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U.S. Building-Sector Energy Efficiency Potential

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Abstract

This paper presents an estimate of the potential for energy efficiency improvements in the U.S. building sector by 2030. The analysis uses the Energy Information Administration's AEO 2007 Reference Case as a business-as-usual (BAU) scenario, and applies percentage savings estimates by end use drawn from several prior efficiency potential studies. These prior studies include the U.S. Department of Energy's Scenarios for a Clean Energy Future (CEF) study and a recent study of natural gas savings potential in New York state. For a few end uses for which savings estimates are not readily available, the LBNL study team compiled technical data to estimate savings percentages and costs of conserved energy. The analysis shows that for electricity use in buildings, approximately one-third of the BAU consumption can be saved at a cost of conserved energy of 2.7 ¢/kWh (all values in 2007 dollars), while for natural gas approximately the same percentage savings is possible at a cost of between 2.5 and 6.9 $/million Btu (2.4 to 6.6 $/GJ). This cost-effective level of savings results in national annual energy bill savings in 2030 of nearly $170 billion. To achieve these savings, the cumulative capital investment needed between 2010 and 2030 is about $440 billion, which translates to a 2-1/2 year simple payback period, or savings over the life of the measures that are nearly 3.5 times larger than the investment required (i.e., a benefit-cost ratio of 3.5).

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Introduction

The goal of this analysis is to estimate the potential for energy efficiency improvements in the U.S. building sector by 2030, to inform the study on America's Energy Future being conducted by the National Academy of Engineering.[1]

The output of the study is a techno-economic potential for energy savings, which includes cost-effectiveness criteria but ignores the effect of policy implementation. Results are expressed in terms of cost of conserved kWh of electricity and million Btus of natural gas.

Methodology and Data

Business-As-Usual Forecast

This analysis starts with the Energy Information Administration's Annual Energy Outlook (AEO) 2007 Reference Case as business-as-usual (BAU) scenario, segmented by fuel and end use (US DOE 2007b).[2] We adjusted the published AEO end use consumption values in 2030 to allocate some of the consumption in the "Other Uses" end use (mainly cooking and electronics) to the traditional end uses where it appropriately belongs. This re-allocation was based on data published by the Department of Energy (US DOE 2007a).[3] Tables 1 and 2 show the revised AEO Reference Case that is used here as the BAU scenario, presented in terms of site energy. We only consider electricity and natural gas in this analysis. These forms of energy account for about 92% of primary energy use in U.S. buildings.

The BAU scenario, which includes some level of energy efficiency improvement driven by market forces as well as codes and standards, assumes that residential electricity use increases 1.4% per year and that commercial electricity use increases 1.9% per year on average during 2006-2030. For comparison, residential electricity use increased 2.4% per year and commercial use 2.8% per year on average during 1990-2006 (US DOE 2007c). With respect to natural gas use, the BAU scenario assumes growth rates of 0.8% per year in the residential sector and 1.6% per year in the commercial sector during 2006-2030.

Savings Potential and Cost-effectiveness

To calculate cost-effective energy savings potential in 2030, we compiled percentage savings estimates by end use, drawn from several prior studies, and applied these to the BAU scenario described above. For most end uses, the Scenarios for a Clean Energy Future (CEF) study was used to estimate savings potential (Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies 2000, Koomey et al. 2001). For the residential natural gas end uses, we used savings estimates from a recent study of natural gas savings potential in New York state (Mosenthal et al. 2006). For selected end uses that were not analyzed in the CEF study, we

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[1] See http://www8.nationalacademies.org/cp/projectview.aspx?key=48844.

[2] Although a preliminary version of the AEO 2008 was available, a revised version was being prepared to include the effects of the recently passed 2007 Energy Independence and Security Act (EISA); full documentation for this revised version was not available in time to incorporate here.

[3] The "adjust to SEDS" calibration factor contained in the AEO "Other Uses" end use was also allocated proportionally to each of the other end uses, according to their relative share of 2005 consumption.

compiled technical data to estimate savings percentages and costs of conserved energy. The specific data source used for each end use is identified in Tables 1 and 2. Each of these studies is described in more detail below.

To provide a better sense of the technologies that were used to estimate these potentials, Tables 3 and 4 list the principal technologies or efficiency improvement assumptions used for each end use. For the most part the technologies are widely available in the marketplace and well proven as of 2008. A few of the technologies such as heat pump water heaters are still produced on a limited scale and can be considered near-term emerging technologies.

Table 1: Summary of residential buildings consumption, savings potential and measure costs in 2030, by end use

Fuel	End-use	Business As Usual 2030 U.S. Consumption (1)	Technoeconomic Potential: % Savings Relative to BAU case	Technoeconomic Potential: Consumption Savings	Cost of Conserved Energy	Data Source
Electricity		*(TWh)*		*(TWh)*	*(2007¢/kWh)*	
	Space heating	164	17%	28	3.5	2
	Space cooling	328	27%	89	5.3	2
	Water heating (5, 7)	149	27%	39	2.0	2
	Refrigeration	121	31%	38	4.6	2
	Cooking (7)	103	0%	0	N/A	2
	Clothes Dryers (7)	103	0%	0	N/A	2
	Freezers	42	21%	9	7.4	2
	Lighting	338	50%	169	1.2	2
	Clothes Washers	9	50%	4	2.3	2
	Dishwashers	11	11%	1	5.8	3
	Color Televisions	267	25%	67	0.9	2
	Personal Computers	68	57%	39	4.3	3
	Furnace Fans	40	25%	10	3.7	3
	Other Uses	154	48%	74	1.9	2
	Total electric	**1,896**	**30%**	**567**	**2.7**	
Natural gas		*(Quads)*		*(Quads)*	*(2007$/MBtu)*	
	Space heating	3.89	30%	1.15	5.5	4
	Space cooling	0.00	0%	0.00	N/A	
	Water heating	1.20	29%	0.35	11.8	4
	Cooking	0.26	0%	0.00	N/A	
	Clothes dryers	0.09	3%	0.00	2.9	4
	Other Uses	0.04	10%	0.00	1.1	4
	Total gas	**5.47**	**28%**	**1.51**	**6.9**	

(1) 2007 AEO reference case end use consumption for the “Other” end use was re-allocated to match the 2007 DOE Buildings Energy Databook (US DOE 2007a) end use shares, and the "adjust to SEDS" calibration value was allocated proportionally to each end use rather than lumped into the "Other" end use.
(2) Source for potential savings and CCE is the CEF study Table D-1.1 (Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies 2000). CCEs are from the CEF Advanced Case; calculated using a real discount rate of 7% and lifetimes as shown in CEF report Appendix C-1.
(3) Source for potential savings and CCE is the LBNL analysis documented in Tables 5 and 6.
(4) Source for potential savings and CCE is the New York State natural gas potential study (Mosenthal et al. 2006).
(5) CCE for electric water heating was incorrect in the original CEF report and has been corrected here.
(6) End uses with costs of conserved energy listed as N/A were not analyzed in this study.
(7) CEF results were adjusted to remove fuel switching (electric to gas) as a measure for water heaters, cooking and clothes dryers.
(8) Consumption and CCEs are based on site energy.

Table 2: Summary of commercial buildings consumption, savings potential and measure costs in 2030, by end use

Fuel	End-use	Business As Usual 2030 U.S. Consumption (1)	Technoeconomic Potential: % Savings Relative to BAU Case	Technoeconomic Potential: Consumption Savings	Cost of Conserved Energy	Data Source
Electricity		*(TWh)*		*(TWh)*	*(2007¢/kWh)*	
	Space heating	77	39%	30	0.5	2
	Space cooling	238	48%	115	2.8	2
	Water heating	59	11%	6	1.2	2
	Ventilation	131	45%	59	0.5	2
	Cooking	11	32%	3	8.4	3
	Lighting	543	25%	137	5.2	2
	Refrigeration	89	38%	34	1.3	2
	Office equip.-PCs	120	60%	71	3.9	3
	Office equip.-non-PCs	271	25%	68	3.2	3
	Other Uses	523	35%	182	1.4	2
	Total electric	**2,062**	**34%**	**705**	**2.7**	
Natural gas		*(Quads)*		*(Quads)*	*(2007$/MBtu)*	
	Space heating	2.30	47%	1.09	1.9	2
	Space cooling	0.06	38%	0.02	4.1	2
	Water heating	1.06	15%	0.16	2.3	2
	Cooking	0.47	31%	0.15	7.4	3
	Other Uses	0.47	20%	0.09	1.9	2
	Total gas	**4.36**	**35%**	**1.51**	**2.5**	

(1) AEO reference case end use consumption for the "Other" end use was re-allocated to match the 2007 DOE Buildings Energy Databook (US DOE 2007a) end use shares, and the "adjust to SEDS" calibration value was allocated proportionally to each end use rather than lumped into the "Other" end use.
(2) Source for potential savings and CCE is the CEF study Table D-1.1 (Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies 2000). CCEs are from the CEF Advanced Case; calculated using a real discount rate of 7% and lifetimes as shown in CEF report Appendix C-1.
(3) Source for potential savings and CCE is the LBNL analysis documented in Tables 5 and 6.
(4) Consumption and CCEs are based on site energy.

To estimate aggregate savings potential in 2030, we multiplied the energy savings potential shown by end use in Tables 1 and 2 by the estimates of energy consumption by end use in the BAU scenario. The cost of conserved energy (CCE) is the levelized annual cost of the efficiency measures over their lifetime divided by the estimated annual energy savings. The CCE accounts for incremental measure costs only; no cost is assumed for policies or programs aimed at stimulating measure adoption. Consistent with the CEF study, a real discount rate of 7% was used to calculate these values. Cost of conserved energy values from the CEF and New York state studies were inflated to 2007 dollars using the GDP implicit price deflator (BEA 2008).

