntary ENERGY STAR® program. Users can – and very often do – disable the power management software, leading to a much lower power management-enabled rate for PCs than theoretically possible. In the commercial sector, the Y2000 power management-enabled rate stood at about 25% (Nordman et al., 2000), whereas more than 90% of desktop PCs sold that year were ENERGY STAR®-capable (Webber et al., 2000). As many PCs have extended periods of inactivity during the workday and an estimated 54% of commercial PCs remain on in “active” mode throughout the night (Webber et al., 2001, from night audits), the power management-enabled rate has a

[31] A relatively small quantity operate in industrial settings; they are included in the commercial building category.

major influence on PC annual energy consumption. Desktop PCs also draw a low level of power when turned off but plugged in.

Thus, decreases in the power draw of major energy consuming components, particularly CPUs, and increases in the power management-enabled rate are the two primary ways of reducing the AEC of desktop PCs (see Table AVI-2 Appendix A-VI contains calculation details).

Table A9- 2: Desktop PC Technology Levels and UEC Values (Commercial and Residential)

Technology/Standard Level	UEC (KW-h)		Comments
	Comml.	Res.	
Typical New	325	56	Pentium III CPU; 25 % Power management-enabled rate
Installed Base	297	52	Pentium II CPU; 25 % Power management-enabled rate
Minimum Efficiency Standard	N/A	N/A	No minimum efficiency standard for PCs
50% Power management-enabled rate	257	54	Pentium III CPU
100% Power management-enabled rate	178	50	Pentium III CPU
Laptop Computer	35	27	100% Power management-enabled rate
Low-Power Design	56	15	25% Power management-enabled rate; laptop power draw
1W Sleep Power Draw	313	47	Pentium III CPU; 25 % Power management-enabled rate

The “typical new” desktop PC has a Pentium III CPU, with 25% of the installed base of machines power management-enabled. It consumes slightly more energy than the average desktop PC (installed base) because of the CPU used in “typical new” PCs draws more power than its predecessor.

Desktop PCs do not have a minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program. The ENERGY STAR® program states that the PC must go into sleep mode after a period of inactivity, with the default time set to less than 30 minutes. Any system that consumes less than 15 W in the active mode is not required to have a sleep mode. The 50% and 100% Power management-enabled rate levels in Table 9-2 both refer to rates for the *entire population* of PCs, not for an individual PC – an individual PC is either enabled or not. Clearly, since over 90% of PCs sold most PCs are ENERGY STAR®-compliant, most PCs are currently capable of having the ENERGY STAR® power management features enabled. Increasing the Power management-enabled rate can be achieved via an increase in personal awareness/encouragement to enable the feature, modifications to the software (or network software), or electronic devices that detect user inaction and power down the computer. Software enabling network administrators to control the power management settings for all computers connected to the network has recently come to market (EZConserve, 2002). Increases in power management-enabled rates achieved through awareness/encouragement have minimal direct cost impact, as most PCs include power management software. A cost-benefit analysis for the network-wide power management software has yet to be performed.

The “Laptop Computer” option assumes that laptop PCs replace all desktop PCs. Valued for their portability, laptop computers incorporate a range of low-power features to conserve valuable battery power and enable extended unconnected operation. As a result, the “active” mode power draw of laptop PCs is about 75% less than that of desktop PCs[32]. Similarly, the Low-Power Design option represents a desktop computer using the low-power components applied in a laptop computer, i.e., assumes the same power draw as a laptop computer without the display. Laptop PCs are common devices with an installed base of about 23 million devices (ADL, 2002). In addition, other low-power chip options have recently entered the market (e.g., Transmeta Crusoe). A cost-benefit analysis for different CPU options has yet to be performed.

Lastly, the 1 Watt “sleep” option assumes that all desktop PCs consume 1W in “sleep” mode, while the power management-enabled rate does not change. As of February, 2002, more than 20 laptop and notebook computers registered as an ENERGY STAR® device[33] consumed 1W or less in sleep mode, but no desktop computers met this threshold. The desktop computer with the lowest power draw in “sleep” mode, a Dell Dimension 4300, consumes 1.51W in “sleep” mode. In July, 2001, the White House issued an executive order (White House, 2001) to purchase devices using less than 1 Watt in “standby” mode (i.e., “sleep” mode for PCs) “when life-cycle cost-effective and practicable and where the relevant product’s utility and performance are not compromised as a result”. If 1 Watt standby products are not available, “agencies shall purchase products with the lowest standby power wattage”. This will provide impetus for PC manufacturers to make desktop PCs that draw less than 1 Watt in “sleep” mode.

A9.3 Test Procedure Status

Desktop PCs lack a DOE test procedure but do have an ENERGY STAR® test procedure to measure power draw in the sleep mode. Under controlled climatic and power quality conditions specified in the test procedure, the desktop PC is plugged in and let sit for a period of inactivity until it enters “sleep” mode (default time set to less than 30 minutes). The tester then measures the true standby power of the device with a resolution of 0.1 W, taking care to average the measurement over a sufficiently long time period to obtain an accurate value.

Because the ENERGY STAR® test procedure does not measure “active” power draw, it does not correlate closely with device UEC because the active mode dominates device UECAEC, i.e., the active mode accounts for 96% of the installed base of desktop PCs with commercial usage patterns (ADL, 2002). Thus, the test procedure fails to capture any energy savings from reductions in desktop PC active power draw. If the power management-enabled rate increased to 100%, the test procedure becomes more relevant, as the “sleep” mode then accounts for more than 60% of installed base UEC.

[32] Including power for the screen.
[33] Information available at:

Similarly, the ENERGY STAR® test procedure correlates weakly with the peak demand impact of desktop computers because the computer active mode dominates the peak power impact of desktop computers (most commercially-used computers are active during the work day) and the test procedure measures only “sleep” mode power draw. Even if the power management-enabled rate reached 100%, the active mode would continue to dominate aggregate desktop PC peak demand.

In contrast, the ENERGY STAR® test procedure will fully capture the energy consumption, energy savings, and peak demand reduction impact of the 1W “sleep” mode power level.

A9.4 Energy Savings Estimates and Calculations

Desktop PC energy consumption and savings calculations reflect surveys of power management-enabled rates (Nordman et al., 2000), combined with daytime usage estimates (Kawamoto et al., 2001) and night-status audits (Webber et al., 2001). All desktop PC energy savings estimates are calculated relative to an installed base of PCs with a Pentium III CPU and a 25% power management-enabled rated, i.e., the “typical new” device. Table A9-3 and Table A9-4 presents the energy consumption and potential saving estimates for commercial and residential desktop PCs respectively.

Table A9-3: Commercial Desktop PC Energy Saving Potential

Technology/Standard Level	UEC (KW-h)	% Energy Savings Potential	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030) (quads)
Typical New (Pentium III CPU, 25 % Power management-enabled)	325	N/A	N/A	N/A
50% Power management-enabled (Pentium III CPU)	257	21	0.044	0.89
100% Power management-enabled (Pentium III CPU)	178	45	0.095	1.9
Laptop Computer (100% ENERGY STAR®)	35	89	0.19	3.8
Low-Power Design (25 % Power management-enabled)	56	83	0.17	3.6
1 W "sleep" (Pentium III CPU, 25 % Power management-enabled)	313	4	0.008	0.16

Table A9-4: Energy Savings Potential of Residential Desktop PCs

Technology/Standard Level	UEC (kW-h)	% Energy Savings Potential	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Typical New (Pentium III CPU, 25 % Power management-enabled)	56	N/A	N/A	N/A
50% Power management-enabled (Pentium III CPU)	54	4	0.001	0.03
100% Power management-enabled (Pentium III CPU)	49	12	0.004	0.08
Laptop Computer (100% ENERGY STAR®)	26	53	0.017	0.35
Low-Power Design (25 % Power management-enabled)	15	73	0.023	0.48
1 W "sleep" (Pentium III CPU, 25 % Power management-enabled)	47	17	0.0054	0.11

For all technologies, PCs used in commercial buildings have much higher energy savings potentials than residential PCs due to much higher usage levels. Table AVI-1, Table AVI-2 and Table AVI-7 (see Appendix A-VI) provide the calculation details for the two preceding tables.

Table A9-5: Total Desktop PC Energy Savings Potential displays the total energy savings potentials for the different desktop PC technologies and standard level.

Table A9-5: Total Desktop PC Energy Savings Potential

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030) (quads)
Typical New (Pentium III CPU, 25 % Power management-enabled)	N/A	N/A
50% Power management-enabled (Pentium III CPU)	0.045	0.92
100% Power management-enabled (Pentium III CPU)	0.099	1.98
Laptop Computer (100% ENERGY STAR®)	0.20	4.15
Low-Power Design (25 % Power management-enabled)	0.20	4.08
1 W "sleep" (Pentium III CPU, 25 % Power management-enabled)	0.013	0.27

Overall, the technologies that reduce "active" power draw, i.e., the "Laptop Computer" and "Low-Power Design" cases, have the largest energy savings potentials (4.2 and 4.0 quads, respectively). Increasing the ENERGY STAR® rate of the entire installed base to 50% and 100% would create savings of 0.92 and 1.98 quads. A 1-Watte "sleep" mode energy savings potential equals 0.27 quads.

It is important to note that the market share of laptop PCs continues to grow, as their price declines and user opt for their portability, leading an expert to projected that laptops will outsell desktops in Y2003 (Economist, 2000). If this came to pass and the market share of laptop PCs continued to grow, much of the projected energy savings *for all cases studied* would occur without any regulation.

In addition, the sales of PCs and monitors have trended upwards over the past five years, suggesting that the installed base of monitors may grow in the future.

A9.5 Regulatory Actions and Cumulative Burden

Desktop PCs have not been subject to regulation for energy efficiency. The extent to which other regulations impact desktop PCs, such as health and safety regulations, was not determined.

A9.6 Issues Impacting Potential Energy Efficiency Standards

Several issues warrant consideration in determining whether or not to pursue the development and implementation of efficiency standards for desktop PCs. First, PCs have – and continue to – evolve very rapidly, with raw CPU speed doubling roughly every two years and a very short lifetime. Consequently, PCs will almost certainly evolve markedly in the period between completion and implementation of a rulemaking, creating the potential to make rules that become obsolete over the intervening period of time. Second, PCs are sold and purchased as productivity tools, and the amount of energy consumed by the average desktop PC over its lifetime (~$80[34]) is a small fraction of its first cost and are swamped by any incremental gains in productivity. Consequently, energy consumption is rarely a consideration when purchasing a PC and energy efficiency provided minimal impetus to purchase a more efficient PC. Third, mandating increases in the power management-enabled rate depend on fixing the power management settings for devices, either via software on the computer, on a computer network, or via hardware when the device becomes "inactive" after a certain period of time. It is not clear whether or not regulation specifying when a device *must* power down can be promulgated. Furthermore, as computers become more integrated into peoples' lives, the demand for "always on" functionality almost certainly increase, making the definition of "inactive" and "certain period" important. Fourth, low-power designs will likely encounter resistance in the desktop PCs due to their first, cost, the necessity of manufacturers re-design and a public demand for faster CPUs (which tend to increase power draw; Low-Power Designs used in laptop computers run at slower clock speeds than the latest CPUs used in desktop PCs).

[34] $0.08/kW-h, 3-year lifetime, 325kW-h/year average UEC.

A10.1 Background

Monitors are almost always paired with desktop personal computers and workstations and convert visual signals generated by the computer into images. The installed base of approximately 121 million units consumed about 0.25 quads of energy in Y2000 (see Table A10-1). Although the monitor stock is split rather evenly between residential and commercial[35] buildings, commercial applications accounted for about 80% of all monitor AEC.

Table A10-1: Background Information for Monitors

Type	Data type	Value	Source
Commercial Monitors	Installed Base, (millions)	63	ADL (2002a) (based on IDC, 2000)
	Equipment Lifetime, years	3	National Safety Council (1999)
	AEC, quads	0.20	ADL (2002a)
Residential Monitors	Installed Base, (millions)	51	ADL (2002a) (based on shipment data from IDC, 2000)
	Equipment Lifetime, years	3	National Safety Council (1999)
	AEC, quads	0.051	Kawamoto et al. (2001) and Calculation (see Appendix A-VII)

Monitors have short lifetimes and are replaced, on average, every three years, often as part of the purchase of a new computer.

A10.2 Product Technology Descriptions and Market Presence

Cathode ray tube (CRT) monitors made up ~97% of the monitor installed base in Y2000, with liquid crystal displays (LCDs) capturing most of the rest of the market (ADL, 2000). Thus, the 'typical new' and 'installed base'

Many monitors "power-down" into a lower-power "sleep" mode after a period of computer inactivity using power management software installed on the computer connected to the monitor, usually to comply with the voluntary ENERGY STAR® program. Users can – and very often do – disable the ENERGY STAR® power management software, leading to a lower power management-enabled rate for monitors than theoretically possible. In the commercial sector, the Y2000 power management-enabled rate stood at about 60% (Nordman et al., 2000), whereas more than 90% of the monitors sold that year were ENERGY STAR®-capable (Webber et al., 2000). As many PCs and monitors have extended periods of inactivity during the workday and an estimated 30% of commercial monitors remain on in "active" mode throughout the night[36] (Webber et al., 2001, from night audits), the power management-enabled rate has a major influence on monitor annual energy consumption. Monitors also draw a low level of power when turned off but plugged in.

[35] A relatively small quantity operate in industrial settings; they are included in the commercial building category.
[36] The same night audits found that 38% are "on" but in "sleep" mode at night.

Thus, decreases in the "active" power draw of the display and increases in the power management-enabled rate are the two primary ways of reducing the AEC of monitors (see Table A10-2; Appendix A-VII contains calculation details).

Table A10-2: Monitor Technology Levels and UEC Values (Commercial and Residential)

Technology/Standard Level	UEC (KW-h)		Comments
	Comml.	Res.	
Typical New	333	92	17-inch CRT, 60% Power management-enabled
Installed Base	333	92	17-inch CRT, 60% Power management-enabled
Minimum Efficiency Standard	N/A	N/A	No minimum efficiency standard for monitors
CRT, 100% Power management-enabled	149	84	17-inch display
LCD	51	17	15-inch display, 60% Power management-enabled
Cholesteric LCD	4.5	1.9	15-inch display, 60% Power management-enabled
Organic Light-Emitting Diode (OLED)	17		15-inch display, 60% Power management-enabled
1 W "Sleep" Mode	301	64	17-inch CRT, 60% Power management-enabled

Monitors do not have a minimum efficiency standard, but do fall under the voluntary ENERGY STAR® program. The ENERGY STAR® program states that the monitor must go into sleep mode after a period of inactivity, with the default time set to less than 30 minutes. The 100% power management-enabled rate levels in Table A10-2 refers to rates for the *entire population* of PCs, not for an individual PC – an individual PC is either enabled or not. Because over 90% of PCs sold most PCs are ENERGY STAR®-compliant, most PCs are currently capable of having the power management features enabled. Increasing the power management-enabled rate can be achieved via an increase in personal awareness/encouragement to enable the feature, modifications to the software (or network software), or electronic devices that detect user inaction and power down the computer. Software enabling network administrators to control the ENERGY STAR® power management settings for all computers and their monitors connected to the network has recently come to market (EZConserve, 2002). In addition, an electronic device exists that automatically shuts down individual monitors after a prescribed period of inactivity (Bayview, 2002).

