Large Filing Separator Sheet

Case Number: 09-512-GE-UNC

File Date: 11/15/2010

Section: 3 of 3

Number of Pages: 156

Description of Document: Replies

Attachment D:

"Advanced Power Strip background"

Section 1: **ADVANCED POWER STRIP**

1.1 DESCRIPTION

The measure reduces stand-by equipment energy by turning off the power supplied to equipment that is plugged into a power strip when it's not in use. Typical uses are home-office and home-entertainment systems. The power strip monitors the power draw on one outlet to control the availability of power on the other outlets on the strip.

This measure applies to new and existing homes.

The savings have been quantified for two power strip sizes: a 5-plug strip and a 7-plug strip.

1.2 BASIS FOR SAVINGS

We studied the provided spreadsheets showing savings estimates and the report done for BC Hydro by Power Smart Engineering. We also studied three papers that present the research on phantom energy use. The documents are:

- *Smart Strip Electrical Savings and Usability,* Power Smart Engineering, October 27, 2008
- *Final Field Research Report, Ecos Consulting,* October 31, 2006. Prepared for California Energy Commission's PIER Program.
- *Developing and Testing Low Power Mode Measurement Methods,* Lawrence Berkeley National Laboratory (LBNL), September 2004. Prepared for California Energy Commission's Public Interest Energy Research (PIER) Program.
- *2005 Intrusive Residential Standby Survey Report,* Energy Efficient Strategies, March, 2006.

In our search for a comprehensive study done for this measure we found a detailed study done by Navigant Consulting for San Diego G&E, March 31, 2009 titled, *Smart Strip Portfolio of the Future.*

The study done by Navigant compiles findings from various sources including ECOS and LBNL studies referenced above and a home electronics survey done by Hiner and Partners in California, October 2008 titled *Statewide Home Electronics Assessment Survey.*

1.3 SAVINGS ANALYSIS

The analysis considers two applications: home entertainment and home office. For each peripheral piece of equipment there are two consumption rates to consider: the standby mode consumption and the off mode consumption. For each of these modes the percent time in that mode is also considered along with the percent time that each peripheral is used with out the control device (TV or computer). The home office computer is assumed to not be in use 85.6% of the time while the home entertainment TV is assumed to not be in use for 77.7% of the time based on the Hiner and Partners survey.

The average savings per peripheral is calculated using the following formula:

Power = [(Power in standby) x (time standby) + (power in off) x (time in off)] x [1-(%time used without PC/TV)]

The following table presents the values used to calculate the savings per peripheral.

Equipment	Power Consumption in Standby Mode (W)	Power Consumption in Off Mode (W)	% of Time in Standby Mode	% of Time in Off Mode	% of Peripherals Used Without PC/TV	Average Savings Per Peripheral (kWh/year)
Flat panel monitor	1.36	1.25	38.5%	61.5%	0.0%	9.66
CRT	3.95	1.47	38.5%	61.5%	0.0%	18.13
Printer	3.44	1.435	41.3%	58.7%	20.0%	13.54
Multifunction printer no fax	7.85	7.75	55.6%	44.4%	33.3%	38.89
Multifunction printer with fax	7.6	7.5	69.3%	30.7%	42.7%	32.44
Speakers, subwoofers, bass	20.44	1.62	16.7%	83.3%	0.0%	35.55
Scanner	4.05	0.46	26.9%	73.1%	4.5%	10.17
Copier	1.2	0.052	23.3%	76.7%	41.9%	1.39
Modem	7.21	1.74	86.3%	13.7%	9.6%	43.66
Shredder	0	0	29.6%	70.4%	51.3%	0.00
Router	5.85	0.06	86.5%	13.5%	6.7%	35.34
External hard drive	4.53	0	25.0%	75.0%	0.0%	8.46
DVD player	11.77	1.57	5.4%	94.6%	6.7%	13.43
VCR	12.85	5.02	11.5%	88.5%	2.1%	39.31
Stereo	27.38	2.29	7.1%	92.9%	49.3%	14.00
Speakers, subwoofers	11.07	11.07	20.7%	79.3%	13.8%	64.74
Video game consoles	4.05	0.88	12.0%	88.0%	2.0%	8.38
Computer only used for video/music entertainment	46.97	3.17	33.3%	66.7%	33.3%	80.37

For the 5-plug strip three equivalent control peripherals have been assumed. For the 7-plug strip five equivalent control peripherals have been assumed. The following table shows the allocation of peripherals and savings per strip for both the home office and home entertainment.

	Three Peripherals per Power Strip		Five Peripherals per Power Strip	
Equipment	**% of Peripherals plugged into APS**	**Average Savings Per Peripheral Plugged into APS (kWh/year)**	**% of Peripherals plugged into APS**	**Average Savings Per Peripheral Plugged into APS (kWh/year)**
Flat panel monitor	73.4%	7.09	73.4%	7.09
CRT	26.6%	4.82	26.6%	4.82
Printer	77.8%	10.53	77.8%	10.53
Multifunction printer no fax	7.2%	2.80	7.2%	2.80
Multifunction printer with fax	15.0%	4.87	15.0%	4.87
Speakers, subwoofers, bass	1.3%	0.45	3.8%	1.35
Scanner	17.0%	1.73	50.9%	5.18
Copier	10.9%	0.15	32.7%	0.45
Modem	18.5%	8.07	55.4%	24.21
Shredder	29.1%	0.00	87.3%	0.00
Router	22.5%	7.96	67.6%	23.89
External hard drive	0.8%	0.06	2.3%	0.19
Home Office Total	**300.0%**	**48.53**	**500.0%**	**85.37**
DVD player	100.0%	13.43	100.0%	13.43
VCR	40.8%	16.02	100.0%	39.31
Stereo	59.2%	8.29	100.0%	14.00
Speakers, subwoofers	27.1%	17.57	54.3%	35.15
Video game consoles	68.6%	5.75	137.1%	11.49
Computer only used for video/music entertainment	4.3%	3.44	8.6%	6.89
Home entertainment total s	**300.0%**	**64.51**	**500.0%**	**120.27**