Table 3: Residential building measures included in efficiency potential studies used for this analysis

Fuel	End-use	Efficiency measure description
Electricity		
	Thermal shell	Existing electric-heated homes: no efficiency measures; New homes: up to 40% savings compared to 2006 IECC
	Space heating equipment	Switch electric furnace to heat pump, improved heat pump efficiency
	Space cooling equipment	Improved efficiency central and room air conditioners, variable speed RAC
	Water heating	Reduced standby-loss electric resistance water heater, heat pump water heater, horizontal axis clothes washer
	Refrigeration	Best-in-class Energy Star refrigerator, 2008
	Freezers	Best-in-class Energy Star freezer, 2008
	Lighting	Compact fluorescent fixtures, Halogen infrared lamps, Reduced wattage
	Clothes washers	Horizontal axis washer with improved motor
	Dishwashers	Dishwasher with improved pump design and improved motor
	Color televisions	Reduced standby power use
	Personal computers	Energy Star-rated PC and monitor, power-management enabled
	Furnace fans	Electronically commutated permanent magnet furnace-fan motor, single-
	Other uses	More efficient motors in ceiling fans, pool pumps and other small motors;
Natural gas		
	Thermal shell	Air sealing, R-19 floor insulation, R-21 wall insulation, R-49 attic insulation, Integrated design for new construction (SF 30% > code, MF 50% > code), Triple-pane low-e windows, Insulated attic hatch
	Space heating equipment	Insulate/seal/balance ducts, Place ducts within thermal shell, Condensing
	Space cooling equipment	N/A
	Water heating	On-demand water heater, 0.63 EF gas water heater, low-flow plumbing fittings, Energy Star clothes washer, Reduced WH tank temp., Graywater heat exchanger/GFX, Pipe insulation
	Cooking	N/A
	Clothes dryers	Humidity sensor control
	Other uses	Pool and spa covers

Table 4: Commercial building measures included in efficiency potential studies used for this analysis

Fuel	End-use	Efficiency measure description
Electricity		
	Thermal shell	No efficiency measures
	Space heating equipment	Up to 55% savings in existing buildings from improved HVAC equipment and controls
	Space cooling equipment	Up to 55% savings in existing buildings from improved HVAC equipment and controls
	Water heating	20% savings compared to frozen efficiency baseline
	Ventilation	Up to 55% savings in existing buildings from improved shell, HVAC equipment and controls
	Cooking	Energy Star-rated dishwasher, fryer, hot food holding cabinet, and
	Lighting	T-8 lamps and electronic ballasts; 32% combined savings from occupancy controls, daylight dimming, and improved lighting design
	Refrigeration	20% to 45% savings compared to frozen efficiency baseline
	Office equip.-PCs	Energy Star-rated PC and monitor, power-management enabling software
	Office equip.-non-PCs	Energy Star-rated copiers and printers
	Other Uses	More efficient motors in ceiling fans, pool pumps and other small motors;
Natural gas		
	Thermal shell	No efficiency measures
	Space heating equipment	Up to 55% savings in existing buildings from improved shell, HVAC equipment and controls
	Space cooling equipment	Up to 55% savings in existing buildings from improved shell, HVAC equipment and controls
	Water heating	10% savings compared to frozen efficiency baseline
	Cooking	Energy Star-rated fryer and steamer; more efficient broilers, griddles and ovens
	Other Uses	10% reduction in miscellaneous gas use; Up to 55% reduction in district

Scenarios for a Clean Energy Future Study

The CEF study contains detailed end use technology data and savings potential over the 2000 to 2020 time period.[4] Tables 1 and 2 list these values and the associated CCE for each end use. Technology costs were drawn from the CEF "Advanced" case, which assumed a greater penetration of more advanced efficiency technologies. While the CEF study also defined policy pathways to implement these technologies (Koomey et al. 2001), we only make use of the technoeconomic potentials it reported. Those savings potentials are based on a "phased-in" approach, which explicitly accounts for stock turnover using retirement functions for buildings and equipment.[5] This approach gives the most realistic picture of potential energy savings in the face of real limits on how fast the capital stock is replaced, and assumes no early replacement of equipment before its economic lifetime.

[4] Results of the spreadsheet analysis are drawn from Appendix D-1 of the CEF report (Interlaboratory Working Group on Energy-Efficient and Clean-Energy Technologies 2000). These results differ slightly from the "final" integrated CEF results derived from energy sector-wide runs of the National Energy Modeling System (NEMS) forecasting model, which include the effect of energy supply and price feedbacks.

[5] Although, as Tables 3 and 4 indicate, CEF did not include thermal shell retrofits for most types of existing buildings.

In using the CEF savings potentials to estimate the national savings potential in 2030, we assume that the CEF savings potential estimated for 2000-2020 would still be applicable for the 2010-2030 period. While some efficiency measures such as compact fluorescent lamps, more efficient lighting devices for commercial buildings, and Energy Star personal computers and other electronic devices have already been adopted to a significant degree, new efficiency measures have entered the marketplace since 2000 and others are under development and expected to be commercialized in the near future. This effect is probably best illustrated with residential central air conditioners (CAC). The CEF study assumed that the most efficient residential CAC had a seasonal energy efficiency ratio (SEER) of 18, which represented a significant savings potential compared to the minimum Federal standard of 10 SEER at that time. Since the CEF study was published, the minimum Federal standard has been increased to 13 SEER, which implies that a significant portion of the savings potential in the CEF study has been incorporated into today's baseline efficiency levels (and thus should not be "counted" in a savings potential analysis beginning in 2010). The most efficient products that are commercially available now, however, significantly exceed the efficiency of the best products available at the time of the CEF study. In fact, as of this writing there are over 30 CAC models that are rated at higher than 18 SEER, and several that are rated at 23 SEER (CEE 2008). In addition, there now exist national standards for quality installation of heating and cooling systems, which help ensure that the potential savings from high-efficiency systems are actually realized in practice. For all these reasons, we believe that the improvements in the high-efficiency segment of the CAC market roughly compensate for the lost savings potential due to the increased Federal minimum standard, and this same pattern can be observed in other end uses as well. Thus, while today's energy efficiency baseline has improved somewhat since 2000, we assume that the number of efficiency technologies and practices yet to be adopted have kept pace with this improvement, keeping the overall efficiency potential roughly constant. Later in this report, we analyze changes in the AEO reference case to help assess whether this assumption is reasonable.

New York State Natural Gas Savings Potential Study

Because the CEF study did not model the savings potential of shell retrofits to existing homes, which resulted in unrealistically low savings potential for gas-heated homes, we instead used estimates of residential natural gas savings derived from a recent study of New York state (Mosenthal et al. 2006). The applicability of that study to the national context rests on the assumption that the *percentage* savings (relative to baseline consumption) in New York is representative of the country as a whole. The CCE, however, depends on the absolute consumption savings for a given measure, so we scaled the CCEs to account for heating degree-day differences between New York state and the national average.[6] The CCEs were calculated using a 7% discount rate, to be consistent with the other end uses in this analysis.

LBNL Analysis of Additional End uses

Several end uses were not analyzed in the CEF study, either due to lack of data or resources. These end uses are: commercial office equipment (both PCs and non-PCs), commercial cooking, residential office equipment, residential furnace fans, and residential dishwashers. For these end uses, we compiled technology performance and cost data and developed savings potential

[6] The potential savings estimates for "downstate" New York (New York City and its immediate environs) were used for this study. Adjusting to the national-average climate increased the CCEs by about 15% and was only applied to the space heating end use.

estimates as part of this analysis. The details of these technology data are shown in Tables 5 and 6, with detailed references provided in the notes to those tables. For the commercial and residential office equipment end uses, we primarily drew on information from the U.S. EPA Energy Star program and analysis performed by TIAX LLC for the U.S. Department of Energy (Roth et al. 2004, Roth et al. 2007). For the commercial cooking end use, the savings estimates are mainly based on information from the Energy Star program and the Food Service Technology Center (FSTC 2002). For residential furnace fans and dishwashers, we rely on data compiled for the U.S. Department of Energy's standards rulemakings for those products (Rosenquist et al. 2004, US DOE 2007d).

Table 5: Technology Data for LBNL-derived Electricity Efficiency Measures

Sector / End-use	Product Type	Measure	Annual Unit Energy Consumption	Savings		Measure Energy Notes	Unit Cost	Cost Notes	Lifetime	CCE
			(kWh/yr)	(kWh/yr)	(%)		(2007 $)		(years)	(2007¢/kWh)
Commercial Buildings										
Office Equipment – PCs	*Monitors and displays*	Baseline	263			E1				
		Energy Star monitor	179	84	32%	E2	$ 10.93	C1	4	3.8
		Power management software	80	99	55%	E3	$ 14.49	C2	4	4.3
		Total		183	69%		$ 25.42			4.1
	PCs and workstations	Baseline	542			E4				
		Energy Star PC	400	142	26%	E5	$ 20.00	C3	4	4.2
		Power management software	262	137	34%	E6	$ 14.49	C2	4	3.1
		Total		280	52%		$ 34.49			3.6
	End-use Average				60%	E7				3.9
Office Equipment – non-PCs	*Printers and copiers*	Baseline	660			E8				
		Energy Star copier	495	165	25%	E9	$ 25.00	C4	6	3.2
	End-use Average				25%					3.2
Cooking	*Dishwashers*	Baseline	13,824				$ 12,000			
		Energy Star dishwasher	11,520	2,304	17%	E10	$ 15,000	C5	20	3.1
	Fryers	Baseline	18,196				$ 5,551			
		Energy Star fryer	17,017	1,179	6%	E11	$ 10,259	C6	12	50.3
	Hot food holding cabinets	Baseline	6,570				$ 2,069			
		Energy Star holding cabinet	2,628	3,942	60%	E12	$ 3,782	C7	12	5.5
	Steam cookers	Baseline	11,600				$ 10,000			
		Energy Star steam cooker	4,980	6,620	57%	E13	$ 10,000	C8	10	0.0
	Broilers	Baseline	24,960				$ 2,000			
		High efficiency broiler	20,218	4,742	19%	E14	$ 3,696	C9	10	5.1
	Griddles	Baseline	11,232				$ 1,000			
		High efficiency griddle	10,670	562	5%	E15	$ 1,850	C9	10	21.5
	Ovens	Baseline	28,915				$ 4,500			
		High efficiency oven	17,638	11,277	39%	E16	$ 8,325	C9	10	4.8
	Ranges	Baseline	16,200				$ 4,000			
		High efficiency range	12,388	3,812	24%	E17	$ 7,400	C9	10	12.7
	End-use Average				32%	E18				8.4

Table 5, continued: Technology Data for LBNL-derived Electricity Efficiency Measures

Sector / End-use	Product Type	Measure	Annual Unit Energy Consumption	Savings		Measure Energy Notes	Unit Cost	Cost Notes	Lifetime	CCE
			(kWh/yr)	(kWh/yr)	(%)		(2007 $)		(years)	(2007¢/kWh)
Residential Buildings										
Dishwashers	*Dishwashers*	Baseline	181							
		High efficiency dishwasher	161	20	11%	E19	$ 27.51	C10	13	5.8
	End-use Average				11%					5.8
Furnace Fans	*Furnace Fans*	Baseline	496			E20				
		High efficiency motor	372	124	25%	E21	$ 48.92	C11	20	3.7
	End-use Average				25%					3.7
Personal Computers	*Monitors and displays*	Baseline	85			E22				
		Energy Star monitor	36	49	58%	E23	$ 10.93	C1	4	6.5
		Power management enabling	31	5	13%	E23	$ -	C12	4	0.0
		Total		54	64%		$ 10.93			6.0
	PCs	Baseline	235			E24				
		Energy Star PC	173	62	26%	E25	$ 20.00	C3	4	9.6
		Power management enabling	97	76	44%	E26	$ -	C12	4	0.0
		Total		138	59%		$ 20.00			4.3
	Notebooks	Baseline	72			E24				
		Power management enabling	52	20	28%	E26	$ -	C12	4	0.0
		Total		20	28%		$ -			0.0
	End-use Average				57%	E27				4.3

Notes to Table 5:

Measure Energy Notes:

E1) Baseline consumption from Energy Star monitor savings calculator (US EPA 2008f).