Increases in power management-enabled rates achieved through awareness/encouragement have minimal direct cost impact, as most PCs include power management software. A cost-benefit analysis for the network-wide power management software[37] or electronic devices[38] has yet to be performed.

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[37] The EZConserve system had a list price in February, 2002 of $15 or $20 per computer, depending upon the number of computers hooked up to the network.

[38] The Bayview Technology Group *MonitorMiser Plus* units has list prices of up to $59 per monitor, depending upon the number of units purchased.

The LCD level assumes that a 15-inch LCD[39] replaces all CRT displays, while the ENERGY-STAR®-enabled rate remains the same. As of Y2000, LCDs represented less than 3% of the total monitor stock, but their sales doubled from 1999 to 2000. In January, 2002, a 15-inch LCD had about a $250 price premium relative to a 17-inch CRT (PC Connection, 2002); for an electricity price of $0.08/kW-h, this translates into payback periods of greater than 10 and 40 years for commercial and residential usage patterns. LCD market share is expected to continue to grow aggressively in the years to come as their price decreases further and people opt for the improved image quality and more compact footprint of LCDs relative to CRTs.

Cholesteric LCDs are a type of "bi-stable" display technology. In contrast to CRTs or LCDs, which always update each line or pixel at a fixed rate, each pixel of a bi-stable display continues to display the same information until it changes. For cholesteric LCDs, this could potentially result in up to a 10-fold reduction in energy consumption relative to conventional LCDs. Excessive cost and slow addressing (update) speeds have kept – and will likely continue for several years to keep - cholesteric LCDs out of the monitor market (ADL, 2002).

Organic light-emitting diode (OLED) displays consist of light-emitting diodes sandwiched between an anode and cathode, which create a voltage difference across the diode to generate light. They eliminate the energy-consuming backlight and, ultimately, could reduce the power consumption by factor of 3 relative to LCDs (Economist, 2001). To date, a limited number of cell phone models have used OLEDs for small display because of their superior resolution and low power consumption. No computer monitors currently use an OLED-based display. In the future, OLED-based displays offer the potential for reduced costs relative to LCDs; however, currently, they are not cost-competitive with LCDs and problems remain with sustaining color quality over time.

As of January, 2002, the ENERGY STAR® website[40] listed 90 17-inch or larger monitors that draw 1-Watt or less in "sleep" mode; the model with the lowest sleep mode power draw (the Fujitsu Siemens 17P3) consumes 0.08W. The price premium – if any – of implementing a 1-Watt sleep mode is not known. In July, 2001, the White House issued an executive order (White House, 2001) to purchase devices using less than 1 Watt in "standby" mode (i.e., "sleep" mode for monitors) "when life-cycle cost-effective and practicable and where the relevant product's utility and performance are not compromised as a result". This will provide impetus for monitor manufacturers to make monitors that draw less than 1 Watt in "sleep" mode.

A10.3 Test Procedure Status

Monitors lack a DOE test procedure but do have an ENERGY STAR® test procedure to measure power draw in the sleep mode. Under controlled climatic and power quality

[39] Because LCD screens have higher resolution and have a greater viewable area (for the same nominal display size) than a CRT display, a 15-inch LCD effectively replaces a 17-inch CRT monitor.
[40] See the list of qualifying products at: http://yosemite1.epa.gov/estar/consumers.nsf/content/monitor.htm, values for "deep sleep". The "deep sleep" mode is most relevant, because the bulk of "sleep" mode energy consumption occurs during nights and weekends, i.e., extended periods when the monitor would have enough time to enter the ENERGY STAR® "deep sleep" mode.

conditions specified in the test procedure, the monitor is plugged in and let sit for a period of inactivity until it enters “sleep” mode (default time set to less than 30 minutes). The tester then measures the true standby power of the device with a resolution of 0.1 W, taking care to average the measurement over a sufficiently long time period to obtain an accurate value.

Because the ENERGY STAR® test procedure does not measure “active” power draw, it does not correlate closely with device UEC because the active mode dominates device UECAEC, i.e., the active mode accounts for 89% of the installed base of monitors with commercial usage patterns (ADL, 2002). Thus, the test procedure fails to capture any energy savings from reductions in monitor active power draw. If the power management-enabled rate increased to 100%, the test procedure still remains weakly relevant, as the “sleep” mode then accounts for about 32% of monitors’ AEC.

Similarly, the ENERGY STAR® test procedure correlates weakly with the peak demand impact of monitors because the monitor’s active mode dominates the peak power impact of monitors (most commercially-used computers and their monitors are active during the work day) and the test procedure measures only “sleep” mode power draw. Even if the power management-enabled rate reached 100%, the active mode would continue to dominate aggregate monitor peak demand.

In contrast, the ENERGY STAR® test procedure will fully capture the energy consumption, energy savings, and peak demand reduction impact of the 1W “sleep” mode power level.

A10.4 Energy Savings Estimates and Calculations

Monitor energy consumption and savings calculations reflect surveys of power management-enabled rates (Nordman et al., 2000), combined with daytime usage estimates (Kawamoto et al., 2001) and night-status audits (Webber et al., 2001). All desktop PC energy savings estimates are calculated relative to a “typical new” 17-inch CRT monitor. Table A10-3 and Table A10-4 present the energy consumption and potential saving estimates for the different monitor technologies, as applied to residential and commercial monitors, respectively (Appendix A-VII offers calculation details).

Table A10-3: Residential Monitor Energy Savings Potential

Technology/Standard Level	UEC (kW-h)	% Energy Savings Potential	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Typical New 17-inch CRT (60% Power management-enabled)	92	NA	NA	NA
17-inch CRT (100% Power management-enabled)	84	9	0.005	0.10
15-inch LCD (60% Power management-enabled)	17	79	0.041	0.84
15-inch Cholesteric LCD (60% Power management-enabled)	1.9	98	0.050	1.0
15-inch Organic Light Emitting Diode (100% Power management-enabled)	11	88	0.45	0.93
17-inch CRT, 1 W-Sleep (60% Power management-enabled)	64	30	0.016	0.32

Table A10-4: Commercial Monitor Energy Savings Potential

Technology/Standard Level	UEC (kW-h)	% Energy Savings Potential	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Typical New 17-inch CRT Technology (60% Power management-enabled)	333	NA	NA	NA
17-inch CRT (100% Power management-enabled)	149	57	0.13	2.6
15-inch LCD (60% Power management-enabled)	51	79	0.17	3.6
15-inch Cholesteric LCD (60% Power management-enabled)	4.5	99	0.22	4.5
15-inch Organic Light Emitting Diode (100% Power management-enabled)	17	95	0.21	4.3
17-inch CRT, 1 W-Sleep (60% Power management-enabled)	301	10	0.02	0.44

Table A10-5: Total Monitors Energy Savings Potential

Technology/Standard Level	Annual Energy Savings Potential(quads)	Energy Saving Potential (2008-2030), (quads)
Typical New 17-inch CRT Technology (60% Power management-enabled)	NA	NA
17-inch CRT (100% Power management-enabled)	0.135	2.70
15-inch LCD (60% Power management-enabled)	0.211	4.44
15-inch Cholesteric LCD (60% Power management-enabled)	0.27	5.5
15-inch Organic Light Emitting Diode (100% Power management-enabled)	0.66	5.23
17-inch CRT, 1 W-Sleep (60% Power management-enabled)	0.036	0.76

In both residential and commercial applications, the technologies which reduce the "active" monitor power draw, LCD, cholesteric LCD, and OLED displays, all have a larger energy savings potential than the 100% power management-enabled and 1 Watt "sleep" approaches.

Four factors discernable today will affect the energy savings potentials calculated above. First, the market share of LCDs has grown rapidly and some project the LCD market share to approach 20% by 2004 (IDC, 2000). This would replace a large number of CRT monitors with low-power LCDs. Second, the market share of laptop PCs continues to grow, as their price declines and user opt for their portability, leading an expert to projected that laptops will outsell desktops in Y2003 (Economist, 2000). Laptops use liquid crystal displays precisely because their low power draw increases battery life. Assuming the market share of laptop PCs continued to grow and does surpass that of desktop PCs, it would have the same effect as replacing a (somewhat smaller) portion of the CRT monitor market with LCDs. Third, the sales of PCs and monitors have trended upwards over the past five years, suggesting that the installed base of monitors may grow in the future (ADL, 2002). Fourth, monitor sales figures reveal that the size of the average monitor sold has steadily increased over the past five years. This trend would tend to increase monitor AEC because larger monitors typically consume more power (ADL, 2002).

A10.5 Regulatory Actions and Cumulative Burden

Monitors have not been subject to regulation for energy efficiency. The extent to which other regulations impact monitors, such as health and safety regulations, was not determined.

A10.6 Issues Impacting Potential Energy Efficiency Standards

At least two issues warrant consideration in determining whether or not to pursue the development and implementation of efficiency standards for monitors. First, monitors have a very short lifetime of about three years, implying that the installed base will “turn over” twice in the period between completion and implementation of a rulemaking. If a significant technology shift does occur over that period (e.g., to LCDs), it could render the rulemaking obsolete and/or moot. Second, mandating increases in the power management-enabled rate depend on fixing the power management settings for devices, either via software on the computer, on a computer network, or via hardware when the device becomes “inactive” after a certain period of time. It is not clear whether or not regulation specifying when a device *must* power down can be promulgated. Furthermore, as computers become more integrated into peoples’ lives, the demand for “always on” functionality almost certainly increase, making the definition of “inactive” and “certain period” important.

A11.1 Background

Fluorescent lamps are started and operated by fluorescent ballasts. Of the lamp types listed in Table A11- 1, there were approximately 1,552 million fluorescent lamps installed in commercial, industrial, and other non-residential applications in the US in 2001. These fluorescent lamp/ballast systems consumed about 2.2 quads of energy per year in these sectors (see Table A11- 1). In 2001, the T12 lamps with magnetic ballasts accounted for about 65% of the installed base and about 74% of total fluorescent annual energy consumption. The T8 systems with electronic ballasts made up about 35% of the stock in 2000.

Table A11- 1: Fluorescent Lamp Background Data

Type	Data type	Value	Source
F40T12	Installed Base, millions (2001)	790	ADL (2002c)[41]
	Annual Shipments, millions (2001)	139.8	
	Equipment Lifetime, years	5.1	
	AEC, quads (2001)	1.38	
F32T8	Installed Base, millions (2001)	532	
	Annual Shipments, millions (2001)	119.4	
	Equipment Lifetime, years	4.9	
	AEC, quads (2001)	0.74	
U-tubes (T12 & T8)	Installed Base, millions (2001)	49	
	Annual Shipments, millions (2001)	11.7	
	Equipment Lifetime, years	5.1	
	AEC, quads (2001)	0.09	
F96T12	Installed Base, millions (2001)	180	
	Annual Shipments, millions (2001)	52.4	
	Equipment Lifetime, years	2.6	
	AEC, quads (2001)	0.78	
F96T8	Installed Base, millions (2001)	2.6	
	Annual Shipments, millions (2001)	0.49	
	Equipment Lifetime, years	3.3	
	AEC, quads	0.004	

A11.2 Product Technology Descriptions and Market Presence

A *fluorescent lamp* consists of a glass tube with a phosphor material coating the inside walls. The sealed tube is filled with inert gases and a small amount of mercury. A heated cathode produces electrons, and when high voltage is applied between the electrodes, an electrical arc is struck between the cathode and anode at opposite ends of the tube. This causes the gas to ionize, and an electric current flows through the tube. This current excites the vaporized mercury, and UV (ultraviolet) radiation is emitted as the mercury

[41] The shipments estimate included in ADL(2002c) were mathematically derived using the installed base, average life and average operating hours.

atoms return to their ground state. This UV radiation is absorbed by the phosphor coating and re-emitted as visible light.

The most common fluorescent lamp in use is the “reduced-wattage” (sometimes called “energy saver”) F40T12, which consumes 34W as opposed to the standard F40T12 which uses 40W (nominal lamp wattage). Although more efficacious phosphor coatings exist, the most common is halophosphate. This lamp is available both in straight tube form, and a U-shape, or U-tube, for a shorter fixture. The U-shaped lamp has a slightly lower efficacy (lumens per Watt) than the straight lamp. The T12 lamp comes in various lengths, with four-foot lamps being the most common, followed by eight-foot or “slimline” lamps. High output fluorescent lamps also come in a range of lengths, and are operated with a higher current to achieve greater lumen output.

The T12 lamp can be operated with an old "standard" ballast, an "energy-efficient" magnetic ballast (the “energy-efficient” ballast has become the conventional ballast since the January 1990 NAECA/EPCA regulations), a cathode cutout or hybrid ballast, or an electronic high-frequency ballast.

Rare-earth phosphor lamps (sometimes referred to as tri-phosphor lamps) use several different rare-earth phosphors that emit visible light in the primary color spectra. These phosphors have high color rendering, and the lumen output is higher, increasing the lamp efficacy. Lamps using rare-earth phosphors are available in several versions that vary in light output and color rendering index.

T8 lamps are one inch in diameter and use only the tri-phosphor (rare-earth) coatings. They fit in the same sockets as T12 lamps, require a different ballast. The T8 lamp can be operated by an energy-efficient magnetic ballast or an electronic ballast. The combination of a T8 lamp with an electronic ballast is one of the most efficacious fluorescent light sources on the market and is identified at the “best available” technology. These lamps are available in various lengths, with four-foot being by far the most common. T8 lamps are also available in U-shaped form.

Fluorescent lamps are used with fluorescent lamp ballasts. The ballast type often drives the choice of lamp type. T12 lamps, both standard wattage and reduced-wattage lamps, are most often used with magnetic ballasts. T8 lamps, on the other hand, are most often used with electronic T8 ballasts. Electronic ballasts that drive T12 lamps are available, but are not commonly installed.

This analysis considers the five different lamps shown in Table A11- 1. For all T12 lamps, the baseline lamp has a halophosphor coating with an energy-efficient electromagnetic ballast. For T8 lamps, 700-series rare earth phosphor lamps is the baseline (i.e., the “FEMP Recommended” level of scenario 1).

Table A11-2 presents the UEC values for different lamp technologies for 4- and 8-foot T12 lamps (see Appendix A-VIII for more information, including different lamp types).