E2) Savings based on Energy Star monitor vs. non-Energy Star LCD monitor, from Energy Star monitor savings calculator (US EPA 2008f).

E3) Savings based on 17" LCD from Roth et al. (2004), table 4-44.

E4) Baseline assumes non-Energy Star desktop PC, with power management disabled and always turned off at night, from Energy Star computer savings calculator (US EPA 2008a).

E5) Savings based on Energy Star PC vs. non-Energy Star PC, with power management disabled and always turned off at night, from Energy Star PC savings calculator (US EPA 2008a).

E6) Savings from Roth et al. (2004), table 4-44.

E7) Monitor and PC savings and costs are weighted-averaged according to the 2002 estimated national energy consumption for each product type (16.5 TWh for monitors and 19.6 TWh for PCs) (Roth et al. 2004).

E8) Baseline assumes medium-speed copier (21-40 ipm) from the Energy Star copier calculator (US EPA 2007a).

E9) Savings based on "average savings" from the Energy Star printer and copier web page (US EPA 2008g).

E10) Savings based on Single Tank Conveyor, High Temperature dishwasher, from Energy Star dishwasher savings calculator (US EPA 2008b). Only includes idle electricity savings (no water heating).

E11) Savings based on Energy Star electric fryer savings calculator (US EPA 2008c).

E12) Savings based on Energy Star hot food holding cabinet savings calculator (US EPA 2008e).
E13) Savings based on FEMP designated product fact sheet (FEMP 2007).
E14) Baseline consumption for electric underfired broiler (FSTC 2002). Savings percentage from Energy Star restaurant guide (US EPA 2007b).
E15) Baseline consumption for electric griddle from FSTC (2002), Table 3-3. Savings percentage from Energy Star restaurant guide (US EPA 2007b).
E16) Baseline consumption for electric combination oven (FSTC 2002). Savings percentage from Energy Star restaurant guide (US EPA 2007b).
E17) Baseline consumption for electric combination range top and oven (FSTC 2002), table 5-4. Savings percentage from FSTC (2002), table 5-2.
E18) Commercial cooking savings and costs are weighted-averaged according to estimated 1993 national energy use by product type (Arthur D. Little Inc. 1993).
E19) Savings based on improved food filter and spray arm geometry, as well as 10% more efficient motor (Rosenquist et al. 2004). Savings only apply to dishwasher machine energy use, not hot water use.
E20) Baseline consumption assumes single-stage, 78 AFUE gas furnace with permanent split capacitor (PSC) blower motor and forward-curved impeller blades, from US DOE (2007d), table 7.8.1.
E21) Savings assume electronically commutated permanent magnet motor, single-speed operation from Arthur D. Little (1999), table 3-12.
E22) Baseline consumption from Roth et al. (2007), table 4-37.
E23) Savings derived from Roth et al. (2007), table 4-43, based on best-in-class 17-inch LCD with average usage. Power management savings assume 100% enabling rate.
E24) Baseline consumption from Roth et al. (2007), table 4-25. Assumes "typical" PC in 2005, with average power-management enabling rates.
E25) Savings based on same percentage savings as commercial office PC, per note E5 above.
E26) Savings based on 100% PM enabling rate, compared to baseline PM settings reported by Roth et al. (2007), page 4-31
E27) Residential PC savings and costs are weighted-averaged according to estimated 2005 national energy use by product type from Roth et al. (2007), table 4-2.

Cost Notes:

C1) Cost assumes improved power supply efficiency, from Roth et al. (2004), p. 4-29. Lifetime from US EPA (2008f).
C2) Cost assumes $10 per PC to purchase 1e software per Roth et al. (2004), p. 4-83 + 25% per year O&M cost for years 2-4 (1e 2008) + $9 installation labor. Half of the cost is allocated to the monitor and half to the PC. Lifetime is set to match monitor lifetime.
C3) Cost assumes improved power supply and motherboard power conversion efficiency (CSCI 2007). Lifetime from US EPA (2008a).
C4) Cost is assumed to be similar to that for an Energy Star PC, including improved power supply and some motherboard improvements, increased by 25% to account for larger power supply size for copier (CSCI 2007 and LBNL estimate). Lifetime from Energy Star copier calculator (US EPA 2007a).
C5) Cost and lifetime source: Energy Star dishwasher savings calculator (US EPA 2008b). CCE assumes that only 25% of incremental unit cost is applied to idle energy savings; the remaining cost increment is for design changes that are needed for hot water savings upgrade not included in this measure.
C6) Cost and lifetime source: Energy Star electric fryer savings calculator (US EPA 2008c).
C7) Cost and lifetime source: Energy Star hot food holding cabinet savings calculator (US EPA 2008e).
C8) Cost and lifetime source: Energy Star gas steam cooker savings calculator (US EPA 2004), assuming electric has same incremental cost ($0) as gas.
C9) Baseline cost for typical units found in internet search. Incremental cost assumed to be same percentage as electric fryer (85% cost premium over baseline).
C10) Cost and lifetime from Rosenquist et al. (2004).
C11) Cost assumes ECM motor with single-stage burner, from Arthur D. Little (1999), table 3-12. Lifetime from US DOE (2007d).
C12) Assumes no monetary cost for residential user to enable monitor and PC power management.

Table 6: Technology Data for LBNL-derived Natural Gas Efficiency Measures

Sector / End-use	Product Type	Measure	Annual Unit Energy Consumption	Annual Unit Energy Savings		Measure Energy Notes	Unit Cost	Cost Notes	Lifetime	CCE
			(MBtu/yr)	(MBtu/yr)	(%)		(2007 $)		(years)	(2007$/MBtu)
Commercial Buildings										
Cooking	*Fryers*	Baseline	163				$ 6,206			
		Energy Star fryer	112	50	31%	E1	$ 10,001	C1	12	9.5
	Steam cookers	Baseline	69				$ 10,500			
		Energy Star steam cooker	40	30	43%	E2	$ 10,500	C2	10	0.0
	Broilers	Baseline	354				$ 2,000			
		High efficiency broiler	288	66	19%	E3	$ 3,223	C3	10	2.7
	Griddles	Baseline	86				$ 1,000			
		High efficiency griddle	82	4	5%	E4	$ 1,610	C3	10	20.2
	Ovens	Baseline	137				$ 5,000			
		High efficiency oven	83	53	39%	E5	$ 8,050	C3	10	8.1
	Ranges	Baseline	160				$ 3,000			
		High efficiency range	120	40	25%	E6	$ 4,830	C3	10	6.5
	End-use Average				31%	E7				7.4

Notes to Table 6:

Measure Energy Notes:

E1) Savings based on Energy Star gas fryer savings calculator (US EPA 2008d).
E2) Savings based on Energy Star gas steam cooker savings calculator (US EPA 2004).
E3) Baseline consumption and savings percentage from Energy Star restaurant guide (US EPA 2007b), assuming $1/therm rate for natural gas.
E4) Baseline consumption for gas griddle from FSTC (2002), Table 3-2. Savings percentage from Energy Star restaurant guide (US EPA 2007b).
E5) Baseline consumption for gas combination oven (FSTC 2008). Savings percentage from Energy Star restaurant guide (US EPA 2007b).
E6) Baseline consumption for gas combination range top and oven from (FSTC 2002), table 5-3. Savings percentage from FSTC (2002), table 5-2.
E7) Commercial cooking savings and costs are weighted-averaged according to estimated 1993 national energy use by product type (Arthur D. Little Inc. 1993).

Cost Notes:

C1) Cost and lifetime source: Energy Star gas fryer savings calculator (US EPA 2008d).
C2) Cost and lifetime source: Energy Star gas steam cooker savings calculator (US EPA 2004).
C3) Baseline cost for typical units found in internet search. Incremental cost assumed to be same percentage as gas fryer (61% cost premium over baseline).

Efficiency Supply Curves

Figures 1 through 4 show the potential for energy efficiency improvements over the 2010-2030 period for the residential and commercial sectors, for electricity and natural gas. The x-axis shows the total reduction in 2030 energy consumption, while the y-axis shows the CCE in fuel-specific units. Each step on the curve represents the total savings for a given end use for all the cost-effective efficiency measures analyzed for that end use. These are referred to as "supply curves" because they indicate how much energy savings is available for a given cost. The CCE is calculated as the savings-weighted average for all the measures in that end use cluster. End uses that do not have technology costs reported in Table 1 are not included in these plots (i.e., residential cooking and clothes dryers).

Each of the supply curves indicates that the projected BAU energy consumption in 2030 can be reduced by about 30% at a cost less than current retail energy prices. Table 7 compares the weighted-average cost of conserved energy from each supply curve to national average retail energy prices as of 2007. The data in the table show that the average cost of conserved energy is well below the retail energy price both fuels in both residential and commercial buildings, meaning that adopting efficiency measures is cost effective for households and businesses. Of course factors such as local energy prices and weather will influence cost effectiveness in any particular location.

Table 8 provides data about the aggregate costs and benefits of these efficiency technologies for the entire building sector. The cumulative capital investment needed between 2010 and 2030 is about $440 billion, to achieve annual energy bill savings in 2030 of nearly $170 billion. These savings result in a 2-1/2 year simple payback period, or savings over the life of the measures that are nearly 3.5 times larger than the investment required (i.e., a benefit-cost ratio of 3.5).