Table A11-2: Fluorescent Lamp Technology Levels and UEC Values

Technology Level	Value		Comments/Source
	4-Foot	8-Foot	
Stock, UEC (kWh/yr)	133	266	ADL (2002c)
Typical New, UEC (kWh)	133	266	Same as stock technology
Minimum Efficacy Standard	See Table A11-3	See Table A11-3	Energy Policy Act of 1992
Scenario 1 – FEMP Recommended, UEC (kWh/yr)	122	253	Assumes increase in lamp efficacy to FEMP Recommended lumen levels decreases lamp wattage
Scenario 2 – FEMP Best Available, UEC (kWh/yr)	118	231	Assumes increase in lamp efficacy to FEMP Best Available lumen levels decreases lamp wattage
Energy Star Level	N/A	N/A	

All of the technology options for the three scenarios are commercially available from several manufacturers.

Table A11-3 displays the current EPAct fluorescent lamp standard levels.

Table A11-3: Energy Policy Act Fluorescent lamp Standard Levels

Lamp Type	Nominal Lamp Wattage	Minimum CRI	Minimum Average Lamp Efficacy (lumens/Watt)
4-foot medium bi-pin	>35 W	69	75.0
	<= 35 W	45	75.0
2-foot U-shaped	>35 W	69	68.0
	<= 35 W	45	64.0
8-foot slimline	>65 W	69	80.0
	<= 65 W	45	80.0
8-foot high output	>100 W	69	80.0
	<= 100 W	45	80.0

A11.3 Test Procedure Status

The DOE test procedure Final Rule was issued on May 29, 1997 and is codified in 10CFR430 Subpart B, Appendix R: *Uniform Test Method for Measuring Average Lamp Efficacy (LE) and Color Rendering Index (CRI) of Electric Lamps.* This test procedure measures average lamp efficacy (LE), based on measurements of light output and lamp wattage, and color rendering index (CRI). Thus, the test procedure correlates well with lamp energy consumption.

The test procedure references IESNA LM-9 (Illuminating Engineering Society of North America) *IES Approved Method for the Electrical and Photometric Measurements of Fluorescent Lamps*, except that lamps shall be operated at the appropriate voltage and current conditions as described in ANSI C78.375 and in ANSI C78.1, C78.2 or C78.3, and lamps shall be operated using the appropriate reference ballast as described in ANSI C82.3. The test procedure probably does not need to be changed. Language should probably be added to the DOE test procedure to clarify that the most recent IESNA test procedure standard be used.

A11.4 Energy Savings Estimates and Calculations

Energy savings calculations are performed for two scenarios, both of which study a change to make T12 and T8 lamps more efficacious. Scenario 1 assumes a lamp efficacy standard in which fluorescent lamps (4-foot, 8-foot, and U-tube) meet the FEMP procurement Recommended lumen output levels (FEMP, 2000). Scenario 2 assumes a lamp efficacy standard in which fluorescent lamps (4-foot, 8-foot, and U-tube) meet the FEMP procurement Best Available lumen output levels (FEMP, 2000). Savings arise from improvements in T12 and T8 lamp efficacy, not from substitution of T8 lamps for T12 lamps.

This analysis was performed using two alternate base cases. The first was a *static base case*, which used the same methodology as the analyses for the other technologies. In this base case, annual consumption for the year 2001, for each of the 5 system types, was assumed to represent consumption for all years (2008 – 2015).

However, for this product, the static base case does not incorporate the interactive effects of the fluorescent lamps and their fluorescent ballasts. As the fluorescent ballast market changes, due to market trends as web as the upcoming DOE ballast standards, fluorescent lamp technology tends to change accordingly. Typically, the switch to electronic fluorescent ballasts is accompanied by a switch from T12 to T8 fluorescent lamps. Therefore, a *dynamic base case* was also created, which incorporated an annual projection of fluorescent consumption, based on the market trends and the standards impacts as projected in the fluorescent ballast TSD (DOE, 2000). The resulting savings were far lower than those estimated under the static base case.

Scenarios 1 and 2 are analyzed (under both base cases) assuming that as the efficacy of the lamp increases with the standard scenario, the lumen output is held constant so wattage decreases proportionally. To keep light levels constant, designers and specifiers may respond to this standard by selecting ballasts with lower energy consumption, or have fewer lamps per fixture or fewer fixtures in lit spaces. Table A11-4 presents the energy consumption and saving estimates for the two scenarios for the static base case. Table A11-5 presents the results for the dynamic base case.

Table A11-4: Fluorescent Lamp Scenarios Potential Saving Estimates, Static Base Case

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline	NA	NA
Scenario 1 – FEMP Recommended	0.15	1.84
Scenario 2 – FEMP Best Available	0.30	3.54

Table A11-5: Fluorescent Lamp Scenarios Potential Saving Estimates, Dynamic Base Case

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline	NA	NA
Scenario 1 – FEMP Recommended	varies	0.14
Scenario 2 – FEMP Best Available	varies	0.47

Data for the analysis were derived from the Draft Phase I report (ADL 2002c) and the ballast standards analysis (Turiel et al., 2000 and LBNL, 1996-2002). See Appendix A-VIII for calculation details, including the different baselines used for different lamps.

For Scenarios 1 and 2, number of installed lamps, the operating hours and average wattage are all derived from the Draft Phase I inventory report (ADL 2002c). This study derives its estimates chiefly from building audits and end-use metering studies. Baseline technology wattages are normalized42 watts from the ballast standards analysis, as are the ballast factors (Turiel et al., 2000 and LBNL, 1996-2002).

There are two uncertainties in the energy savings calculations. First, it is assumed that if more efficacious lamps become the standard, lighting engineers will hold today's light output levels constant. If you put a more efficient lamp in a fixture, you simply get more light; it still operates at the same wattage. To actually keep light output constant, you would have to replace ballasts in all of today's fixtures, which would be more expensive than simply installing a new bulb. Second, the Draft Phase I inventory (ADL, 2002c) is based on audits and monitoring studies conducted in the 1990s. This data was then statistically extrapolated using a smaller sample of more recent audits, to establish a new baseline for 2001; thus the shares of T12 vs. T8 are estimated. The market shares of T8 fixtures in the baseline should be higher than the shares of T12 fixtures by 2008. This is because of a market trend toward electronic ballasts (usually with T8 lamps), which will be rapidly accelerated when the DOE ballast standards take effect in 2005 and in 2010. Therefore the T12/T8 mix in the installed base will change over the analysis period, but this change is not reflected in the static base case. Regulatory Actions and Cumulative Burden

A11.5 Regulatory Actions and Cumulative Burden

Existing EPA mercury disposal requirements apply, but EPA issued a final rule July 6, 1999, including lamps as Universal Hazardous Waste.

Fluorescent lamps are regulated under the Energy Policy Act of 1992. The law set standards for common 4-foot, 2-foot U-tube, 8-foot slimline, and 8-foot high output

[42] Watts are normalized by the ratio of baseline ballast factor to the technology option ballast factor, so that lumen output is equivalent for the baseline and the technology option.

fluorescent lamps. The metric is a combination of efficacy (lumens/Watt) and CRI (color rendering index). The effect is that the 40-watt and 75-watt ("standard wattage") T12 lamps with halophosphor coatings do not comply; most of these lamps have now been phased out of the stock. The reduced-wattage (energy saver) 34-watt and 60-watt T12 lamps are the least expensive lamps that meet the standard. However, more efficacious T12 lamps such as rare earth phosphor T12 lamps are also compliant, as well as all T8 lamps. Table 1-2 shows the different technology levels for fluorescent lamps while Table 1-3 shows the EPAct standard levels.

Fluorescent lamps are also required to be labeled under the Energy Policy Act. Compliant products must be marked with the letter "E" in a circle to indicate compliance.

Fluorescent lamp ballasts are regulated under NAECA/ECPA. The new ballast standards published in 2000 will require ballasts to be electronic for new luminaires beginning in 2005, and replacement ballasts to be electronic in 2010. Although electronic T12 ballasts meet the standards, nearly all the electronic ballasts purchased are expected to be T8 ballasts, following the present market trends cited above. Therefore, most fluorescent lamps purchased with new ballasts are likely to be T8 lamps.

A11.6 Issues Impacting Potential Energy Efficiency Standards

The major issue is that fluorescent lamps are part of a lamp/ballast system, so that regulations on lamps are affected by the ballast standards.

A12 Energy Consumption and Saving Estimates for High Intensity Discharge Lamps

A12.1 Background

High Intensity Discharge (HID) lamps can commonly be found outdoors, illuminating roadways and parking lots, as well as inside in high-bay spaces such as retail outlets and gymnasiums. Similar to fluorescent lighting, HID lamps are started and operated by ballasts. The approximately 167 million HID lamps installed in the US consume about 1.38 quads of energy per year (see Table A12- 1). One type of HID lamp, Mercury Vapor, comprises about 13.2% of the installed base and about 18.8 % of total HID annual energy consumption.

Table A12- 1: High Intensity Discharge Lamp Background Data

Type	Data type	Estimated Value	Source
Mercury Vapor	Installed Base, millions (2000)	22	See Appendix A-IX
	Annual Shipments, millions (2000)	1.8	
	Equipment Lifetime, years	6.5	
	AEC, quads	0.26	
Metal Halide	Installed Base, millions (2000)	74	
	Annual Shipments, millions (2000)	18	
	Equipment Lifetime, years	4.8	
	AEC, quads	0.45	
High Pressure Sodium	Installed base, millions (2000)	71	
	Annual Shipments, millions (2000)	11.5	
	Equipment Lifetime, years	7.0	
	AEC, quads	0.67	

A12.2 Product Technology Descriptions and Market Presence

The three basic types of HID lamps include mercury vapor, metal halide, and high-pressure sodium. These three lamp types are constructed in a similar fashion, with an arc tube enclosed inside an outer bulb. The arc tube contains the electrodes and starting gas. Similar to fluorescent lamps, but at higher internal pressures, when a current is applied the lamps will start emitting light. While there are other types, only Edison base lamps are considered in this analysis. Table A12-2 summarizes the range performance characteristics of the three basic HID lamp types.

Table A12-2: Summary of HID Lamp Technology Performance Characteristics

Characteristic	Mercury Vapor	Metal Halide	High Pressure Sodium
Wattage Range (W)	40-1000	70 - 1500	35 - 1000
Luminous Efficacy (LPW)	17-50	70 – 100+	32-55 for <100W 60-115 for >100W
Color Rendering Index	16-43	60-85	20-32 and color improved 65-75
Starting time	3-7 minutes	2-10 minutes	3-4 minutes
Restrike time	3-7 minutes	up to 15 minutes	1 minute

Mercury Vapor (MV) lamps produce light by passing current through mercury vapor at a relatively high-pressure (30 to 60 psi). MV is the oldest HID source and the least efficient. MV efficacies range from 10 to 63 lumens per watt making them more efficient than incandescent (9 to 23) but less efficient than fluorescent (29 to 73).

Most mercury lamps are constructed with two envelopes: an inner envelope (arc tube) and an outer envelope, which protects the arc tube and contains an inert gas. The arc tube is usually made of fused silica with the current conductors sealed into the ends. The starting gas for MV is argon and the outer bulb contains an inert gas (nitrogen) that prevents oxidation and maintains the operating temperature. MV lamps operate under high pressure and very high temperature.

A significant portion of the energy radiated by the mercury arc is in the ultraviolet region. Through the use of phosphor coatings on the inside surface of the outer envelope, some of this ultraviolet light is converted to the visible spectrum by the same mechanism employed in fluorescent lamps.[43] MV lamps are available clear or coated and range in wattage from 40 to 1000 watts. The clear lamps have a bluish-white color and poor color rendering index (CRI) (16 to 22). The phosphor-coated lamps have a better color appearance and color rendering (CRI is 35 to 63).

MV lamps are most commonly found in interior industrial applications, streetlighting, security lighting, floodlighting, air/bus/train terminals, gymnasiums, and high ceiling interior commercial applications. Currently MV is rarely used in new lighting systems but is a big seller as a “dusk to dawn” exterior fixture either leased from a utility company or purchased from home repair outlet stores.

Metal Halide (MH) lamps are generally similar in construction to the MV lamps. The principal difference is the addition of iodides of metal halides (salts) to the arc tube gases. These salts can include indium, scandium, sodium, and thallium, in addition to the mercury vapor and argon gas. Since MH lamps are a mixture of salts, light color can vary slightly from lamp batch to batch. In addition, they normally change color throughout their life and are sensitive to lamp position (base up, down or horizontal). As with MV lamps, MH lamps operate under high pressure and temperature. As with all HID lamps, there is a possibility that the arc tube might rupture. When this happens, if the outer lamp fails to

[43] Lighting Handbook Reference and Application

contain the ruptured arc tube, particles of very hot quartz as well as glass fragments could create a risk for personal injury or fire. As a result most manufacturers caution that certain MH lamps only be operated in fixtures which provide enclosures designed to keep any glass fragments inside the fixture.

MH lamp shipments have increased three-fold between 1990 and 2000 (NEMA, 2002). The combination of EPAct standards for incandescent reflector lamps, combined with improvements in MH life times and the development of lower wattage lamps, have contributed to this significant growth. Recent studies have also found that “white-light” lamp sources have advantages over high-pressure sodium (HPS) sources for nighttime exterior lighting. Indeed, many cities are replacing their HPS lamps in downtown areas with MH.

MH starting times range from 2 to 10 minutes and during that time the lamp will go though several color changes until it reaches its equilibrium color. MH has a longer restart time due to their operation at higher temperatures than MV. It takes longer for the MH to cool and lower the vapor pressure; consequently the restrike time may be as long as 15 minutes.

High Pressure Sodium (HPS) lamps produce light by having an electric current pass through sodium vapor. Like other HID lamps, HPS have two envelopes; an inner arc tube is constructed of ceramic (which resists sodium attack at high temperatures) and an outer glass envelope. The ceramic arc tube is translucent and provides good light transmission. The arc tube contains xenon as a starting gas and a small quantity of sodium-mercury amalgam. Lamp types are available with diffuse coatings on the inside of the outer envelope.

The HPS color of light is usually described as “golden white”, and is most often found illuminating streets and highways. Improved HPS color lamps are available, which operate under a higher arc tube pressure and have better color rendering properties (a CRI of 65 or greater). However, this performance characteristic comes at the expense of lamp life and luminous efficacy.

Table A12-3 summarizes the HID lamp technology levels and the performance characteristics used for the energy savings potential analysis.

Table A12-3: HID Lamp Technology Levels and UEC Values

Technology Level	Value			Comments/Source
	MV	MH	HPS	
UEC (kWh/yr)	1,062	688	486	Assumes a 243 system Watt MV lamp would be replaced by either a 157 system Watt MH lamp or a 111 system Watt HPS lamp. Wattage is based on lamp/ballast system input Watts (LBNL, 2002)
Mean Lumens	8,250	7,400-8,000	8,850	GE Lighting Catalogue; Philips Lighting Lamp Specification and Application Guide
Minimum Efficacy Standard	N/A	N/A	N/A	HID are not regulated for energy efficiency
Best Available UEC (kWh)	N/A	N/A	N/A	Minimal gains relative to similar types of HID lamps
Energy Star Level	N/A	N/A	N/A	HID lamps are not part of the ENERGY STAR® PROGRAM

A12.3 Test Procedure Status

The Energy Policy Act of 1992, Section 346 and Title 42, chapter 77, section 6317 of the U.S. Code specifies that for high-intensity discharge lamps the Secretary shall, within 30 months after October 24, 1992, prescribe testing requirements for those high-intensity discharge lamps for which the Secretary makes a determination that energy conservation standards would be technologically feasible and economically justified, and would result in significant energy savings. At this time there are no parallel authorities in the CFR for this section (42 USC 6317).