Figure 1: Residential Electricity Savings Potential, 2030

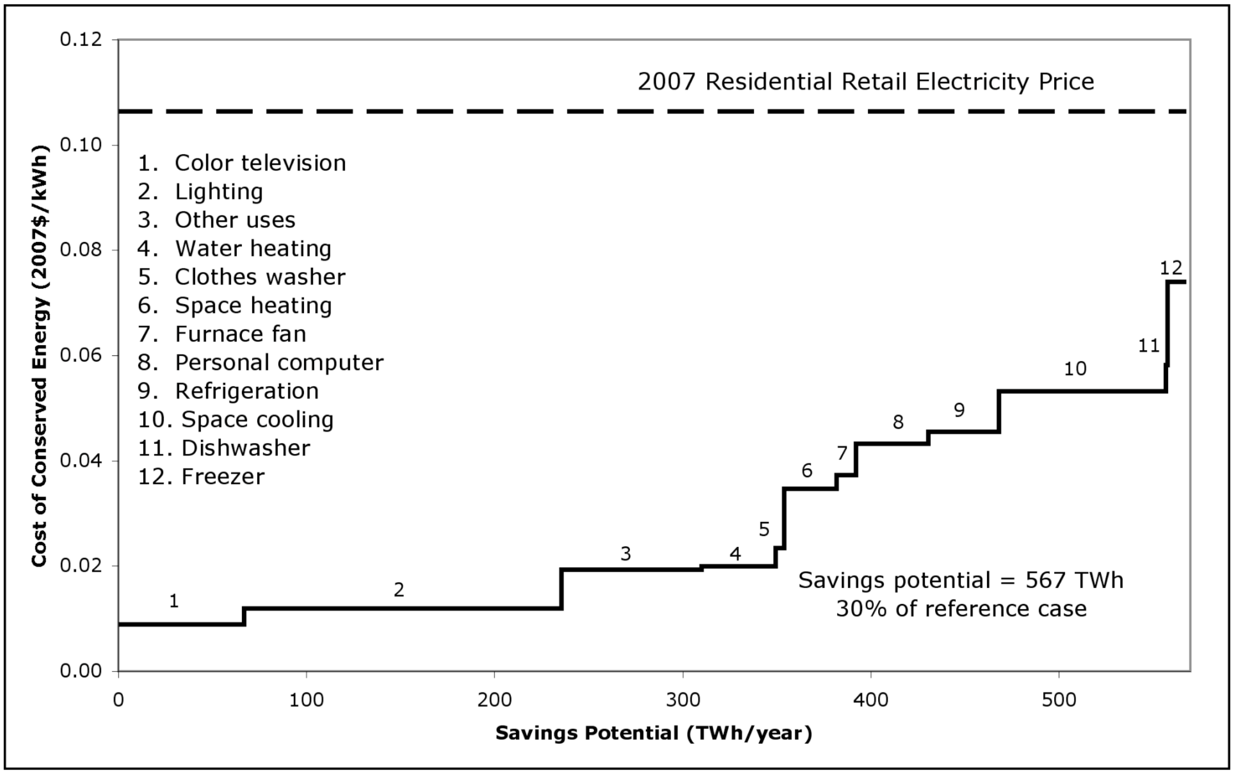


Figure 2: Residential Natural Gas Savings Potential, 2030

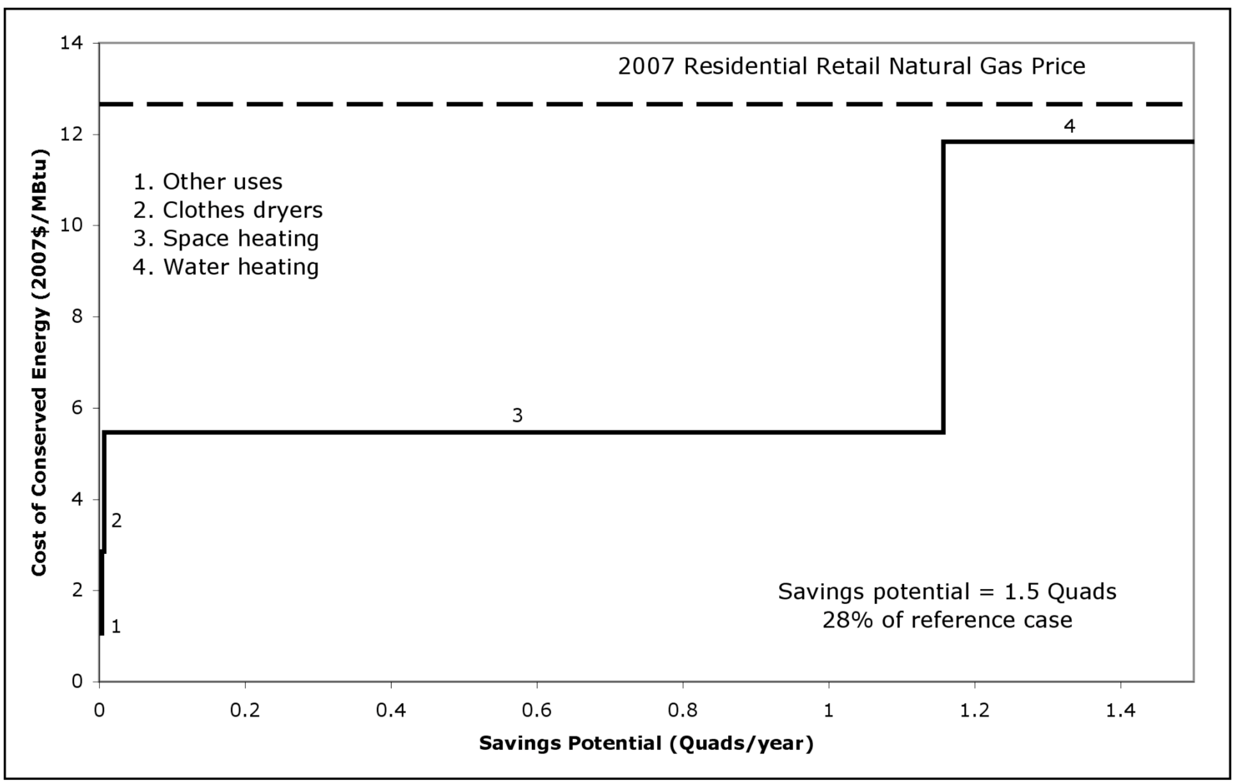


Figure 3: Commercial Electricity Savings Potential, 2030

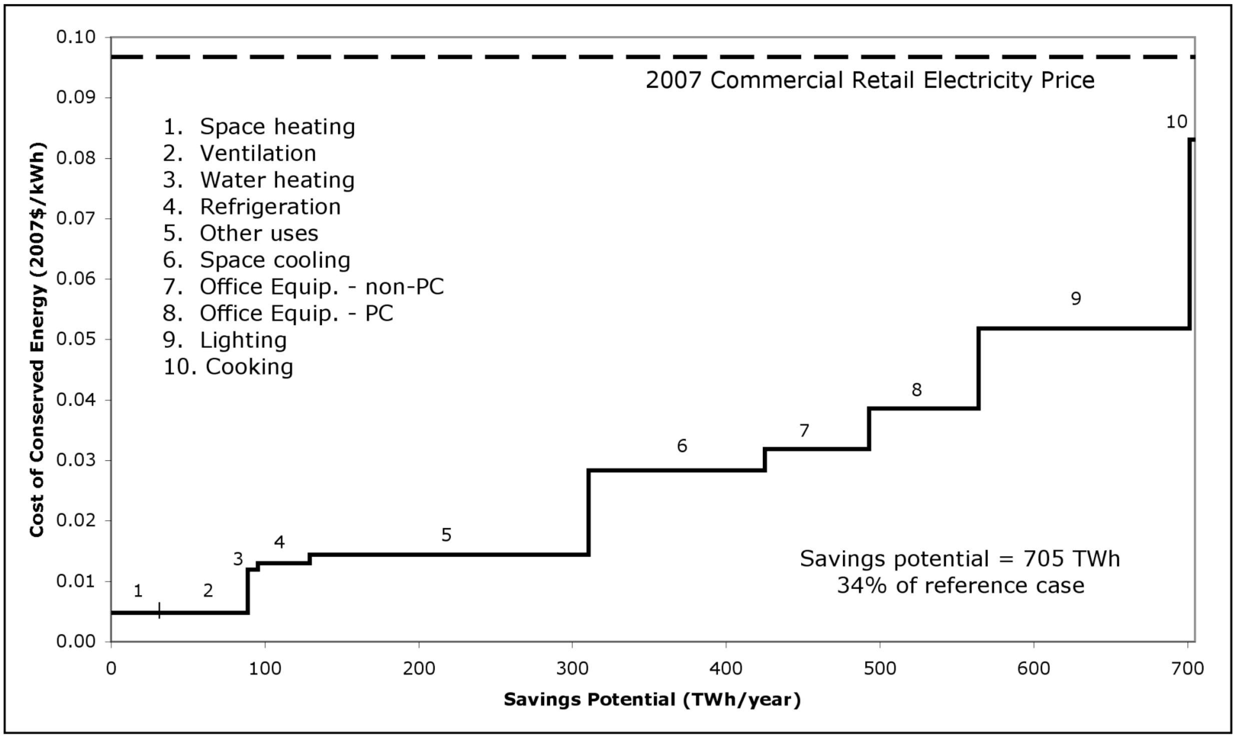


Figure 4: Commercial Natural Gas Savings Potential, 2030

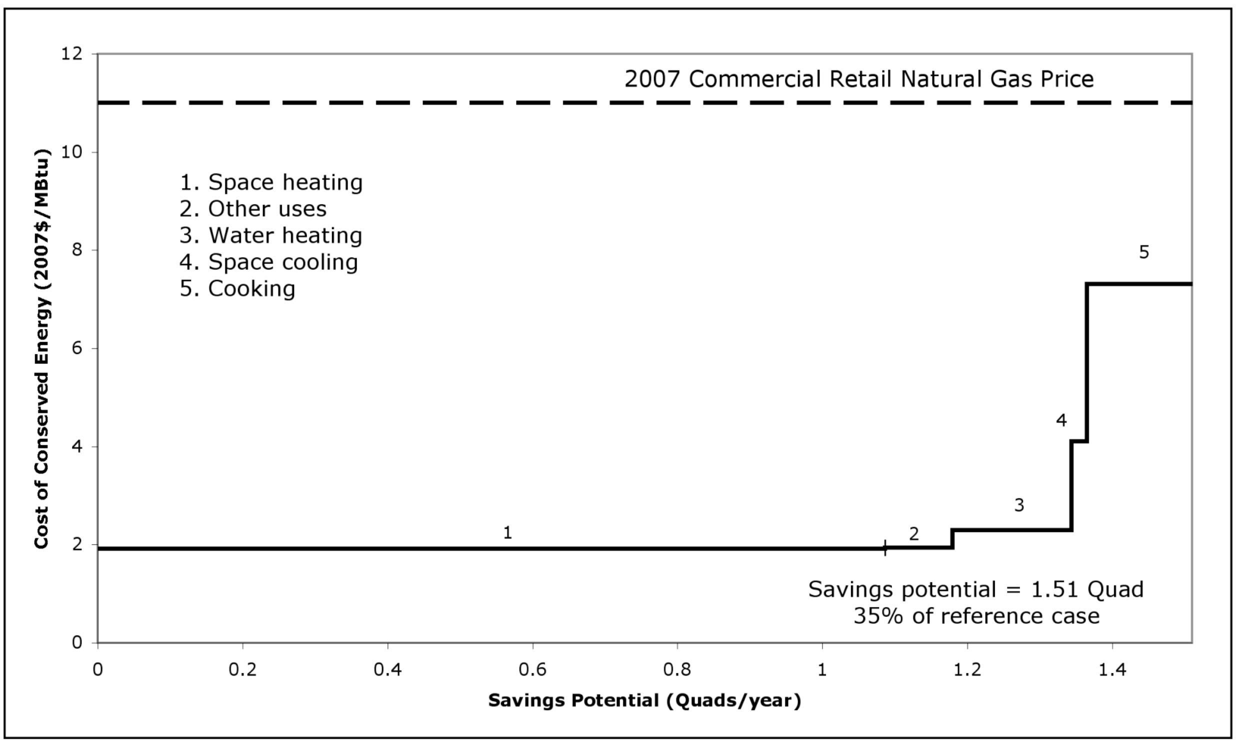


Table 7: Comparison of Average Cost of Conserved Energy and Retail Energy Prices

Sector and Energy Type	*Average Cost of Conserved Energy (¢/kWh or $/MBtu)*	*National Average Retail Energy Price (1) (¢/kWh or $/MBtu)*
Residential		
Electricity	2.7	10.6
Natural Gas	6.9	12.7
Commercial		
Electricity	2.7	9.7
Natural Gas	2.5	11.0

(1) Energy price data are 2007 national average values as reported by the Energy Information Administration (US DOE 2008).