Currently the DOE has not established a test procedure for HID lamps, presumably because they are inherently more efficient than other types of lamps. In other words, lamp conversion from less efficient technologies to HID results in significant energy savings. Therefore, NIST has not taken action to establish a DOE test procedure for HID lamps (Treado, 2002). Existing industry test procedures for HID lamps are in place should DOE initiate a standards rulemaking process. These include: IESNA Test Procedure LM-51-00 *Electrical and Photometric Measurements of HID Lamps*. This test procedure measures photometric total flux and light intensity.

Other considerations impacting performance of HPS lamps include ballast design circuits that enable ballasts with igniter circuits to disconnect the igniter when the lamp fails. In the absence of a disconnect circuit, the ballast may not recognize that the HPS lamp has failed and will continually try to restart the lamp, thereby destroying the igniter and possibly the ballast as well. If an HPS lamp is not replaced within a week or so, the igniter and possibly the ballast might have to be replaced as well. This can double or triple the cost of lamp replacement.

A12.4 Energy Savings Estimates and Calculations

The energy savings calculations supposed that in 2008 all HID lamps rated at 100W or higher must have an efficacy of at least 50 lumens per watt. Since current MV lamps do not meet these efficacies they would not meet the standard. Operating hours for MV lamps are assumed to be 12 hours per day, 365 days per year, as many of these lamps are used in exterior fixtures controlled by a photocell. All wattages are system Watts and include ballast inputs watts. The wattages were calculated in 1996 using the HID Analysis ballast database (LBNL, 1994-1996). Table 1-3 summarizes the potential energy savings from the two HID lamp scenarios; Appendix A-IX provides additional calculation details.

Table A12-4: HID Lamp Energy Savings Potential Estimate

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline	NA	NA
Minimum Efficacy = 50 lumens/Watt	0.067	1.4

A12.5 Regulatory Actions and Cumulative Burden

High Intensity Discharge lamps are a regulated product under the Energy Policy Act of 1992 but are currently not being regulated by DOE (i.e., the DOE has yet to make a decision to promulgate standards for HID lamps). In the early 1990s DOE initiated an analysis of HID lamps for possible standards. DOE determined that the HID analysis was a low priority in early 1997 because preliminary estimates indicated 30 year cumulative savings would be less than one quad.

A12.6 Issues Impacting Potential Energy Efficiency Standards

The first cost (price) disparity between “dusk to dawn” mercury vapor lamps, combined with non-user ownership in many instances, make it unlikely that many end-users would exchange a MV fixture for a more expensive (and efficacious) alternative. In 1993, the popular “dusk to dawn” fixture, which is equipped with a 175-Watt lamp, represented approximately one-half of MV sales (LBNL, 2002). Utility customers use them to mark their driveways, light barn exterior, light areas near fuel tanks, etc. That fixture can be purchased for about $30 while its HPS equivalent costs about $70 at the same stores. In many instances, rural utilities lease ‘dusk to dawn’ fixtures to its customers, which tends to decrease the incentive for the customers to invest in a more efficient lamp technology. In cities and suburbs contractors purchase them at electrical suppliers, while and private citizens purchase them at hardware stores or home development retail stores.

A13 Energy Consumption and Saving Estimates for Incandescent Lamps

A13.1 Background

There are approximately 3,788 million incandescent general service, or A-type, lamps installed in the US, of which 3,529 million (93 percent) are in the residential sector. Incandescent lamps consume about 2.5 quads of energy per year, 1.7 quads (67 percent) of which is in the residential sector and 0.83 quads in the commercial/industrial/other[44] sectors (see Table A13-1). The hours of operation of incandescent lamps in the residential sector are considerably lower than the hours for the non-residential sectors.

Table A13-1: Incandescent Lamp Background Data

Type	Data type	Value	Source
General service / A-type – residential	Installed Base, millions (2001)	3,529	ADL (2002c)
	Annual Shipments, millions (2001)	2,429[45]	
	Equipment Lifetime, years	1.5	
	AEC, quads	1.68	
General service/ A-type – commercial / industrial / other	Installed Base, millions (2001)	259	
	Annual Shipments, millions (2001)	884[46]	
	Equipment Lifetime, years	0.4	
	AEC, quads	0.83	

A13.2 Product Technology Descriptions and Market Presence

An *incandescent* lamp heats a tungsten metal filament enclosed in a glass bulb filled with argon and a small amount of nitrogen. An applied voltage causes the filament to incandesce, producing visible light. However, much of the incandescent lamp's emissions are in the infrared, (thermal) range of the electromagnetic spectrum. This heat provides no light and is the reason for the relatively low efficacy (i.e., lumens per Watt) of the incandescent lamp.

The two major categories of incandescent lamps are *general service* and *reflector* lamps. General service are pear-shaped "A-lamps". Reflector lamps, such as flood or spot lights, are used for special applications requiring directional illumination. The following discussion covers incandescent general service lamps.

The *reduced-wattage* incandescent lamp operates at a slightly lower wattage than the standard lamp it replaces, and has reduced light output. Several design features are available to increase efficacy (although some lamps are not more efficacious than their full-wattage counterparts). Some major manufacturers have eliminated the molybdenum

[44] The “other” sector includes other stationary lighting installations such as airport runways, stadium lighting, street lighting, billboard lighting and so on. These installations are subject to EPACT 1992.
[45] The shipments estimate included in ADL(2002c) was mathematically derived using the installed base, average life and average operating hours.
[46] The shipments estimate included in ADL(2002c) was mathematically derived using the installed base, average life and average operating hours.

filament supports and/or have changed the composition and reduced the diameter of the lead-in wires. These techniques reduce conduction heat loss from the tungsten filament.

The *tungsten halogen capsule* lamp contains a quartz capsule surrounding the filament filled with a halogen gas (usually iodine or bromine), which slows down the evaporation of tungsten by redepositing the tungsten on the filament via the "halogen regenerative cycle." This redeposition of tungsten allows the filament to operate at a higher temperature, increasing efficacy and lamp life. Generally, halogen lamps are about 15% more efficacious and last more than twice as long as the normal lamp they're replacing.

Prototype *halogen infrared (HIR)* general service lamps have been produced. Because over 90 percent of energy radiated by incandescent lamps is in the form of heat (infrared radiation), efficacy can be improved by reflecting the infrared portion of the spectrum back onto the lamp filament. This enables the filament to achieve its desired operating temperature using fewer watts, hence improving the light output per watt consumed. HIR lamps use a thin film coating on the halogen capsule to reflect the infrared light.

Table A13-2 shows the different technology levels for incandescent lamps.

Table A13- 2: Incandescent Lamp Technology Levels and UEC Values

Technology Level	Value		Comments/Source
	Res	Non-Res	
Stock, UEC (kWh/yr)	43	293	Wattage and lighting hours from ADL (2002)
Typical New, UEC (kWh)	43	293	Assumed same as stock
Minimum Efficacy Standard	N/A	N/A	General service incandescent lamps are not subject to minimum efficiency standards
Scenario 1 – 1.5% Efficacy Increase, UEC (kWh/yr)	43	289	Assumes 1.5% increase in lamp efficacy used to decrease bulb wattage
Scenario 2 – 3.0% Efficacy Increase, UEC (kWh/yr)	42	284	Assumes 3.0% increase in lamp efficacy used to decrease bulb wattage
Best Available (Scenario 3) – Improved Halogen, UEC (kWh/yr)	36	244	Watts from LBNL (2002); lighting hours from ADL (2002)
ENERGY STAR® Level	N/A	N/A	No ENERGY STAR® Program for incandescent lamps

The 1.5% and 3.0% efficacy increase cases are not commercially available, but represent hypothetical improvements in incandescent lamps. Halogen lamps are commercially available, but scenario 3 assumes their efficacy has been improved (to 20% above existing incandescent efficacy); i.e., the efficacy level considered is not available.

A13.3 Test Procedure Status

The DOE test procedure Final Rule was issued on May 29, 1997 and is codified in 10CFR430 Subpart B, Appendix R: *Uniform Test Method for Measuring Average Lamp Efficacy (LE) and Color Rendering Index (CRI) of Electric Lamps.* This test procedure measures average lamp efficacy (LE), based on measurements of light output and lamp wattage, and color rendering index (CRI). Thus, the test procedure correlates well with lamp energy consumption, excepting lamps subject to frequent dimming.

The DOE test procedure references *IESNA LM-45 IES Approved Method for Electrical and Photometric Measurements of General Service Incandescent Filament Lamps*. The test procedure does not need to be changed for the standard. Language should probably be added to the DOE test procedure to clarify that the most recent IESNA test procedure standard be used.

A13.4 Energy Savings Estimates and Calculations

All three Standards Scenarios study a standard setting a minimum level for lamp efficacy. Scenario 1 assumes a lamp efficacy standard in which incandescent lamps must have an efficacy 1.5% higher than the existing average. Scenario 2 assumes a lamp efficacy standard in which incandescent lamps must have an efficacy 3% higher than the existing average. Scenario 3 assumes a lamp efficacy standard in which incandescent lamps must have an efficacy 20% higher than the existing average, which would be achievable using improved halogen technology. The three Scenarios are analyzed assuming that as the efficacy increases, lumen output remains constant and the wattage decreases proportionally. Table 1-3 presents the energy consumption and saving estimates for the three scenarios.

Table A13-3: Incandescent Lamp Scenarios Potential Saving Estimates

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline – Incandescent	NA	NA
Scenario 1 – 1.5% Efficacy Increase	0.04	0.80
Scenario 2 – 3.0% Efficacy Increase	0.07	1.57
Scenario 3– Halogen Technology	0.42	8.52

The number of installed lamps, the average wattage of the baseline case, and the operating hours are all derived from a lighting inventory study (ADL 2002c). This Inventory derives its estimates chiefly from building audits and end-use metering studies. Appendix A-X contains calculation details.

A13.5 Regulatory Actions and Cumulative Burden

Incandescent lamps are not subject to any energy-efficiency regulations in the US. These lamps are subject to a labeling program under the Energy Policy Act of 1992. General service incandescent lamps sold or imported in the US must have labels on their packaging. The labeling program was designed by the Federal Trade Commission (FTC) and took effect in 1995.

As mentioned above, incandescent reflector lamps are subject to labeling requirements. No energy-efficiency standards currently exist for incandescent general service lamps. Other products made by lamp manufacturers are subject to regulation under EPAct (incandescent reflector lamps and fluorescent lamps). Those manufacturers who make ballasts as well as incandescent lamps must comply with the NAECA fluorescent ballast regulations (present and future).

A13.6 Issues Impacting Potential Energy Efficiency Standards

The issue of halogen lamps on the market that have identical wattage to incandescent lamps - but higher lumen output - would need to be addressed for an effective standard. These lamps are more efficacious than the incandescent lamps they replace, but do not necessarily save energy, as people may install lamps of the same wattage and produce more light instead of using reduced-wattage lamps to produce the same light output. Use of halogen technology also increases lamp life, providing more utility to consumers (the lamp lifetime calculations take this into account).

Also, exempted lamps (and their metrics) would have to be carefully considered to avoid loopholes. For example, in the EPACT 1992 regulations for incandescent reflector lamps, “rough and vibration service” lamps and “colored” lamps had to be carefully defined.

Many energy-efficiency programs have focused on encouraging consumers to switch from incandescent to compact fluorescent lamp (CFL) technology. Nevertheless, incandescent lamps remain quite common, especially in residential applications. In some of these applications, CFL substitutes are not available, or are not economically justified. In addition, many consumers have concerns with the quality of light (e.g., CRI) produced by CFLs.

A14 Energy Consumption and Saving Estimates for Incandescent Reflector Lamps

A14.1 Background

Many incandescent reflector lamps, including most PAR lamps, have minimum efficacy standard levels. There are approximately 120 million PAR lamps installed in the U.S., which for simplicity we assume represent the stock of regulated reflector lamps. These lamps consume about 0.29 Quads of energy per year (see Table A14-1).

Table A14-1: Regulated Incandescent Reflector Lamp Background Data

Type	Data type	Value	Source
Incandescent Reflector PAR	Installed Base, millions (2001)	120.3	ADL (2002c), LBNL
	Annual Shipments, millions (2001)	141.5[47]	
	Equipment Lifetime, years	085	
	AEC, quads	0.29	

In addition, there are approximately 226 million unregulated incandescent reflector lamps, i.e., BR and ER lamps and exempted PAR and R lamps, installed in the U.S. These unregulated reflector lamps consume about 0.30 quads of energy per year (see Table A14-2).

Table A14-2: Unregulated Incandescent Reflector Lamp Background Data

Type	Data type	Value	Source
Incandescent Reflector BR, ER, and Other	Installed Base, millions (2000)	226.2	ADL (2002c)
	Annual Shipments, millions (2000)	224[47]	
	Equipment Lifetime, years	1.01	
	AEC, quads	0.30	

A14.2 Product Technology Descriptions and Market Presence

An *incandescent* lamp heats a tungsten metal filament enclosed in a glass bulb filled with argon and a small amount of nitrogen. An applied voltage causes the filament to incandesce, producing visible light. However, much of the incandescent lamp's emissions are in the infrared (thermal) range of the electromagnetic spectrum. This heat provides no light and is the reason for the relatively low efficacy of the incandescent lamp.

The two major categories of incandescent lamps are *reflector* and *general service* lamps. Reflector lamps, such as flood or spot lights, are used for special applications requiring directional illumination. General service are pear-shaped "A-lamps". The following discussion covers incandescent reflector lamps.

[47] The shipments estimate included in ADL(2002c) was mathematically derived using the installed base, average life and average operating hours.

Reflector lamps use specular reflective interior surfaces and lenses to control light emission. "PAR" (parabolic aluminized reflector) lamps are cone-shaped and have a heavy pressed-glass lens cover for protection against outdoor exposure. "R" lamps are longer and have a cylindrical section near the screw base; their lens cover is thinner glass. PAR lamps tend to give better directional control and tend to be more efficacious than R lamps. Two other reflector lamps, elliptical reflector ("ER") and bulged reflector (“BR”) lamps also give better directional control than the R lamp, particularly when installed in enclosed fixtures such as a recessed ceiling downlight. In these fixtures, BR and ER lamps deliver more light for the same energy consumption.

The *reduced-wattage* reflector lamp operates at a slightly lower wattage than the standard lamp it replaces, and may have reduced light output Improved optics from better reflector shape (e.g., changing from “R” to “BR” will allow for a reduction in wattage that could, depending the magnitude of the reduction, result in a drop in light output.

The *tungsten halogen capsule* reflector lamp contains a quartz capsule surrounding the filament filled with a halogen gas (usually iodine or bromine). The halogen atmosphere around the filament slows down the evaporation of tungsten by re-depositing the tungsten back on the filament via the halogen regenerative cycle. This re-deposition of tungsten allows the filament to operate at a higher temperature, increasing efficacy and lamp life. Generally, halogen reflector lamps are about 20% more efficacious and last more than twice as long as the standard reflector lamps they replace.

Halogen infrared (HIR) reflector lamps use a thin film coating on the halogen capsule or on the reflector surface to reflect the infrared light back onto the filament. Because over 90 percent of energy radiated by a lamp’s filament is in the form of heat (infrared radiation), efficacy can be improved by reflecting the infrared portion back, reducing the number of watts required to stay at operating temperature. This technology is presently commercialized for reflector PAR lamps and for higher wattage double-ended quartz halogen lamps.

For the different technologies considered, Table A14-3 summarizes the UEC values for regulated reflector lamps, and Table A14-4 summarizes the UEC values of unregulated reflector lamps.

Table A14-3: Regulated Incandescent Reflector Lamp Technology Levels and UEC Values

Technology Level	Value	Comments/Source
Stock UEC (kWh/yr)	313	Wattage and lighting hours from ADL (2002c)
Typical New UEC (kWh/year)	313	Assumed same as stock technology
Minimum Efficacy Standard	See Table A14-7	Energy Policy Act of 1992
Scenario 1 UEC – 1.5% Efficacy Increase	309	Assumes 1.5% increase in lamp efficacy used to decrease bulb wattage
Scenario 2 UEC – 3.0% Efficacy Increase	304	Assumes 3.0% increase in lamp efficacy used to decrease bulb wattage
Best Available (Scenario 3) UEC – HIR	241	LBNL (2002) estimates of efficacy improvement for HIR lamp; lighting hours from ADL (2002c)
ENERGY STAR® Level	N/A	No ENERGY STAR® program for incandescent reflector lamps

Table A14-4: Unregulated Incandescent Reflector Lamp Technology Levels and UEC Values

Technology Level	Value	Comments/Source
Stock, UEC (kWh/yr)	198	ADL (2002c); BR lamps
Typical New, UEC (kWh) or Power	198	Assumed same as stock technology
Minimum Efficacy Standard	See Table 1-3	Energy Policy Act of 1992
Scenario 1 UEC -1.5% Efficacy Increase	195	
Scenario 2 UEC - Halogen	167	ADL (2002c)
Best Available (Scenario 3) UEC – HIR	129	LBNL (2002) estimates of efficacy improvement for HIR lamp; lighting hours from ADL (2002c)
ENERGY STAR® Level	N/A	No ENERGY STAR® program for incandescent reflector lamps

All the technology options for the three regulated lamp scenarios are commercially available. For the unregulated lamps, only the technology option for scenario 1 is commercially available.

A14.3 Test Procedure Status

The DOE test procedure Final Rule was issued on May 29, 1997 and is codified in 10CFR430 Subpart B, Appendix R: *Uniform Test Method for Measuring Average Lamp Efficacy (LE) and Color Rendering Index (CRI) of Electric Lamps.* This test procedure measures average lamp efficacy (LE), based on measurements of light output and lamp wattage, and color rendering index (CRI). Thus, the test procedure correlates well with lamp energy consumption, excepting lamps subject to frequent dimming.

The DOE test procedure references IESNA LM-20*: IESNA Approved Method for Photometric Testing of reflector-Type Lamps*. The test procedure does not need to be changed for the standard. Language should probably be added to the DOE test procedure to clarify that the most recent IESNA test procedure standard be used.

A14.4 Energy Savings Estimates and Calculations

All six Standards Scenarios study a standard that sets a minimum level for lamp efficacy.

For the regulated lamps, Scenario 1 assumes a lamp efficacy standard in which incandescent reflector lamps have a marginal improvement in efficacy, 1.5% higher than the existing average. Scenario 2 assumes a lamp efficacy standard in which incandescent reflector lamps realize a 3% improvement in efficacy. Scenario 3 assumes a lamp efficacy standard in which reflector lamps have an efficacy 30% higher than the base case, which represents the increase from halogen to halogen infrared (HIR) technology.

For the unregulated lamps, Scenario 1 assumes a lamp efficacy standard in which incandescent reflector lamps have a marginal improvement in efficacy, 1.5% higher than the existing average. Scenario 2 assumes a lamp efficacy standard in which incandescent reflector lamps shift to halogen technology, and realize an 18% improvement in efficacy. Scenario 3 assumes a lamp efficacy standard in which reflector lamps have an efficacy 54% higher than the base case, which represents the increase from incandescent to halogen infrared (HIR) technology.

The six Scenarios are analyzed assuming that as efficacy increases with the standard, lumen output is held constant and the wattage decreases proportionally. Table A14-5 presents the energy consumption and saving estimates for the three scenarios for the regulated lamps. Table A14-6 presents the data for the three scenarios for the unregulated lamps.

Table A14-5: Regulated Incandescent Reflector Lamp Scenarios Potential Saving Estimates

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline – Incandescent Lamp	NA	NA
Scenario 1 – 1.5% Efficacy Increase	0.004	0.09
Scenario 2 – 3.0% Efficacy Increase	0.008	0.18
Scenario 3 – 30% efficacy increase, HIR Technology	0.067	1.44

Table A14-6: Unregulated Incandescent Reflector Lamp Scenarios Potential Saving Estimates

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Baseline – Incandescent Lamp	NA	NA
Scenario 1 – 1.5% Efficacy Increase,	0.004	0.10
Scenario 2 – 18% Efficacy Increase, Halogen	0.047	1.00
Scenario 3 – 54% efficacy increase, HIR Technology	0.106	2.26

The number of installed lamps, the average wattage of the baseline case, and the operating hours are all derived from a lighting inventory study (ADL 2002c). This Inventory derives its estimates chiefly from building audits and end-use metering studies. Appendix A-XI contains calculation details.

A14.5 Regulatory Actions and Cumulative Burden

Incandescent reflector lamps are regulated under the Energy Policy Act of 1992. The standard took effect in November 1995. The law set efficacy (i.e., lumens per Watt) standards by wattage category for common reflector lamps (see Table A14-7). Effectively, standard-wattage and reduced-wattage ("energy saver") reflector lamps do not comply; halogen reflector lamps are the least expensive compliance option.

Table A14-7: Energy Policy Act Incandescent Reflector Lamp Standard Levels

Nominal Lamp Wattage	Minimum Average Lamp Efficacy (lumens/Watt)
40-50	10.5
51-66	11.0
67-85	12.5
86-115	14.0
116-155	14.5
156-205	15.0

BR and ER lamps are exempted from EPAct, and thus do not currently employ halogen technology. There are several other categories of exempted lamps, including rough service and colored lamps. Table A14-7 shows the EPAct efficacy standards levels.

These lamps are also subject to a labeling program under EPAct. Incandescent reflector lamps sold or imported in the US must have labels on their packaging. The labeling program was designed by the Federal Trade Commission (FTC) and took effect in 1995.

Those manufacturers who make ballasts as well as incandescent reflector lamps must comply with the NAECA fluorescent ballast regulations (present and future).

A14.6 Issues Impacting Potential Energy Efficiency Standards

Exemptions to a revised standard for these lamps would have to be carefully considered. Under the current EPAct standards, the Department had to more precisely define certain exempted categories, such as “rough and vibration service” and “colored” lamps in response to concerns from manufacturers, in order to maintain the intent of the standard. The exempted BR lamp, which has lower efficacy than the halogen reflector lamp, was considered by some to be a “loophole” in the EPAct standards, and its sales increased after the standards took effect. For example, recent data for the Canadian market reveals that BR and ER lamps account for ~53% of *all* incandescent lamp sales (NRC, 2002). Other exempted lamps have been questioned as well.

A15 Energy Consumption and Saving Estimates for Residential Dishwashers

A15.1 Background

Dishwashers use heated water and dishwashing detergent to clean and dry dishes. All together, the installed base of approximately 54 million residential dishwashers consumes about 0.24 quads of energy per year (see Table A15-1).

Table A15-1: Residential Dishwasher Background Data

Data Type	Value	Source
Installed Base, millions	54	Appliance Magazine (2001)
Annual Shipments, millions	5.8	Appliance Magazine (2001)
Equipment Lifetime, years	13	DOE (2002)
AEC, quads	0.24	Meyers et al. (2002)

A15.2 Product Technology Descriptions and Market Presence

Dishwashers are primarily categorized by whether or not a soil sensor is used to determine the end of a dishwashing cycle. 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.

The stock unit energy consumption (UEC) levels (see Table A15-2) include dishwashers at and below the current minimum efficiency standard. The Energy Star® level.

Table A15-2: Residential Dishwasher Technology Levels and Energy Factor Values

Technology Level	Energy Factor [cycles/kWh]	Comments/Source
Stock	0.43	DOE (2002)
Minimum Efficiency Standard	0.46	DOE (2002)
Typical New	0.50	ADL (2000)
Energy Star	0.58	http://www.energystar.gov
Best Available	0.94	http://www.energystar.gov

Some dishwashers use much less energy than the minimum standard and the ENERGY STAR® rating. The best available dishwasher uses approximately 49% of the energy level specified in the minimum efficiency standard and approximately 79% 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.

A15.3 Test Procedure Status

The current test procedure is the Department of Energy's "Uniform Test Method for Measuring the Energy Consumption of Dishwashers" (10 CFR 430 Subpt. B, App. C). The current method operates the dishwasher according to manufacturers' recommendation for a full load of normally soiled dishes, but a clean test load of 8 place settings of dishware and six servicing pieces is used as outlined in the industry standard ANSI/AHAM Standard DW-1. The energy consumption for one cycle equals the energy required to complete the load of clean dishes.

Dishwashers must meet or exceed a minimum energy factor (EF) that depends on dishwasher size (10 CFR 430.32(f)). Standard dishwashers (exterior width of 22 inches or greater) must have an energy factor not less than 0.46 cycles/kWh. Compact dishwashers (exterior width less than 22 inches) must have an energy factor not less than 0.62 cycles/kWh. Effective June 17, 2002, the definitions of standard and compact will be based on place setting capacity (ADL, 2001c). A standard dishwasher will have a capacity greater than or equal to eight place settings plus six serving pieces as defined in ANSI/AHAM Standard DW-1; a compact dishwasher will be any unit with less capacity.

The development of soil-sensing dishwashers has necessitated a change in the DOE test method. The current test procedure (as stated above) is subject to change and a notice of proposed rulemaking is imminent. The current standard measures energy consumption for clean dishes but, in contrast, the new standard would create a separate test procedure for dishwashers with soil-sensing capability. Dishwashers with soil sensing capability would be tested at three levels of soiling, and the energy consumption at each level of soil would be weighted as follows: (ADL, 2001c)

- Lightly Soiled: 62%
- Medium Soil: 33%
- Heavy Soil: 5%

Therefore, the energy factor for soil-sensing dishwashers would be calculated as shown in the equation below:

$$EF_{soil\text{-}sensing} = 0.62*EF_{Light} = 0.33*EF_{Medium} + 0.05*EF_{Heavy}\ .$$

The soils used on the dishes would be those listed in ANSI/AHAM Standard DW-1.

Additionally, the estimated annual cycles for energy consumption calculations will decrease to a value of 215 from the current value of 264 for dishwashers with and without soil sensors. Consumer research has revealed that dishwasher frequency of use has decreased as the number of occupants in dishwasher-owning households decreases, the occupants grow older, and consumers eat more prepared foods. (ADL, 2001c).

A15.4 Energy Savings Estimates and Calculations

Table A15-3 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 dishwasher consume energy at the "typical new" level.

Table A15-3: Residential Dishwasher Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (MMBtu/yr)	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Typical Dishwasher (Current Stock)	4.5	NA	NA
'Typical New'	3.9	NA	NA
Energy Star	3.3	0.03	0.4
Soil Sensor	2.8	0.06	0.9
Best Available	2.3	0.09	1.4

The energy savings calculations have two major variables: the number of cycles per year and the energy savings from Soil Sensor dishwashers. As noted in the test procedure status section, DOE will decrease the estimated number of cycles per year for energy consumption calculations to 215 from 264. Fewer cycles mean that dishwashers consume less energy, and the total energy savings potential of each technology would decrease proportionally to the number of cycles per year[48].

The energy savings potential of Soil Sensor technology has significant uncertainty. The pending revisions to DOE's dishwasher test procedure will require the use of soiled dishware in energy factor tests for Soil Sensor dishwashers. Although the energy factors of Soil Sensor dishwashers should still exceed those of non-Soil Sensor dishwashers, they will likely be lower than the currently reported energy factors for Soil Sensor dishwashers. The magnitude of the reduction in energy use for Soil Sensor dishwashers is unknown at this point and dishwasher manufacturers are in the process of evaluating their machines against the pending revisions in the test procedure.

A15.5 Regulatory Actions and Cumulative Burden

Dishwashers are regulated for energy efficiency under NAECA and have the minimum energy efficiency level listed in Table 15-2. The extent to which regulation impacts dishwashers, including health and safety, was not determined.

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

[48] In this case, the AEC and savings calculations assume 250 cycles per year. Assuming that the average dishwasher runs 215 cycles per year, the energy savings would decrease by ~(250-215)/250 = 14%.

A15.6 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%.

A16 Energy Consumption and Saving Estimates for Residential Clothes Dryers

A16.1 Background

Clothes dryers use heat provided by an electric heating element or a gas burner to drive moisture from clothing. All together, the approximately 79 million residential clothes dryers consume about 0.66 quads of energy per year (see Table A16-1), with electric dryers accounting for 77% of the installed base and 90% of total annual energy consumption.

Table A16-1: Residential Clothes Dryer Background Data

Type	Data type	Value	Source
Electric	Installed Base, millions	61	Meyers et al. (2002)
	Annual Shipments, millions	5.1	Appliance Magazine (2001)
	Equipment Lifetime, years	14	Appliance Magazine (2000)
	AEC, quads	0.60	Meyers et al. (2002)
Gas	Installed Base, millions	18	Meyers et al. (2002)
	Annual Shipments, millions	1.5	Appliance Magazine (2001)
	Equipment Lifetime, years	13	Appliance Magazine (2000)
	AEC, quads	0.06	Meyers et al. (2002)

A16.2 Product Technology Descriptions and Market Presence

Clothes dryers are categorized by fuel type. Electric dryers comprise 77% of the residential installed base. Electric dryers heat air by pulling it over an electric heating element, and this hot air dries the clothing in the drum. Gas dryers heat the incoming air with a burner that is typically fueled by natural gas.

An important factor in gas or electric dryer energy consumption is whether a timer or a sensor controls the cycle time. A timer requires the user to guess the length of the drying cycle, so a timed cycle continues whether or not the clothing is still wet, consuming energy to heat exhaust air even when the clothing is dry. In contrast, many dryers incorporate temperature or moisture sensors to determine when the drying cycle should terminate. Moisture sensors directly measure the remaining moisture on clothing in the dryer and terminate the drying cycle when the moisture sensors indicate that the clothes have reached an adequate level of dryness. A drying cycle based on temperature of the exhaust air indirectly measures dryness. Once a certain exhaust temperature has been reached, the dryer cycles the heating element for an additional amount of time before ending the cycle. Generally, moisture sensors save more energy than temperature sensors because they are less likely to over-dry the clothing.