Table 8: U.S. Efficiency Investment and Savings by 2030 (2007$ billions)

Sector and Energy Type	*Cumulative Capital Investment*	*Annual Utility Bill Savings in 2030 (1)*	*Simple Payback Time (years)*
Residential			
Electricity	$136	$60	2.3
Natural Gas	$104	$19	5.5
Commercial			
Electricity	$163	$68	2.4
Natural Gas	$38	$17	2.3
Total	$441	$164	2.7

(1) Assumes 2007 retail electricity and natural gas prices.

Applicability of CEF Study to Estimate Current Potentials

As discussed earlier, a key assumption in this analysis is that the CEF-reported percentage savings potentials in 2020 (measured from a base year of 2000) are still reasonable estimates of the potential remaining in 2030 (measured from a base year of 2010). In other words, we assume that energy efficiency is a "renewable" resource, in that any efficiency improvements realized in the last ten years have been replaced by new potential. Replacement of this efficiency potential can happen through introduction of new efficiency technologies, or through broader application of existing technologies.

As a simple test of this hypothesis, we compared forecasted energy intensities from the 1999 AEO (which served as the BAU case for the CEF study) and the 2007 AEO (which is the BAU case for this analysis) (US DOE 1998, US DOE 2007b). Figures 5 and 6 show these comparisons for the residential and commercial sectors, respectively. To account for changes in number and size of buildings in the stock, we normalized total energy consumption to the forecasted floor area of the building stock to calculate energy intensity. While energy intensity is influenced by many factors, including the saturation of energy-using devices and their intensity of use, improvements in efficiency should serve to reduce the energy intensity, and thus we use it as a rough proxy for changes in energy efficiency in buildings. Figure 5 shows that residential energy intensity is projected to decline at a similar rate in both the 1999 and 2007 AEO forecasts, which indicates that efficiency progress is assumed to be roughly similar in both forecasts. For the commercial sector, both AEO forecasts are essentially flat over the forecast period, indicating that the two forecasts are qualitatively similar (although the more recent AEO actually shows an increase in energy intensity, probably due to increased saturation of energy using devices). Based on these results, we believe that it is reasonable to assume that the magnitude of the savings potential estimated in CEF is still applicable today. For a more detailed analysis, Appendix A compares the two AEO forecasts at the end use level.

Figure 5: Comparison of Residential Energy Intensity Between AEO Forecasts

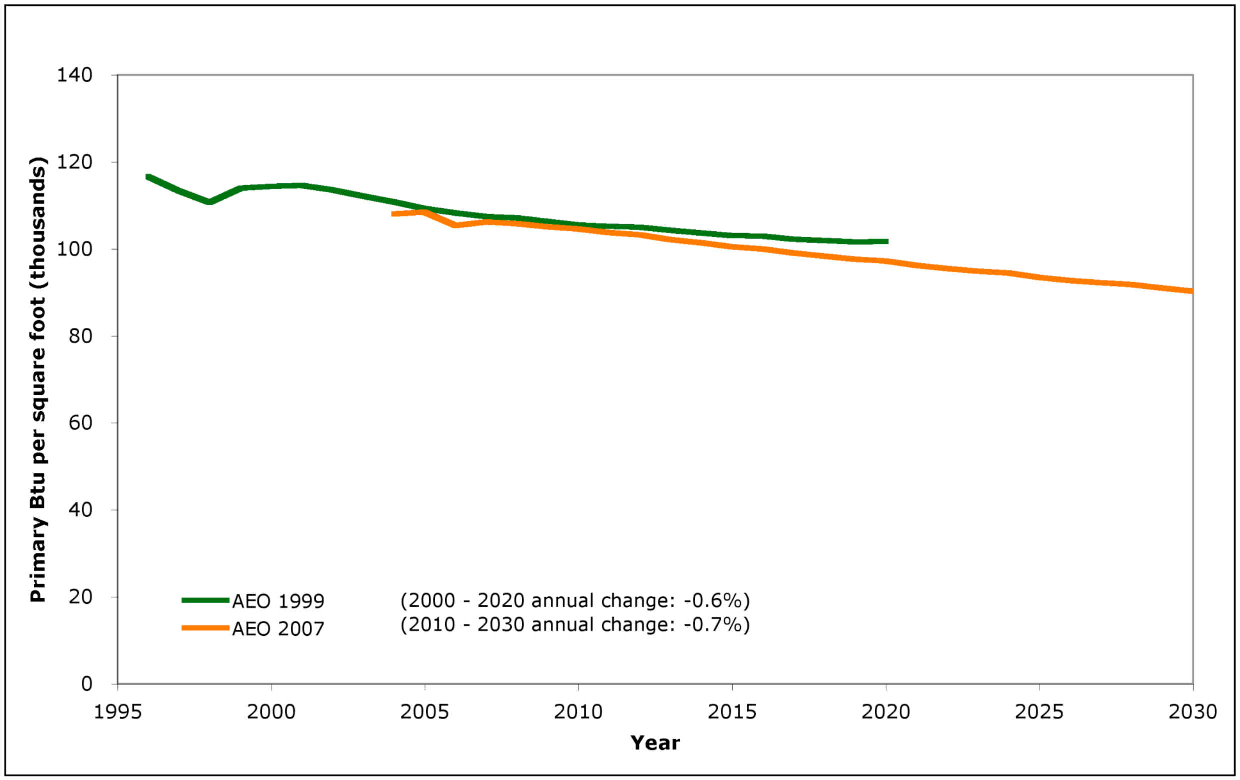
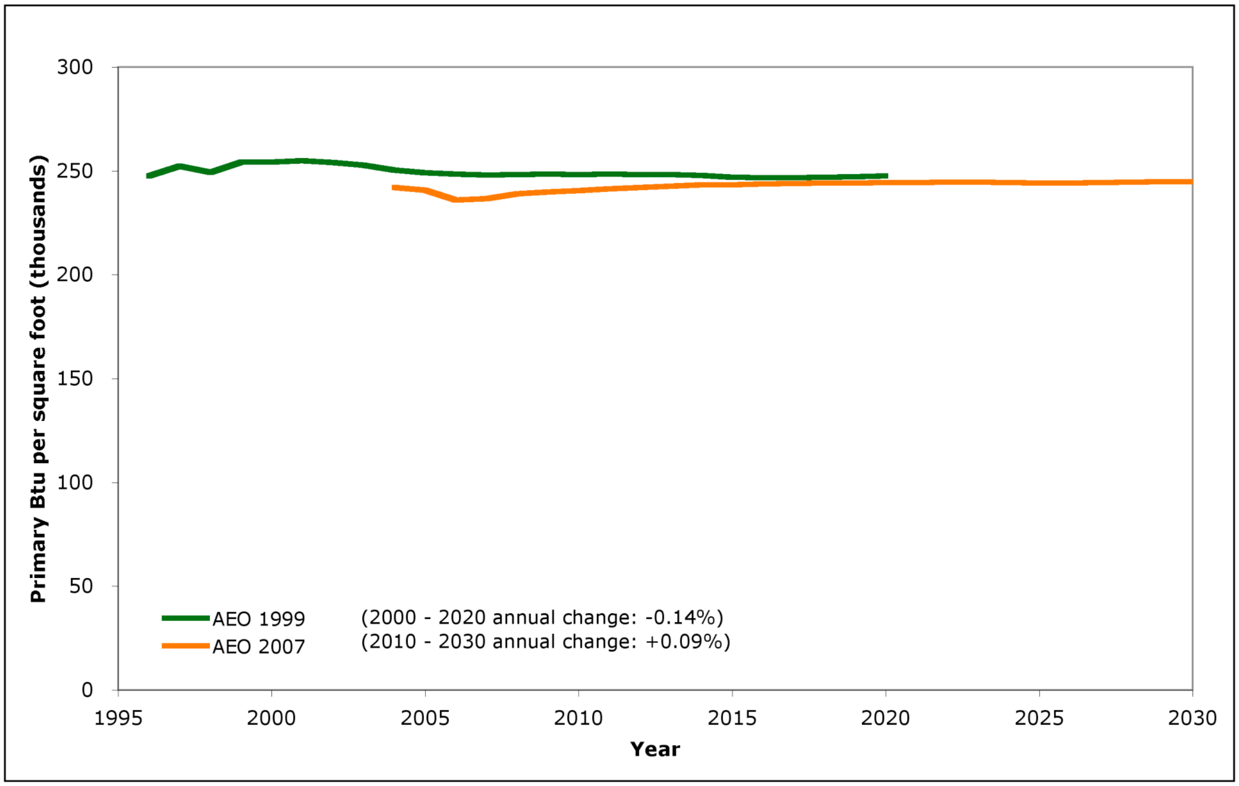


Figure 6: Comparison of Commercial Energy Intensity Between AEO Forecasts



Future Work

Due to time and resource constraints, this analysis relied mainly on data from previous efficiency potential studies. An updated national savings potential analysis seems warranted, in order to inform programs and policies. The most recent study of this type was published by McKinsey and Company (Creyts et al. 2007). This study has received significant attention in the energy policy community, but the detailed inputs and assumptions used in the analysis have not been publicly documented, thus making it difficult to assess the accuracy and validity of its conclusions. An updated, peer-reviewed savings potential study could improve upon this study in several ways:

- The end use technology data used in this study are mostly drawn from the CEF study, which reflects technology and market conditions in the late 1990s. Clearly many factors have changed since then, including new technologies available in the market, changed prices due to increased sales volumes, improved manufacturing processes, transitions to low-cost manufacturing countries, etc. For example, the price for compact fluorescent lamp prices is much lower today than was the case five or ten years ago. An updated study would need to consider the range of efficiency technologies and practices available today or reasonably expected to be available in the coming year.
- Energy prices have risen significantly since the CEF study, which increases the number of energy efficiency technologies that are cost-effective, thus expanding the conservation potential.
- For the residential gas end uses, the New York study is only a rough approximation of savings potential across the country. A national study that includes all relevant

technologies (including shell retrofits for both residential and commercial buildings) is needed.

- The effect of the Energy Independence and Security Act of 2007 (EISA 2007) is considered part of the remaining efficiency potential in this study, not included in the baseline. This assumption probably has the largest effect on the lighting end use, because EISA 2007 contains aggressive provisions for lighting efficiency. An updated study would need to incorporate this into the baseline.