The stock unit energy consumption (UEC) for electric and gas dryers (see Table 16-2) reflects both timer- and sensor-based dryers. The typical new UEC assumes that the dryer includes a temperature or moisture sensor (Consumer Reports, 2000).

Table A16- 2: Clothes Dryer Technology Levels and UEC Values

Technology Level	Value		Comments/Source
	Electric (lbs/kWh)	Gas (lbs/kWh)	
Stock	2.8	2.4	Meyers et al. (2002)
Typical New	3.0	2.7	Meyers et al. (2002)
Microwave	3.5	N/A	EPRI (1998)
Smaller Heat Pump Dryers Available in Europe	4.0	N/A	IEA HPC (2001)
Future Technology	5.7	2.8	Heat pump modulating electric dryer (ADL, 2001d); Gas modulating system (ADL, 2001d)
Minimum Efficiency, Standard, Drum Size (> 4.4 ft^3)	3.01	2.67	CFR (1999)
ENERGY STAR®	N/A	N/A	No ENERGY STAR® program for electric or gas dryers

Microwave, heat pump, and modulating dryers are potential new technologies that can increase electric dryer efficiency. Modulation can also be used to increase gas dryer efficiency.

A microwave dryer uses microwave energy to heat the moisture in the clothing. Because microwaves are preferentially absorbed by liquid, clothing and air temperatures in the dryer remain cooler and the process is more efficient than using heated air to drive away moisture. However, metal objects on or in the clothing (e.g., zippers, buttons, pins, nails etc.) can overheat or arc, potentially scorching or igniting the clothing. A prototype tested within the last five years uses sensors to detect possible scorching and ignition of the clothing (Smith, 1997). The current prototype is also the size of existing microwave ovens, since the target market is apartment dwellings and other locations where space is at a premium. Advantages of microwave technology include possible efficiency improvements of up to 15% and gentler handling of clothing due to lower operating temperatures. However, the potential presence of metal objects remains a significant safety and technical hurdle. Because of the additional sensors required to detect possible scorching and ignition, it is expected that microwave dryers would cost more than typical new electric dryers. As stated earlier, prototype models exist but no microwave dryers are in production.

A heat pump uses a refrigeration cycle in reverse to “pump” heat from the warm dryer exhaust airflow to the air entering the dryer drum. A heat pump is expected to consume approximately half the energy of existing electric dryers, but the selling price is estimated to be approximately double that of a typical, new electric dryer (ADL, 2001d). In addition, heat pump drying cycles are longer than those of current electric dryers. Heat pump dryers have come to market in Europe, but not in the U.S. (IEA HPC, 2001).

A heat pump system can also use a modulating control scheme to offer additional improvements in efficiency. Modulation reduces heat input at the end of the drying cycle, when very little moisture remains in the clothing. This reduction in heat input improves the efficiency of drying and reduces the waste heat lost through the exhaust.

Modulation can also be applied to typical electric dryers that use electric heating elements and to typical gas dryers. The expected increase in efficiency for a gas dryer is approximately 5% (ADL, 2002d). Due to need for additional controls, modulation increases the dryer selling price. Currently, no gas or electric modulating dryers are for sale in the U.S.

A16.3 Test Procedure Status

Both electric and gas dryers have DOE test procedures. The minimum efficiency test procedure measures the amount of energy used to remove a specified quantity of water from a specified type and weight of clothing. For electric dryers, the test measures all of the energy passing through the power cord with the exception of console or lighting systems that draw less than 10 Watts. For gas dryers, the total energy includes the gas and the electrical energy used to power the ignition and control system, with the exception of console or lighting systems that draw less than 10 Watts. The dryer energy consumption is then multiplied by a field use factor, which distinguishes between dryers that have automatic control systems to stop the drying cycle (e.g., temperature or moisture) and those that are timer-based. In most instances, the timer-based control uses more energy because it outputs heat until a time is reached, whether or not the clothes have any moisture remaining. An automatic control system shuts the dryer down after it determines that the clothes are dry. To account for this expected difference in drying time the DOE test procedure multiplies the energy used in a timer-based control by 1.18 and multiplies the energy used in an automatic control system by 1.04. The ultimate dryer efficiency metric, the energy factor (EF), is then computed by dividing the total energy used during the cycle by the total weight of the dry test cloth.

The DOE test procedures for dryers have three potential issues that may reduce their correlation with field-based dryer energy consumption. First, the current minimum efficiency standard does not distinguish between different types of sensor systems that could be used to determine that the drying cycle is complete. However, improved sensors and/or control algorithms may be able to more accurately determine the end of the drying cycle, which would save more energy than other sensor systems. Second, the current minimum efficiency standard distinguishes between only two drum sizes, standard (greater than 4.4 ft^3) and compact (less than 4.4 ft^3). As dryers increase in size, the current minimum efficiency standard may underestimate the average size of the drying load. If the drying load is too small, the dryer may not be running at an optimal load for efficiency, consequently predicting lower operational efficiency than in practice. Additional drum and load size classifications, e.g., as currently specified for clothes washers, are a potential option. Third, the current minimum efficiency standard requires that the cloth moisture content lie between 66.5% and 73.5%. Washing machines that increase the speed of the spin cycle decrease the cloth moisture content, potentially below the range specified in the test procedure. This would decrease the amount of energy needed to dry a given load of clothing and could alter the efficiency of the dryer, potentially decreasing the correlation between the test procedure and actual dryer energy consumption.

Neither electric or gas dryers have an ENERGY STAR® test procedure.

A16.4 Energy Savings Estimates and Calculations

The energy savings calculations assume that both gas and electric dryers with moisture sensors will replace all existing dryers without sensors by 2008. Tables A16-3 and A16-4 list the potential energy consumption and energy saving estimates for new technologies in electric and gas dryers.

Table A16- 3: Electric Dryer Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (kWh/yr)	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Typical Device (current stock)	910	NA	NA
Typical New with Temperature or Moisture Sensor	830	NA	NA
Microwave Dryer	710	0.08	1.2
Heat Pump	480	0.24	3.5
Heat Pump with Modulation	460	0.25	3.8

Table A16- 4: Gas Dryer Current Energy Consumption and Potential Saving Estimates

Technology/Standard Level	UEC (MMBtu/yr)	Annual Energy Savings Potential (quads)	Energy Saving Potential, 2008-2030 (quads)
Typical Device (current stock)	3.6	NA	NA
Typical New with Temperature or Moisture Sensor	3.2	NA	NA
Modulation	3.1	0.003	0.06

Table A16-5 lists the technologies for both electric and gas dryers, along with anticipated annual energy savings and projected savings from 2008 – 2030.

Table A16- 5: Total Dryer Energy Savings Potential Estimates

Technology/Standard Level	Annual Energy Savings Potential (quads)	Energy Saving Potential (2008-2030), (quads)
Modulation (Gas)	0.003	0.06
Microwave Dryer (Electric)	0.07	1.2
Heat Pump (Electric)	0.24	3.5
Heat Pump with Modulation (Electric)	0.26	3.8

Overall, electric dryers have much larger energy savings potentials than gas dryers. The heat pump technology, with or without modulation, offers the greatest potential energy savings. The major uncertainties in the energy savings calculations are the expected efficiencies of microwave dryers and heat pump dryers, since none are currently sold in the U.S. Further development will be required to arrive at an improved energy savings potential. Regulatory Actions and Cumulative Burden
Both electric and gas dryers have been subject to regulation by DOE for energy efficiency. The minimum energy efficiency standards are listed in Table 16-2. The extent to which regulation impacts clothes dryers, including health and safety, was not determined.

Many manufacturers of dryers also produce a variety of other white goods, such as clothes washers, refrigerators & freezers, and dishwashers. All of these products have been subject to other energy efficiency regulations under NAECA, with multiple rounds of DOE rulemaking for more than one of these products.

A16.5 Issues Impacting Potential Energy Efficiency Standards

Potential clothes washer efficiency improvements and potential dryer standby losses could create issues for future energy efficiency standards.

Greater moisture extraction from clothes washers is under consideration in a current rulemaking. Spinning the clothes washer drum faster removes additional moisture, so the dryer uses less energy in drying clothes. Mechanical extraction has been estimated to be much more cost-effective than thermal extraction[49]. Dryer energy use relative the current baseline would drop as these clothes washers enter the market.

The increasing use of microprocessors to control the drying cycle and to run improved electronic user interfaces (e.g., visual displays) increase the potential for standby losses. Standby energy consumption on the order of 10 Watts[50] could increase dryer annual energy usage by on the order of 10%, suggesting that standby energy consumption should be considered for any future energy standards.

No standard currently exists for condensing dryers, which condense the moisture out of the dryer exhaust so that an external vent is not needed. The current test and energy standards are designed for vented dryers and needs to be modified to properly account for the different operation of condensing dryers (DOE, 1995).

[49] For example, in one case, Lovett (1981) estimated that mechanical extraction was ~67 times more efficient.
[50] 10W represents the upper bound of the console or lighting systems than can be disconnected during the DOE test procedures.

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Appendix A-I – TV UEC and Energy Savings Estimates

The power draw and usage data (see Table AI-1) came from Rosen and Meier (1999a), who estimate that the average household contains 2.1 televisions and that all of the televisions in a given household combine to operate in active mode a total of 8.3 hours per day. Their estimate comes from a modification of a Nielsen (1998) estimate of broadcast viewing hours to account for the fact that many households have more than one TVs and additional TVs usage to view videos.

Table AI-1: CRT Television UEC and Energy Savings Potential Estimates (Usage and Power data from Rosen and Meier [1999a])

Type	Active Power, W	Standby Power, W	Active hours (per day)	Standby hours (per day)	Annual UEC, kW-h	% Savings Potential
Typical New	86	5.7	4.0	20	166	NA
Current stock	75	4.5	4.0	20	150[1]	NA
CRT, 3W standby	86	3.0	4.0	20	146	3%
CRT, 1W standby	86	1.0	4.0	20	131	21
CRT, 0.1 W standby	86	0.1	4.0	20	125	25

As noted in the body of the report, a dearth of LCD power draw data required a different methodology to calculate LCD energy savings potential shown in Table AI-2. Specifically, active power draw information was only found for 20-inch and 28-inch LCD TVs, whereas the 'typical new' (CRT) TV has a 25- or 27-inch screen. To estimate the active power draw of a 25-inch LCD TV, the active power draw of the 20-inch and 28-inch LCD TVs were compared to the active power draw of same-sized CRT TVs, and the percent reduction in active power calculated[51] (see Table A-2).

Table AI-2: LCD Active Draw Estimates

Type	Daily Active Draw, W	% Savings Potential, Active Mode	Source
CRT,20-inch Sharp	68	N/A	Rosen and Meier (1999a)
LCD, 20-inch Sharp	53	22	Sharp LC-20C1; www.sharp-world.com .
CRT, Average of 25-27 inch and 30-36 inch	102	N/A	Rosen and Meier (1999a)
LCD, 27-28 inch Sharp	85	17	Sharps LC-28HD1; www.sharp-world.com .
LCD, 25-inch	69	19	Scaled relative to typical new

The average active power draw of LCDs, 19%, equals the average of the savings potential in active draw in each class. The LCD TV UEC calculation uses the estimated active power, combined with the 'typical new' standby power draw (see Table AI-3).

[51] The 28-inch LCD has a larger viewable area than a 28-inch CRT and thus lies between the 25-27 inch and 30 – 36 inch CRT TV. Its active draw was compared to the average active draw of the two sizes

Table AI-3: LCD TV Calculations (CRT Data from Rosen and Meier [1999a])

Type	Active Power (W)	Standby Power (W)	Active Hours/Day	Standby Hours/Day	UEC (kW-h)
CRT, 20-inch	68	5.1	4.0	20	135
LCD, 20-inch (Sharp LC-20C1)	53	5.1	4.0	20	114
CRT, Average of 25-27 inch and 30-36 inch units	102	5.3	4.0	20	186
LCD, 28 inch (Sharp LC-28HD1)	85	5.3[52]	4.0	20	161
LCD, 25-27inch	69[53]	5.7	4.0	20	138

[52] In reality, the Sharp LC-20C1 consumes 0.7W in standby mode and the Sharp LC-28HD1 0.22W in standby mode (from: www.sharp-world.com). The typical new values are used to isolate the energy savings from the LCD.
[53] Scaled relative to average.

Table AII-1 and Table AII-2 present the power draw and usage data used for making the UEC and saving estimates for rack and compact audio's respectively. Because data were not available to distinguish between 'typical new' and 'current stock' power draws, the audio UEC analyses all assume that the 'typical new' and current stock have identical power draw levels in the play, idle, and standby modes. For the 1, 2 and 0.26 W standby cases, the active draw is assumed to be the same as that of the typical new device.

Table AII-1: Rack Audio UEC and Energy Savings Estimates (Usage and Power Draw Data from Rosen and Meier [1999b])

Type	Current Stock	Typical New	2 W Standby	1 W Standby	0.26 W Standby[1]
Play Draw, W	53	53	53	53	53
Idle Draw, W	49	49	49	49	49
Standby Draw, W	3	3	2	1	0.26
Annual Hours Play	526	526	526	526	526
Annual Hours Idle	1664	1664	1664	1664	1664
Annual Hours Standby	6570	6570	6570	6570	6570
UEC, kW-h	129	129	123	116	111
Energy Savings Potential (%)	0	0	5	10	14

Table AII-2: Compact Audio UEC and Energy Savings Estimates (Usage and Power Draw Data from Rosen and Meier [1999b])

Type	Current Sock	Typical New	2 W Standby	1 W Standby	0.25 W Standby[1]
Play Draw, W	22	22	22	22	22
Idle Draw, W	20	20	20	20	20
Standby Draw, W	9.8	9.8	2	1	0.25
Annual Hours Active	526	526	526	526	526
Annual Hours Idle	1664	1664	1664	1664	1664
Annual Hours Standby	6570	6570	6570	6570	6570
UEC, kW-h	109	109	58	51	46
Energy Savings Potential (%)	0%	0%	47%	53%	57%

It should be noted that the power draw data obtained from Rosen and Meier is based on a relatively low listening sound level. Higher volumes will draw more power in the 'play' mode.

[1] Source- ENERGY STAR® Website: http://yosemite1.epa.gov/estar/consumers.nsf/content/homeaudioproducts.htm#receivers .

Appendix A-III - Set-top Boxes UEC and Energy Savings Estimates

The power draw and usage data for the wireless and digital set top boxes (see Table AIII-1 and Table AIII-2) come from Rosen, et al. (2001). The energy consumption models all include the assumption that the “typical new” units, as well as future devices with different standby power levels, have the same “active” power draw as devices comprising the current stock. This reflects a lack of additional active power estimates/measurements for “typical new” and future devices.