This study did not consider the policies that would be needed to achieve these efficiency potentials, so should be considered a hypothetical, rather than practical, estimate of savings potential. Studies, such as CEF, that estimate achievable potential generally find that one-half to two-thirds of the economic potential is actually achievable with aggressive policies.

The results of this analysis are point estimates of savings potential, which ignore uncertainty about how energy use in the building sector will evolve during the next 20+ years. Some of the major areas of uncertainty include energy prices, availability and price of efficiency technologies, and changes in consumer behavior. Using either scenario analysis or uncertainty analysis, it would be useful to estimate ranges or probability distributions of future savings potential.

Efficiency potential studies such as CEF and the New York state study are highly aggregated analyses that tend to ignore the great variability in the building stock (along dimensions such as climate, building configuration, equipment ownership, building occupancy and usage, etc.). Future studies should be conducted at a greater level of disaggregation to address variability in the building stock. One approach is to develop efficiency supply curves at the building level, possibly using the EIA building surveys (RECS and CBECS), which can then be aggregated to assess savings potential by building type, region, technology type, etc. Griffith and Crawley (2006) present a methodology for doing this type of building-level analysis for new commercial buildings.

Conclusion

This paper presents an estimate of the potential for energy efficiency improvements in the U.S. building sector by 2030. The output of the study is a techno-economic potential for energy savings, which includes cost-effectiveness criteria but ignores the effect of policy implementation. The analysis uses the Energy Information Administration's AEO 2007 Reference Case as a business-as-usual (BAU) scenario, and applies percentage savings estimates by end use drawn from several prior efficiency potential studies. These prior studies include the U.S. Department of Energy's Scenarios for a Clean Energy Future (CEF) study and a recent study of natural gas savings potential in New York state. For a few end uses for which savings estimates are not readily available, we compiled technical data to estimate savings percentages and costs of conserved energy. The analysis shows that for electricity use in buildings, approximately one-third of the BAU consumption can be saved at a cost of conserved energy of 2.7 ¢/kWh (all values in 2007 dollars), while for natural gas approximately the same percentage savings is possible at a cost of between 2.5 and 6.9 $/million Btu (2.4 to 6.6 $/GJ). This cost-effective level of savings results in national annual energy bill savings in 2030 of nearly $170 billion. To achieve these savings, the cumulative capital investment needed between 2010 and 2030 is about $440 billion, which translates to a 2-1/2 year simple payback period, or savings over the life of the measures that are nearly 3.5 times larger than the investment required (i.e., a benefit-cost ratio of 3.5).

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Appendix A: Comparison of AEO 1999 and AEO 2007 End Use Efficiency Assumptions

For a few key end uses that have undergone significant changes in efficiency since the publication of the original CEF study (based on the 1999 AEO), we examine whether the efficiency levels in the AEO reference cases changed significantly. For example, we know that the residential cooling baseline has changed significantly due to new (post-1999) Federal efficiency standards for central air conditioners. We compared the underlying end-use efficiency forecasts output by the NEMS model in the course of producing the 1999 and 2007 AEOs.[7] Figure A-1 shows this comparison between the AEO reference case efficiencies for residential central air conditioning, and indicates an approximately 15% improvement in efficiency between the two AEO forecasts (primarily due to the new standards). As discussed in the main body of this report, this difference in AEO baselines is counterbalanced by new efficiency technologies that have been introduced since 1999 for this end use, resulting in roughly the same savings potential.

Figure A-2 shows a similar comparison for an end use (commercial cooling) that did not change much between the two AEO forecasts. Most end uses are similar to this one (i.e., little efficiency improvement in AEO 2007 vs. 1999). Figures A-3 through A-12 offer similar comparisons for other major residential and commercial end uses. Note that residential heat pump heating (Figure A-4) also shows significant efficiency improvement since the 1999 AEO, again due to minimum Federal efficiency standards. The same technology trends that affect central air conditioning, however, also affect this end use, so the savings potential is not significantly affected by this improvement in baseline efficiency. Figure A-10 shows higher efficiencies in the 2007 forecast for commercial hot water heaters, an effect of increasing market penetration of condensing commercial water heaters due to higher natural gas prices. For three of the end uses – residential thermal shell, commercial lighting, and ventilation – the efficiency metric used in the AEO differs between the 1999 and 2007 versions, so we present efficiency values indexed to the base year.

Reviewing all these end uses, we believe that the 1999 and 2007 AEO forecasts do not have significantly different assumptions at the detailed technology level (with the exception of central air conditioners and heat pumps, which have already been discussed).

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[7] The data shown in this appendix are drawn from the Supplemental tables for the AEO reference case, available on the AEO web site: http://www.eia.doe.gov/oiaf/aeo/index.html. The 1999 data are from: http://www.eia.doe.gov/oiaf/archive/aeo99/homepage.html.

Figure A-1: Residential Cooling, Central Air Conditioning Efficiency Trends

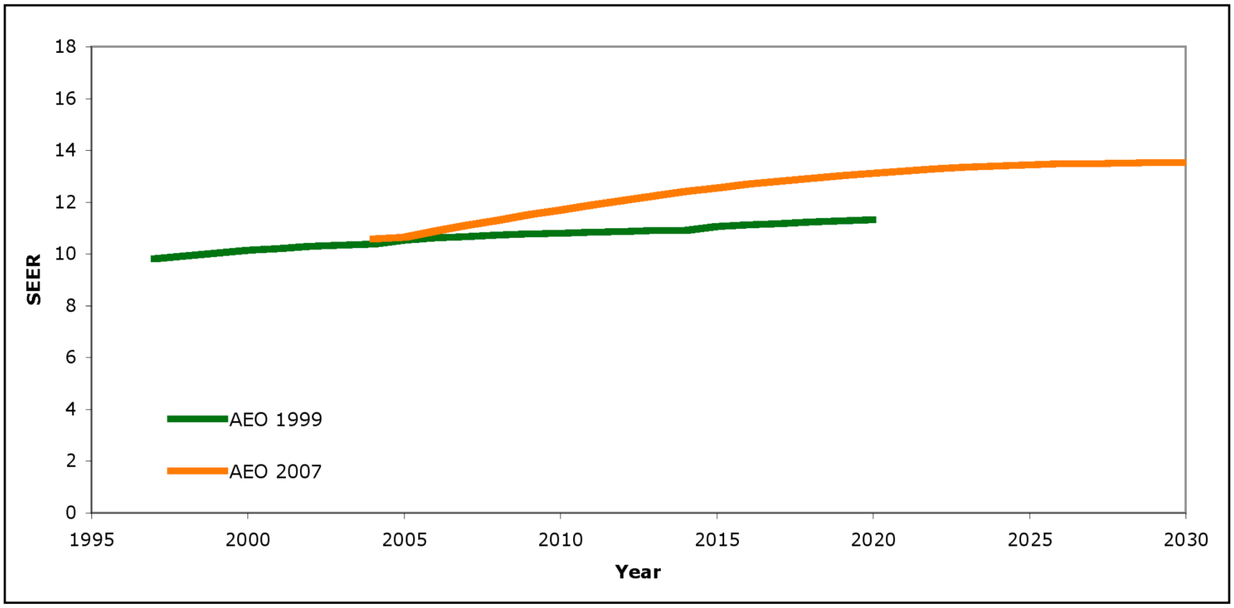

Figure A-2: Commercial Electric Cooling Efficiency Trends

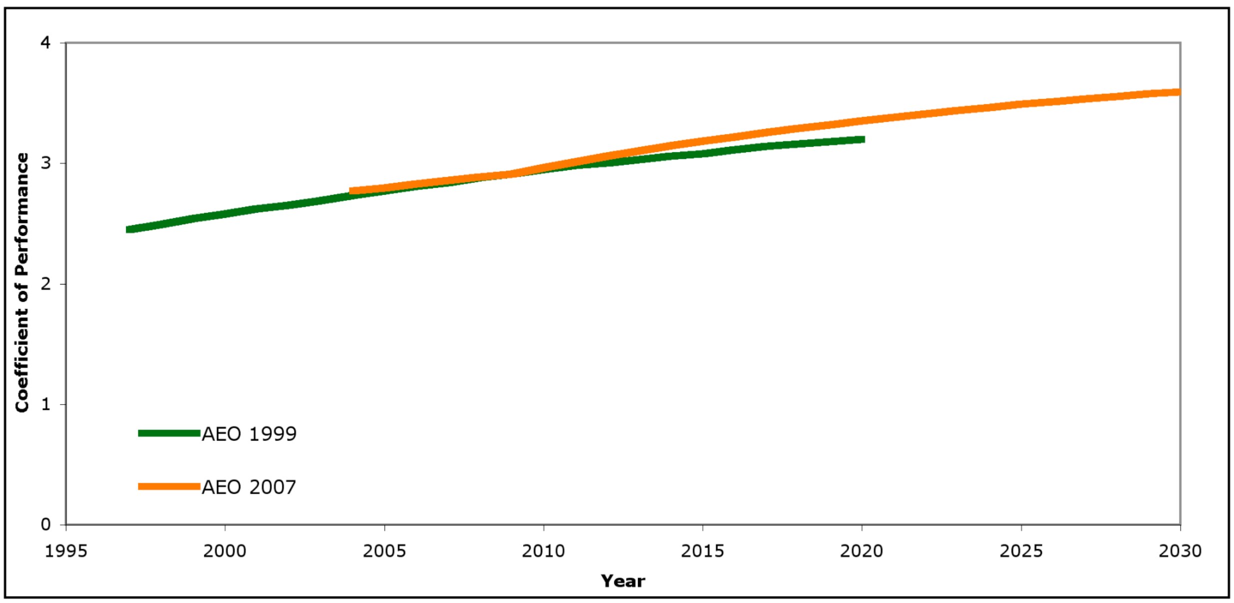

Figure A-3: Residential Heating, Natural Gas Furnace Efficiency Trends

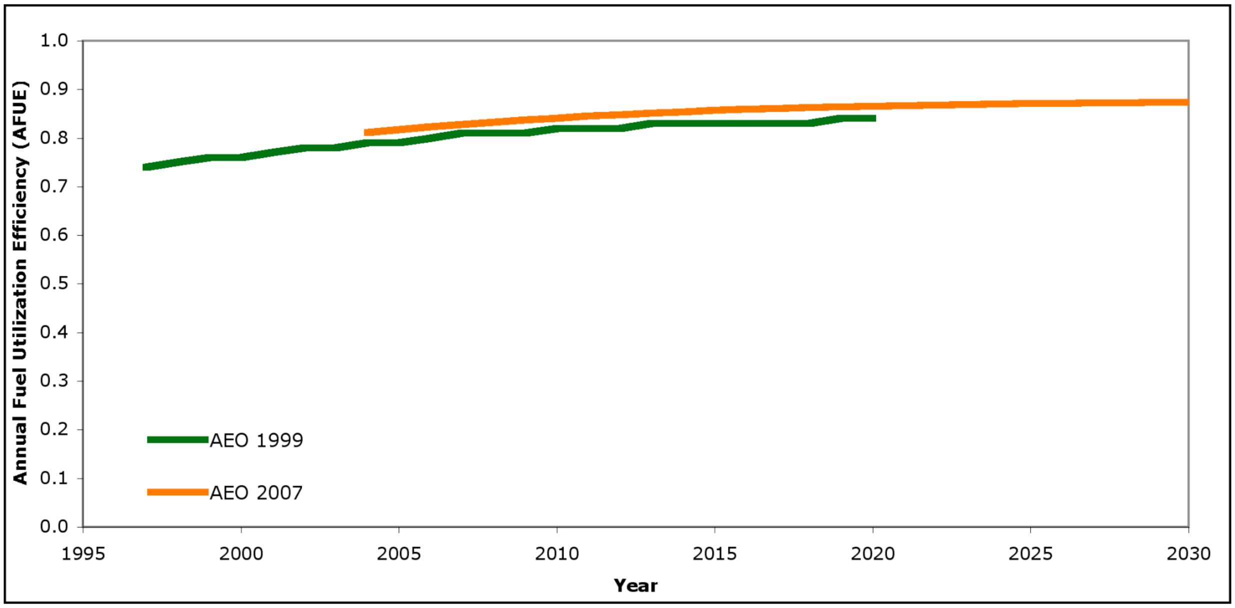

Figure A-4: Residential Heating, Electric Heat Pump Efficiency Trends

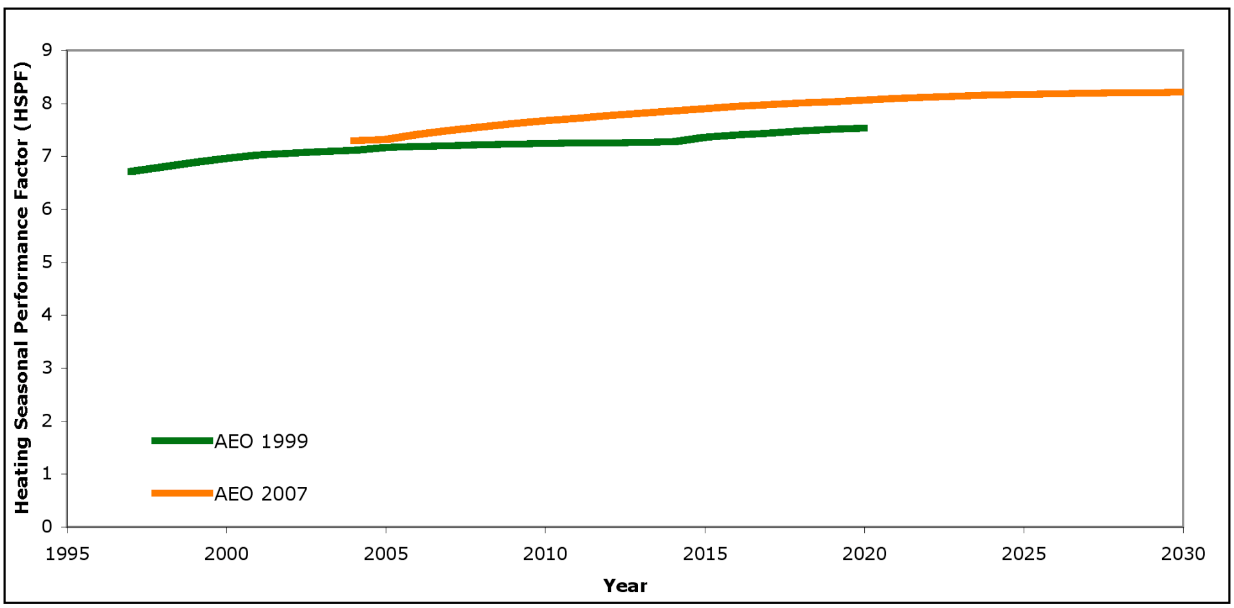

Figure A-5: Residential Natural Gas Water Heating Efficiency Trends

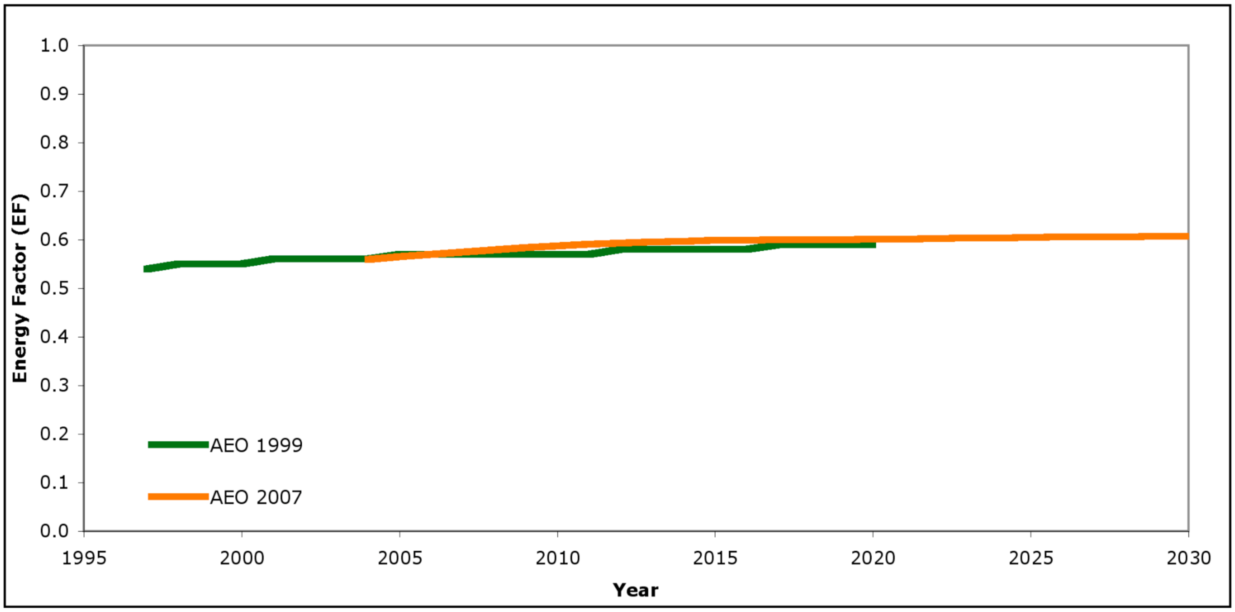

Figure A-6: Residential Refrigerator Efficiency Trends