Table AIII-1: Wireless Set-top Box UEC and Energy Savings Estimates

Data Type	Current Stock	Typical New	15 W Standby	7 W Standby	1 W Standby
Active Draw, W	16.9	16.9	16.9	16.9	16.9
Idle Draw, W	16.2	16.2	15	7	1
Annual Hours Active	1927	1927	1927	1927	1927
Annual Hours Idle	6833	6833	6833	6833	6833
Annual UEC, kW-h	143	143	135	80	39
Energy Savings Potential (%)	NA	NA	6%	44%	72%

Table AIII-2: Digital Set-top Box UEC and Energy Savings Estimates

Data Type	Current Stock	Typical New	15 W Standby	7 W Standby	1 W Standby
Active Draw, W	23	23	23	23	23
Idle Draw, W	22.3	22.3	15	7	1
Annual Hours Active	1927	1927	1927	1927	1927
Annual Hours Idle	6833	6833	6833	6833	6833
Annual UEC, kW-h	197	197	147	92	51
Energy Savings Potential (%)	NA	NA	25%	53%	74%

Appendix A-IV - Ceiling Fan UEC and Energy Savings Estimates

The ENERGY STAR® program quantifies fan performance using an efficacy metric of air flow rate per unit of power consumed (CFM/Watts). The energy savings potential estimates for the air moving components (i.e., fan and fan motor) are based on CFM/Watts comparison at low and high speeds (see Table AIV-1 and Table AIV-2). The average energy savings potential equals the average of the low-speed and high-speed energy savings potentials (see Table AIV-3).

Table AIV-1: Ceiling Fan Performance and Energy Savings Estimates (low speed)

Data Type	Current Stock	Typical New[1]	Aerodynamic Blade[2]	Aerodynamic and More Efficient Motor	ENERGY STAR® Level (air moving only)[3]
CFM	1087	1087	1907	1907	1250
Watts	9.6	9.6	9.1	4.6	8.1<
CFM/Watts	113	113	210	419	155
Energy Savings Potential (%)	N/A	N/A	46	73	27

Table AIV-2: Ceiling Fan Performance and Energy Savings Estimates (high speed)

Data Type	Current Stock	Typical New	Aerodynamic Blade	Aerodynamic and More Efficient Motor	ENERGY STAR® Level (air moving only)
CFM	3110	3110	6470	6470	5000
Watts	50	50	50	25	NA
CFM/Watts	62	62	131	262	75
Energy Savings Potential (%)	N/A	N/A	53%	76%	15%

Table AIV-3: Ceiling Fans Average Energy Savings Potential

Data Type	Aerodynamic Blade	Aerodynamic and More Efficient Motor	ENERGY STAR® Level (air moving only)
Energy Savings Potential (%)	49%	75%	22%

The savings estimate of the 'aerodynamic + more efficient motor' option includes a 100% improvement in the efficiency of the motor relative to shaded pole motors. A motor study by ADL (1999) found that permanent split capacitor (PSC) and brushless DC motors[54] in the size range used for ceiling fan applications could achieve at least a 100% improvement in motor efficiency.

[1] From Parker et al. (1999), with the Emerson CF 705 motor model.
[2] From Parket et al. (1999), using the FSEC/Aerovironment CF-1 airfoil fan.
[3] http://yosemite1.epa.gov/ESTAR/consumers.nsf/content/ceilingfans.htm
[54] Referred to as electronically commutated permanent magnet motors in ADL (1999).

Appendix A-V Gas Unit Heaters and Duct Furnaces UEC and Energy Savings Estimates

A-V1 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 reflect shipment data from GRI (1997) for the period of 1991-1995 (see Table AV-1), using the average annual shipment volume to cover the entire device lifetimes.

Table AV-1: Gas Unit Heaters and Duct Furnaces Annual Shipments (Source: GRI 1997)

Year	Gas Unit heaters	Gas Duct Furnaces
1995	170,935	14,150
1994	167,925	13,925
1993	147,950	13,600
1992	131,425	14,800
1991	137,325	15,875
Average, 1991 to 1995	151,112	14,470
Sum, 1991 to 1995	755,560	72,350

Thus, the installed base estimate equals the product of the average product lifetime and the average annual shipments from 1991 to 1995. The drawback of this approach is that the data are not very recent and that the forward- and backward-extrapolations do not capture sales trends.

A-V2 AEC Calculations

The device 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 AV-1).

Table AV-2: 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 estimate assumes 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 quads 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 (see Table AV-3 for details). Using this method yields an AEC of ~1.0 quads, a value that is clearly too high. The 1998 MECS (EIA) survey estimates that industrial space heating consumed a *total* of about 0.4 quads of gas. Even if unit heaters consume all of this heat, the total gas consumption estimate would be 0.6 quads (0.2 for the commercial consumption (see Table AV-2) 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. In conclusion, the above estimate of 0.54 quads 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:

$$average\ duty\ cycle = \frac{Annual\ heating\ load}{Peak\ heating\ load \cdot 8760\, hrs/year}\ .$$

Warehouse duty cycle data from DOE-2 runs performed for representative warehouses in two climates (from LBL, 1990; see Table AV-4 for results) were used to model duct furnaces duty cycles, as duct furnaces are often deployed in buildings similar to warehouses.

The AEC estimate equals the product of the average duct furnace size, average operational hours per year, and the installed based, divided by the “typical new” seasonal efficiency. Table AV-3 presents the data used for the above calculation.

Table AV-3: Gas Duct Furnace AEC Calculation

Type	Data	Source
Average unit size (output, Kbtu/hr)	321	Calculation based on data from GRI(1997)
Seasonal efficiency (typical new)	72%	ADL (2001b)
Average duty cycle	10.7%	Calculation ,Table AVI-5
AEC(Quads)	0.1	Calculation

The average gas duct furnace size (output in kBtu/hour) equals an approximate shipment-weighted average over the years 1991 to 1995 (Table AV-4).

Table AV-4: 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

A-V3 Energy Savings Potential Calculations

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

$$Savings\ Potential = \frac{AFUE\,(Typical\ New)}{AFUE\,(Tech.\,Level)}\,.$$

This yields the savings potentials displaced below (Table AV-5).

Table AV-5: Gas Unit Heaters and Duct Furnaces Energy Savings Estimates

Type	Seasonal Efficiencies (%, AFUE)	Savings Potential (%)	AFUE Source
Current Stock	70	NA	GRI (1995)
Typical new	72	NA	ADL (2001b)
Condensing	93	23	ASHRAE (1996)
Pulse Combustion	82	10	
Power vent	80	12	

Appendix A-VI-Desktop PCs UEC and Energy Savings Estimates

Tables AVI-1 and AVI-2 present the Desktop PCs usage data in the commercial and residential sectors respectively.

Table AVI-1: Commercial Desktop PCs Usage Data

Type	Active (hrs/week)	Standby (hrs/week)	Off (hrs/week)	Source
Typical New Pentium III (25% Power management-enabled)	98	7	62	Kawamoto et al. (2001) and Webber et al. (2001)
Pentium III (50% Power management-enabled)	61	44	62	
Pentium III (100% Power management-enabled)	19	86	62	
Pentium III (Laptop Technology – replacement of Desktops with Laptops)	19	86	62	
Pentium III (Low Power Design)	98	7	62	

Table AVI-2: Residential Desktop PCs Usage Data

Type	Active (hrs/week)	Standby (hrs/week)	Off (hrs/week)	Source
Typical New Pentium III (25% Power management-enabled)	14	1	153	Kawamoto et al. (2001) (detailed calculations spreadsheet); ADL Estimate
Pentium III (50% ENERGY STAR® Enabled)	12	2	153	
Pentium III (100% Power management-enabled)	10	5	153	Kawamoto et al. (2001) (detailed calculations spreadsheet); ADL (2002a)
Pentium III (Laptop Technology – replacement of Desktops with Laptops)	14	1	153	Kawamoto et al. (2001) (detailed calculations spreadsheet)
Pentium III (Low Power Design)	14	1	153	Kawamoto et al. (2001) (detailed calculations spreadsheet)

The usage estimates reflect estimates of daytime and nighttime usage, as well as the percentage of all PCs that enter low-power "standby" modes via power management (PM) software. Specifically, the PM enabled rate denotes the percentage of equipment that has power management capabilities and whose power management functions properly. Nighttime mode status data for PCs used in commercial applications come from commercial building surveys of office equipment, as do estimates of Power management-enabled (i.e., PM-enabled) rates. Tables AVI-3 through AVI-4 display the data used to develop the commercial and residential usage patterns.

Table AVI-3: Estimate of Weekly Hour Distribution in PCs and Monitors in Commercial and Residential Sectors

Type	Night/Weekend No. of Hours	Day time (weekday) Hours	Source
Residential	158	10	Kawamoto et al. (2001)
Commercial	120	48	

Table AVI- 4: Percent Time in Different Modes for Desktop PCs and Monitors (Day Status), Source: Kawamoto et al. (2001)

Type	Mode	% of Time, PM-Enabled	% of time, PM-Disabled
Residential	Active	100	100
	Standby	0	0
	Off	0	0
Commercial	Active	40	80
	Standby	40	0
	Off	20	20

Table AVI-5: Percent of Time in Different Modes for Desktop PCs (Night Status)

Type	Mode	% of Time in Night	Source
Residential	Active	3	Kawamoto et al. (2001) (detailed calculations spreadsheet)
	Standby	0	
	Off	97	
Commercial	Active	54	Webber et al. (2001)
	Standby	2	
	Off	44	

Table AVI-6: Desktop PCs Hours and Usage distribution in Commercial and Residential Sectors

Type	Mode	Day Hours (PM)	Day Hours (non PM)	Night/Weekend Hours
Residential	Active	10	10	3.6
	Standby	0	0	1.2
	Off	0	0	153
Commercial	Active	19	38	65
	Standby	19	0	2.4
	Off	9.6	9.6	53

Tables AVI-7 presents the power draw data for commercial and residential desktop PCs.

Table AVI-7: Commercial and Residential Desktop PCs Power Draw Data

Type	Active (W)	Sleep (W)	Off (W)	Source
"Typical New" - PC with Pentium III	61	25	1.5	Kawamoto et al. (2001) (detailed calculations spreadsheet); Intel Pentium III data sheets[55]
Low-Power Pentium III (Laptop Technology – replacement of Desktops with Laptops)[56]	15	3	1.5	ADL (2002a)
Pentium III (Low Power Design)	10	4	1	Equivalent to a laptop computer without a display[57]
Pentium III, 1-Watt Sleep Mode	61	1	1	Kawamoto et al. (2001)

[55]The Pentium II CPU best represents the desktop PC "installed base" and a Pentium III CPU best represents a "typical new" machine for Y2001. According to product information available at www.intel.com , a Pentium II (450 MHz, 26.2W) power draws 5.6 Watts less than a Pentium III (900 MHz, 31.8 W). Assuming that the CPU power draw accounts for all of the change in desktop PC power draw between the "installed base" and "typical new" devices yields the 61W active power for the "typical new" desktop PC (i.e., the sum of 55W ["installed base" desktop PC draw] and 5.6W [increase in CPU power draw]).

[56] The power draw values include the power consumed by the screen, i.e., ~5W (ADL, 2002).

[57] ADL (2002a) estimates that a laptop computer consumes ~15W in active mode. LCD power draw data suggest that the LCD accounts for ~5W of laptop computer draw, yielding the 10W active draw value. The 4W standby power draw was derived by assuming the same ratio of active-to-standby power draw as a desktop computer applies to this device, i.e., ~0.4. The "off" power was decreased to account for the absence of a screen (by a factor equal to the "laptop" to "non-laptop" power draw, i.e., 15:10 = 1.5).

Appendix A-VII - Monitors UEC and Energy Savings Estimates

Tables AVII-1 and Table AVII-2 present the monitor usage data in the commercial and residential sectors respectively.

Table AVII-1: Monitors Usage Data in Commercial Sector

Type	Active (hrs/week)	Standby (hrs/week)	Off (hrs/week)	Source
Typical New 17-inch CRT (60% Power management-enabled)	63	57	48	Kawamoto et al. (2001); Nordman et al. (2000); Webber et al. (2001)
17-inch CRT (100% Power management-enabled)	19	101	48	Kawamoto et al.(2001); Nordman et al. (2000), Webber et al.(2001); ADL(2002)
17-inch LCD (60% Power management-enabled)	63	57	48	Kawamoto et al. (2001); Nordman et al. (2000); Webber et al. (2001)
Monitor – 17-inch Cholesteric LCD, (60% Power management-enabled)	63	57	48	Kawamoto et al.(2001); Nordman et al. (2000), Webber et al.(2001); ADL(2002)
Monitor – 17 " OLED, (100% Power management-enabled)	19	101	48	Kawamoto et al.(2001); Nordman et al. (2000), Webber et al.(2001); ADL(2002)
17-inch CRT , 1 W-Sleep (60 % Power management-enabled)	63	57	48	Kawamoto et al. (2001); Nordman et al. (2000); Webber et al. (2001)

Table AVII-2: Monitors Usage Data in Residential Sector

Type	Active (hrs/week)	Standby (hrs/week)	Off (hrs/week)	Source
Typical New 17-inch CRT (60% Power management-enabled)	12	3	153	Kawamoto et al.(2001)
17-inch CRT (100% Power management-enabled)	10	5	153	Kawamoto et al.(2001); ADL(2001)
17-inch LCD & Cholesteric LCD (60% Power management-enabled)	12	3	153	Kawamoto et al.(2001)
17-inch CRT , 1 W-Sleep (Power management-enabled)	12	3	153	Kawamoto et al.(2001)

The monitor usage data follows the same calculation methodology used for the desktop PCs (see Appendix F), while substituting the current Power management-enabled (PM-enabled) rate of 60% for monitors (Nordman et al. 2000). Table G-3 displays the percent of time in different modes for monitors at night. The weekly hour distributions by time of day and by basic mode (i.e., without taking into account PM status) were the same as that for desktop PCs (see Table AVII-3 and Table AVII-4).

Table AVII-3: Percent of Time in Different Modes for Monitors (Night Status)

Type	Mode	% of Time in Night	Source
Residential	Active	3	Kawamoto et al. (2001)
	Standby	0	
	Off	97	
Commercial	Active	30	Webber et al.(2001)
	Standby	38	
	Off	32	

Table AVII-4 presents the calculated usage distribution in the three categories; namely day time (PM enabled), daytime hours (non PM) and night/weekend. Multiplying the hours with the corresponding PM and non-PM rates and summing the totals yields the final usage patterns shown in Table AVII-1 and Table AVII-2.

Table AVII-4: Monitors Usage Distribution in Commercial and Residential Sectors

Type	Mode	Day Hours (PM)	Day Hours (non PM)	Night/Weekend Hours
Residential	Active	10	10	1.9
	Standby	0	0	2.8
	Off	0	0	153.3
Commercial	Active	19.2	38.4	36.0
	Standby	19.2	0	45.6
	Off	9.6	9.6	38.4

Table AVII-5 exhibits the power draw data for different monitor technologies/levels in the commercial and residential sectors.