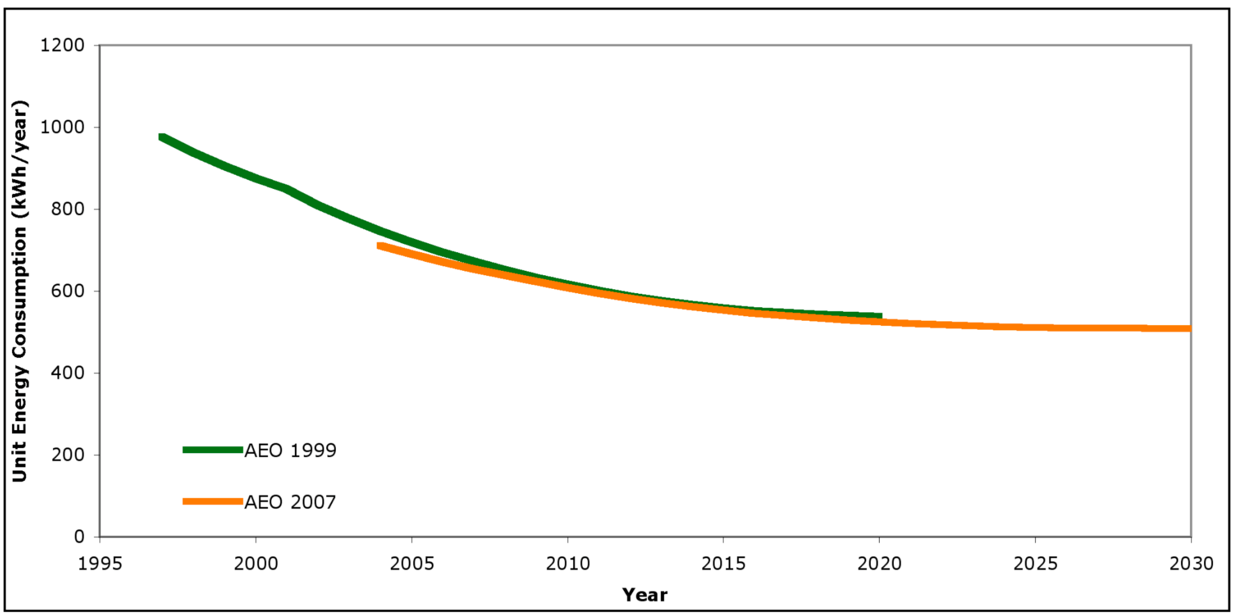

Figure A-7: Residential Thermal Shell (Heating) Efficiency Index Trends

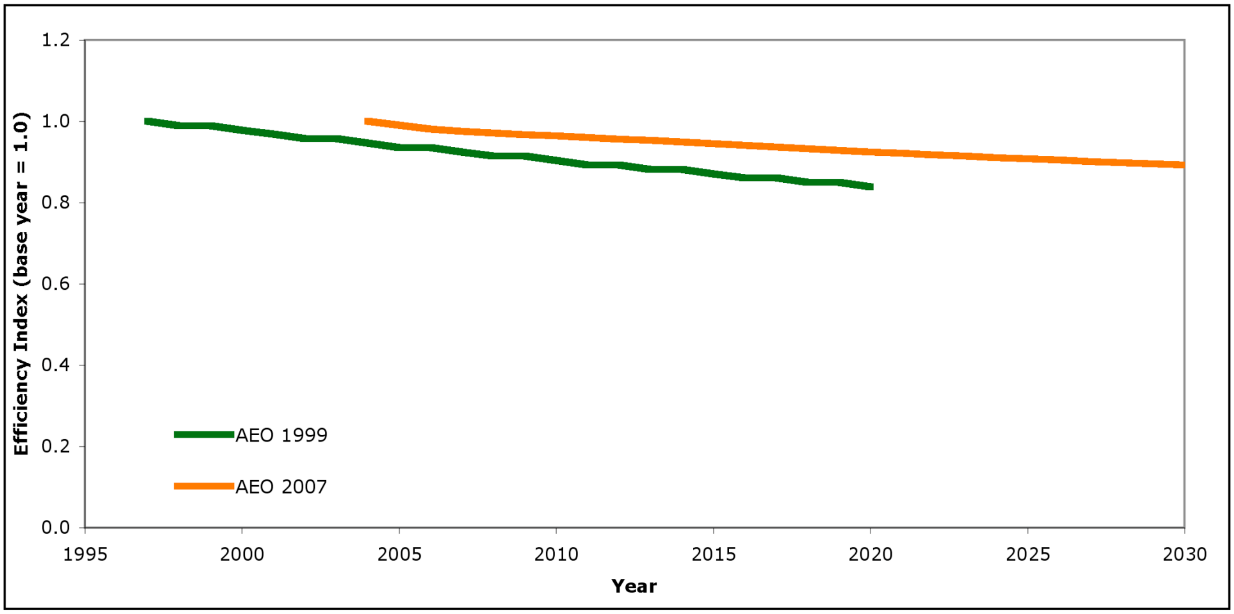

Figure A-8: Commercial Electric Heat Pump Heating Efficiency Trends

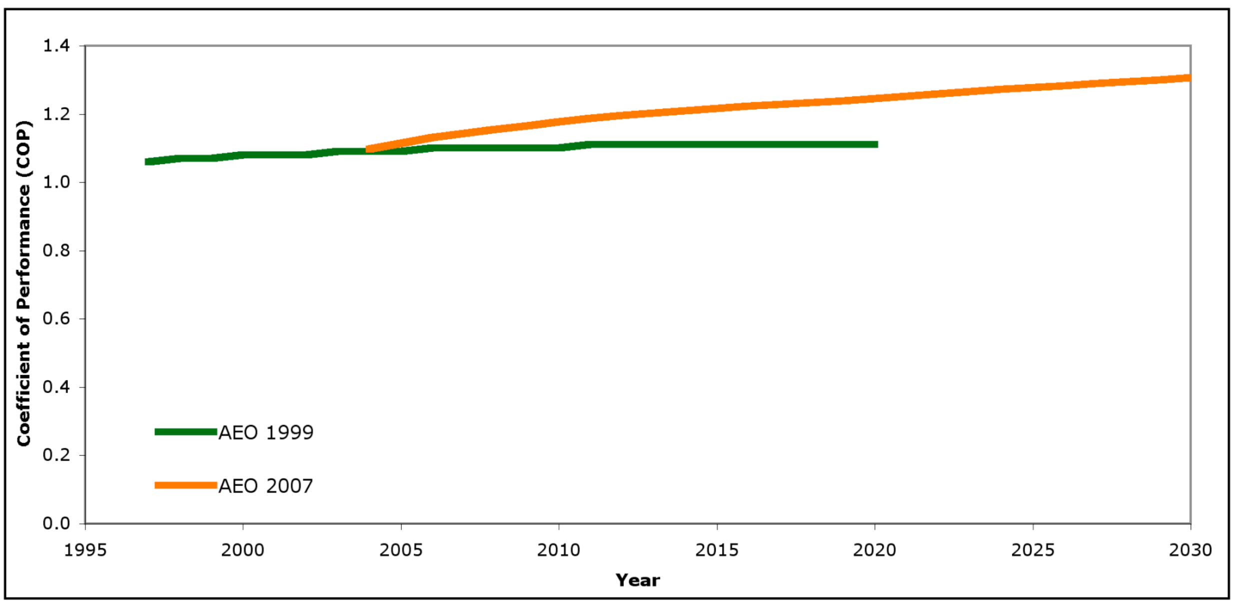

Figure A-9: Commercial Natural Gas Heating Efficiency Trends

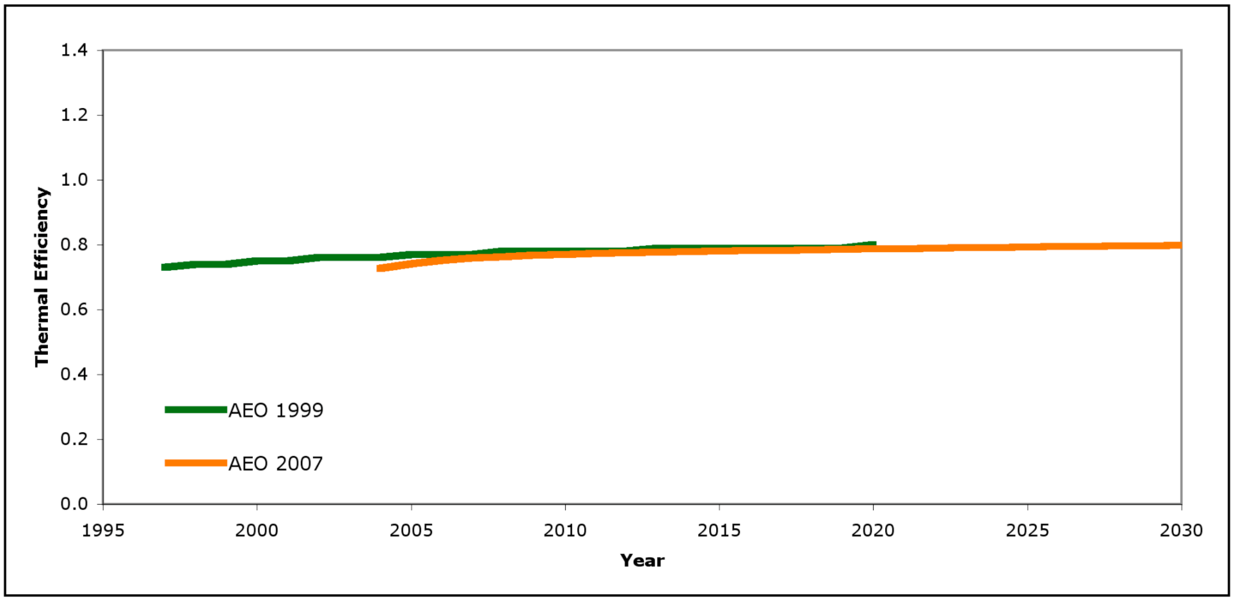

Figure A-10: Commercial Natural Gas Water Heating Efficiency Trends

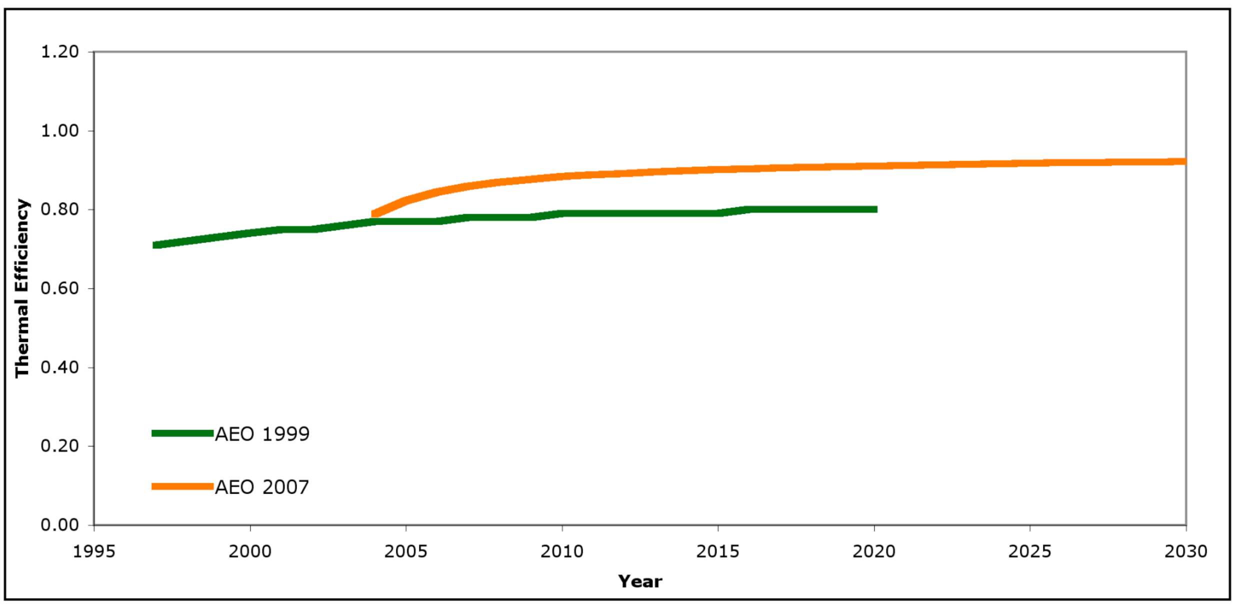

Figure A-11: Commercial Lighting Efficacy Trends

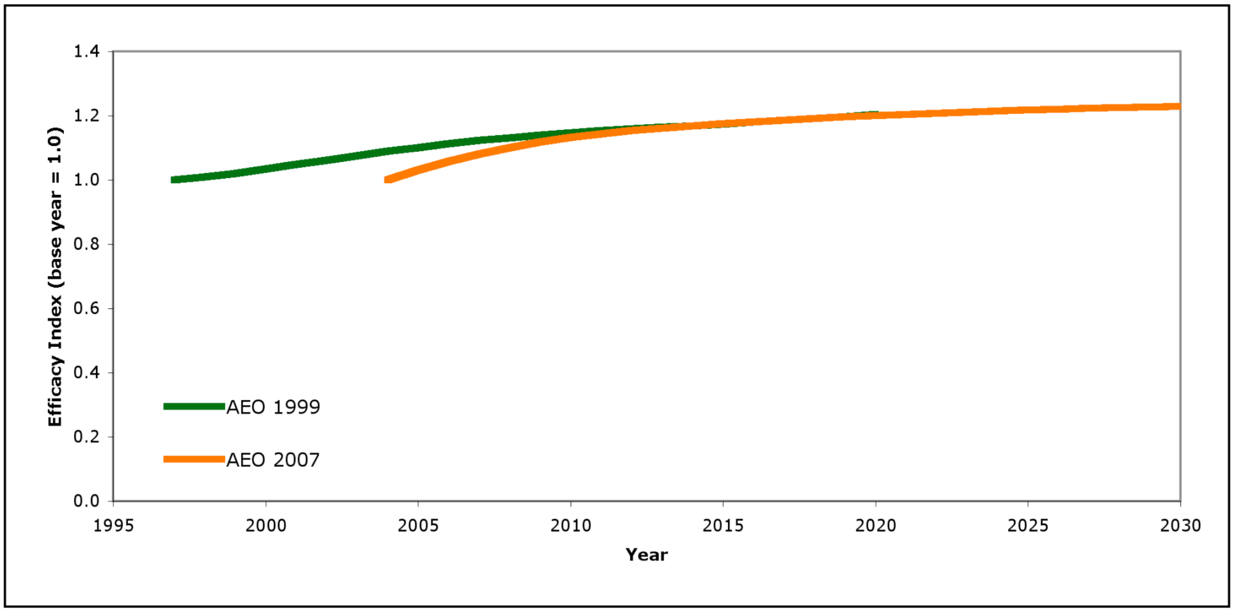

Figure A-12: Commercial Ventilation Efficiency Trends