Table AVII-5: Monitors Power Draw Data in Commercial and Residential Sector

Type	Active (W)	Standby (W)	Off (W)	Source
"Typical New" -17-inch CRT (60% Power management-enabled)	90	9.2	4.3	Meyer and Schaltegger (1999)
17-inch CRT (100% Power management-enabled)	90	9.2	4.3	
15-inch LCD (60% Power management-enabled)	11.7	3.4	1.2	ADL (2002a)
17-inch Cholesteric LCD (60% Power management-enabled)	1.7	0.5	0.1	Gibbs (1996)[58]
17-inch OLED (100% Power management-enabled)	5.6	1.6	1.0	ADL(2002); Economist (2001)
17-inch CRT , 1 W-Sleep (60% Power management-enabled)	90	1.0	1.0	Meyer and Schaltegger (1999)

[58] Gibbs (1996) notes that cholesteric LCDs "should run more than 10 times longer on batteries than present displays can", implying that cholesteric displays consume 1/10th the power of conventional LCDs. All LCD power values were reduced by a factor of 10.

System wattages are calculated per lamp, using a weighted average of wattages of 1, 2, 3, and 4-lamp ballasts. For electronic T8 ballasts, the wattages are an average of those for electronic rapid start and instant start systems. Lumen output data are averaged from several lamp manufacturer catalogs[59] for 2001. The assumption is that the lamp meets the FEMP recommendation for initial lumen level, and the corresponding mean lumen level is used in the calculations, representing mean light output over the lamp's life. Lamp lives are assumed to be 19,000 hours for 4-foot T12 and T12 U-tube lamps used with rapid start magnetic ballasts (DOE, 2000). The weighted average lamp life for U-tube T12 and T8 lamps is 18,800 hours, representing a mixture of lamps used with instant start and rapid start ballasts (DOE, 2000).[60] Lamp lives are 11,000 hours for 8-foot T12 lamps (DOE, 2000), and 14,000 hours for 8-foot T8 lamps (2001 lamp manufacturer catalogs); these represent rated lamp lives adjusted slightly because of the practice of group relamping.

For all T12 lamps, the baseline lamp has a halophosphor coating with an energy-efficient electromagnetic ballast. For T8 lamps, 700-series rare earth phosphor lamps is the baseline (i.e., the "FEMP Recommended" level of scenario 1).

Table AVIII-1: Fluorescent Lamp UEC and Energy Savings Estimates, 4-Foot T12 Lamps

Data Type	Current Stock	Typical New	Scenario 1 - FEMP Recommended	Scenario 2 – FEMP Best Available	Source
Lamp/Ballast Watts	35.7	35.7	32.8	31.7	ADL (2002c); FEMP (2000); Turiel et al. (2000)
Ballast Factor	0.88	0.88	0.88	0.88	Turiel et al. (2000)
Annual Lighting Operating Hours	3725	3725	3725	3725	ADL (2002c)
FEMP Rec. Initial Lumens	N/A	N/A	2800	2900	FEMP (2000)
Mean Lumens	2313	2313	2520	2605	Lamp Catalogs
Annual UEC, kW-h	133	133	122	118	Calculation
% Savings potential with respect to typical new	N/A	N/A	8%	11%	Calculation

[59] Lamp Manufacturer Catalogs used - General Electric, Philips, Osram/Sylvania, as well as information from www.bulbs.com .
[60] Instant start ballasts represented 76% of the electronic ballast lamp market in 2001, per the Bureau of Census Current Industrial Report MQ335C for 2001.

Table AVIII-2: Fluorescent Lamp UEC and Energy Savings Estimates, 4-Foot T8 Lamps

Data Type	Current Stock	Typical New	Scenario 1 - FEMP Recommended	Scenario 2 – FEMP Best Available	Source
Lamp/Ballast Watts	28.6	28.6	29.1	27.5	ADL (2002c); FEMP (2000); Turiel et al. (2000)
Ballast Factor	0.89	0.89	0.885	0.885	Turiel et al. (2000)
Annual Lighting Operating Hours	3725	3725	3725	3725	ADL (2002c)
FEMP Rec. Initial Lumens	N/A	N/A	2800	2900	FEMP (2000)
Mean Lumens	2710	2710	2662	2820	Lamp Catalogs
Annual UEC, kW-h	107	107	108	102	Calculation
% Savings Relative to Typical New	N/A	N/A	(2%)	4%	Calculation

Note that for 4-foot T8 lamps, scenario 1 shows no UEC savings, as the current technology has higher lumen output than the FEMP recommended lumen level used as the potential standard level. Lamp manufacturers no longer produce lamps at the FEMP recommended level for 4-foot T8 lamps, as lamp performance has subsequent to the creation of the FEMP levels.

Table AVIII-3: Fluorescent Lamp UEC and Energy Savings Estimates, U-Tube Lamps (T12 & T8 Combined)

Data Type	Current Stock	Typical New	Scenario 1 - FEMP Recommended	Scenario 2 – FEMP Best Available	Source
Lamp/Ballast Watts	34.1	34.1	32.8	30.1	ADL (2002c); FEMP (2000); Turiel et al. (2000)
Ballast Factor	0.882	0.882	0.882	0.882	Turiel et al. (2000)
Annual Lighting Operating Hours	3725	3725	3725	3725	ADL (2002c)
FEMP Rec. Initial Lumens	N/A	N/A	2650	2800	FEMP (2000)
Mean Lumens	2284	2284	2370	2583	Lamp Catalogs
Annual UEC, kW-h	127	127	122	112	Calculation
% Savings Relative to Typical New	N/A	N/A	4%	12%	Calculation

Table AVIII-4: Fluorescent Lamp UEC and Energy Savings Estimates, 8-Foot T12 Lamps

Data Type	Current Stock	Typical New	Scenario 1 - FEMP Recommended	Scenario 2 – FEMP Best Available	Source
Lamp/Ballast Watts	63.1	63.1	60.0	54.8	ADL (2002c); FEMP (2000); Turiel et al. (2000)
Ballast Factor	0.88	0.88	0.88	0.88	Turiel et al. (2000)
Annual Lighting Operating Hours	4220	4220	4220	4220	ADL (2002c)
FEMP Rec. Initial Lumens	N/A	N/A	5600	6000	FEMP (2000)
Mean Lumens	4905	4905	5152	5640	Lamp Catalogs
Annual UEC, kW-h	266	266	253	231	Calculation
% Savings Relative to Typical New	N/A	N/A	5%	13%	Calculation

Table AVIII-5: Fluorescent Lamp UEC and Energy Savings Estimates, 8-Foot T8 Lamps

Data Type	Current Stock	Typical New	Scenario 1 - FEMP Recommended	Scenario 2 – FEMP Best Available	Source
Lamp/Ballast Watts	56.9	56.9	50.7	48.0	ADL (2002c); FEMP (2000); Turiel et al. (2000)
Ballast Factor	0.85	0.85	0.88	0.88	Turiel et al. (2000)
Annual Lighting Operating Hours	4220	4220	4220	4220	ADL (2002c)
FEMP Rec. Initial Lumens	N/A	N/A	5700	5950	FEMP (2000)
Mean Lumens	5250	5250	5190	5488	Lamp Catalogs
Annual UEC, kW-h	240	240	214	203	Calculation
% Savings Relative to Typical New	N/A	N/A	11%	16%	Calculation

Appendix A-IX - HID Lamp UEC and Energy Savings Estimates

AIX.1 Shipment Data

Table AIX-1 shows the NEMA (2002) data on shipments of HID lamps by lamp technology for the years 1990 through 2000.

Table AIX-1: 1990 to 2000 HID Shipments, Units in millions (NEMA, 2002)

Year	High Pressure Sodium	Metal Halide	Mercury Vapor	Total HID Shipments
1990	7.4	5.7	6.2	19.2
1991	8.2	5.5	4.5	18.2
1992	8.8	6.4	4.7	19.9
1993	9.7	7.3	4.6	21.6
1994	10.6	8.7	4.8	24.0
1995	10.8	10.5	4.5	25.8
1996	11.9	11.6	4.4	27.9
1997	11.9	13.2	3.5	28.7
1998	12.2	15.4	2.8	30.4
1999	12.6	18.1	2.7	33.3
2000	11.5	18.1	1.8	31.3

AIX.2 HID Lamp Lifetimes

There are no data available on the quantity of HID lamps currently in stock. For the purposes of this report, HID lamp stock by technology was estimated (LBNL, 2002), based on several assumptions (see Table AIX-2).

Table AIX-2: HID Lamp Stock Calculations

Lamp Type	Lifetime (years)	Lifetime (hours)	Operational Hours/Week	Nominal Watts	System Watts	Usage
Mercury Vapor	6.5	28,500	72	N/A	243[61]	Outdoors, with photosensors
Metal Halide	4.8	15,000	50	175	210	Indoors
High-Pressure Sodium	7.0	24,000	66	200	251	Indoors and Outdoors

[61] Shipment weighted average, from NEMA (1993).

AIX.2.1 HID Lamp Stocks

Using the average lamp lifetime for each lamp technology calculated above, with the NEMA yearly shipments yields an estimate of the number of lamps of each technology in stock at the end of 2000 (see Table AIX-3).

Table AIX-3: HID Annual Shipments and Calculated Stock (Y2002); Units in millions

Year	High Pressure Sodium	Metal Halide	Mercury Vapor	Total in stock
1994	10.6		2.4	
1995	10.8		4.5	
1996	11.9	9.3	4.4	
1997	11.9	13.2	3.5	
1998	12.2	15.4	2.8	
1999	12.6	18.1	2.7	
2000	11.5	18.1	1.8	
Total Stock	**71**	**74**	**22**	**167**

AIX.2.2 Annual Energy Use for HID Lamps

The product of estimated number of each lamp type in stock (Table AIX-3) and the average lamp wattage for each technology, and the assumed hours of operation for each technology (Table AIX-2) yields the total estimated AEC for all HID lamps (Table AIX-4).

Table AIX-4: Annual Energy Consumption of HID Stock (Y2000)

Characteristic	High Pressure Sodium	Metal Halide	Mercury Vapor	All HID Lamps
Average kW/lamp	0.251	0.210	0.243	N/A
Total GW, all Lamps	17.8	15.6	5.4	39
Lifetime (years)	7.0	4.8	6.5	
Hours per Day	11	10	12	
Days per Year	313	261	365	
TW-h per year	61	41	24	126
Annual Quads	**0.67**	**0.44**	**0.26**	**1.4**

Tables AX-1 and AX-2 contain the technical data used in the calculations, as well as the UEC results. All of the data come from a lighting inventory study (ADL, 2002c) except the "scenario 3" halogen technology efficacy (from LBNL, 2002). Lumen output data represent the average of values from several lamp manufacturer catalogs[62] (for Y2001). The "typical new" wattages are calculated using the average lumen output from catalog listings to calculate efficacy; this efficacy is used to adjust the nominal wattage. Technology option wattages are based on the efficacy ratios between the baseline and the option. For all cases, lamp lives were assumed to be 1,000 hours for incandescent general service lamps and 2,000 hours for halogen general service lamps.

Table AX-1: Incandescent Lamp UEC and Energy Savings Estimates, Residential Sector

Data Type	Current Stock	Typical New	Scenario 1 – 1.5% Efficacy Increase	Scenario 2 – 3.0% Efficacy Increase	Scenario 3 – Halogen Technology	Source
Wattage	63	63	62	61	53	LBNL (2002); ADL (2002c)
Annual Lighting Operating Hours	690	690	690	690	690	Tribwell and Lerman (1996)
Efficacy, lumens/Watt	14.4	14.4	14.6	14.8	17.3	ADL (2002c)
Annual UEC, kW-h	43.4	43.4	42.8	42.2	36.1	Calculation
% Savings potential with respect to typical new	N/A	N/A	1.5%	3%	17%	Calculation

Table AX-2: Incandescent Lamp UEC and Energy Savings Estimates, Commercial, Industrial, and Outdoor Sectors

Data Type	Current Stock	Typical New	Scenario 1 – 1.5% Efficacy Increase	Scenario 2 – 3.0% Efficacy Increase	Scenario 3 – Halogen Technology	Source
Wattage	85	85	84	83	71	LBNL (2002); ADL (2002c)
Annual Lighting Operating Hours	3425	3425	3425	3425	3425	ADL (2002c)
Efficacy, lumens/Watt	16	16	16.2	16.5	19.2	ADL (2002c)
Annual UEC, kW-h	293	293	289	284	244	Calculation
% Savings potential with respect to typical new	N/A	N/A	1.5%	3%	17%	Calculation

[62] Lamp Manufacturer Catalogs used - General Electric, Philips, Osram/Sylvania, as well as information from www.bulbs.com .

Appendix A-XI - Incandescent Reflector Lamp UEC and Energy Savings Estimates

Tables AXI-1 and AXI-2 contain the technical data used in the calculations, as well as some of the results. All of the data come from a lighting inventory study (ADL, 2002c) except the "scenario 3" HIR efficacy (from LBNL, 2002). Lumen output data represent the average of values from several lamp manufacturer catalogs[63] (for Y2001). The "typical new" wattages are calculated using the average lumen output from catalog listings to calculate efficacy; this efficacy is used to adjust the nominal wattage. Technology option wattages are based on the efficacy ratios between the baseline and the option. Lamp lives were assumed to be 2,000 hours for incandescent reflector lamps, 2500 hours for halogen reflector lamps, and 3,000 hours for HIR lamps. The annual lighting hours equal the weighted average based on annual operating hours from different sectors from the Phase I inventory (ADL, 2002c).

Table AXI-1: Regulated Incandescent Reflector Lamp UEC and Energy Savings Estimates (All Sectors)

Data Type	Current Stock	Typical New	Scenario 1 – 1.5% Efficacy Increase	Scenario 2 – Halogen	Scenario 3 – HIR Technology
Wattage	107	107	105	104	82
Annual Lighting Operating Hours, All Sectors	2900	2900	2900	2900	2900
Efficacy, Lumens/Watt	14.2	14.2	14.4	14.6	18.5
Annual UEC, kW-h	313	313	309	304	241
% Savings potential with respect to typical new	N/A	N/A	1.5%	3%	23%

Table AXI-2: Unregulated Incandescent Reflector Lamp UEC and Energy Savings Estimates (All Sectors)

Data Type	Current Stock	Typical New	Scenario 1 – 1.5% Efficacy Increase	Scenario 2 – Halogen	Scenario 3 – HIR Technology
Wattage	100	100	98	84	65
Annual Lighting Operating Hours, All Sectors	2000	2000	2000	2000	2000
Efficacy, Lumens/Watt	12.0	12.0	12.2	14.2	18.5
Annual UEC, kW-h	198	198	195	167	129
% Savings potential with respect to typical new	N/A	N/A	1.5%	16%	35%

[63] Lamp Manufacturer Catalogs used - General Electric, Philips, Osram/Sylvania, as well as information from www.bulbs.com .