	Five-plug Strip Summary		Seven-plug Strip Summary	
	Home Office	Home Entertainment	Home Office	Home Entertainment
Average savings (kWh/year)	48.5	64.5	85.4	120.3
Total savings per home (kWh/year)	113.0		205.6	
Savings per unit (kWh)	**56.5**		**102.8**	
Demand savings (kW)	0.006	0.010	0.011	0.018
Peak demand savings per unit (kW)	0.008		0.015	
Average demand savings per unit (kW)	0.006		0.012	

The tab labeled "power strips" in the "DSD Input Summary" spreadsheet contains the assumptions and the detailed savings calculations.

1.4 COST

The pricing for this measure is based on the data in the following table.

Smart Strip		5 plug	7 plug
Supplier	Manufacturer	Cost of Smart Strip	
Bits Ltd	Bits Ltd	$31.95	$41.95
SmartHome USA	Bits Ltd	$30.95	$40.00
Ace Hardware	Coleman Cable, Inc	$29.99	
Average		**$30.96**	**$40.98**
Power Strip			
Supplier	Manufacturer	Cost of Power Strip	
Best Buy	Spike Master	$14.99	$14.99
Circuit City	Cyber Power	$14.49	$14.49
Ace Hardware	Ace	$13.99	$13.99
Average		**$14.49**	**$14.49**
		5 plug	7 plug
Incremental Cost		**$16.47**	**$26.49**

Attachment E:

"Estimated Energy Savings with HiR Windows"

Estimates of Potential Energy Savings with High Performance Windows

With input from Lawrence Berkeley National Laboratory and the Consortium for Energy Efficiency, the Alliance to Save Energy conducted simulations to estimate the energy savings potential and economics of specifying high-performance windows for new homes and window replacement. The simulation tool used was RESFEN 5.0, a program based on DOE-2.1E and developed by LBNL for modeling the thermal performance of homes based on window choices.[1] The results of these simulations and the assumptions used are summarized below.

Purpose

The primary purpose of our estimates is to determine whether deeper energy savings beyond those achieved through the market penetration of ENERGY STAR® windows are viable. We are mainly looking at the potential of highly-insulating windows that significantly exceed the performance of typical ENERGY STAR Windows in cold and mixed climates. To date, the potential of these windows has remained largely untapped, primarily because of higher retail cost, resulting from higher manufacturing cost and lacking economies of scale.

Highly-insulating windows provide superior energy performance due to advanced frames combined with three glass panes or a heat-reflecting film between two panes of glass. These windows surpass dual-pane windows in energy savings, peak demand reduction and enhanced comfort. Simulated energy savings and peak demand reduction are part of our analysis.

In addition to highly-insulating windows, we looked at the cooling demand reduction potential for solar control windows in cooling climates.

Window Types Examined

Conventional window

- U-factor: 0.50
- SHGC: 0.55

Double-pane windows without low-E coatings in vinyl, wood, or hybrid/composite frames. Although many building energy codes and incentive programs encourage the use of windows with better energy performance than conventional windows can offer, use of these windows is still relatively common due to trade-off options in building codes and lacking code enforcement.

Conventional code-compliant window (South)

- U-factor: 0.50
- SHGC: 0.40

If trade-off options in codes are not used, most codes in the U.S. require in their prescriptive path that windows with better than conventional solar control are used. The U-factor requirements of windows in southern climates are rarely more stringent than 0.50, which is less energy-efficient than the U-factor needed to qualify for ENERGY STAR. Nevertheless, southern codes widely require an SHGC of no more than 0.40 to limit cooling demand.

[1] RESFEN can be downloaded at http://windows.lbl.gov/software/resfen/resfen.html.

Acknowledgment: "This material is based upon work supported by the Department of Energy, National Energy Technology Laboratory under Award Number DE-FC26-06NT42766."

Typical Energy Star window

- U-factor: 0.35
- SHGC: 0.50 (high solar gain), 0.30 (low solar gain)

In our analysis, we define a typical ENERGY STAR window as a window that meets the ENERGY STAR U-factor criterion for the Northern climate zone (0.35). Such windows typically include low-E coatings, gas fills, and low-conductance spacers. In the North, ENERGY STAR windows can either have high-solar-gain, low-solar-gain, or low-E coatings. The type of low-E coating used can alter the SHGC dramatically. In the South, only windows with a low SHGC qualify for ENERGY STAR.

The prescriptive requirements of most northern energy codes specify windows with a U-factor of 0.35 or less. Therefore we did not include a separate category for common code-compliant windows in the North, as this would be equivalent to ENRGY STAR windows. However, due to trade-off options in codes and imperfect code compliance, conventional windows still hold substantial market share in many northern states.

Solar control low-E window

- U-factor: 0.35
- SHGC: 0.25

These windows are similar in performance to typical low-E windows, but have advanced low-E coatings that provide maximum control of solar radiation while still transmitting most visible light.

Moderate cost highly-insulating window

- U-factor: 0.25
- SHGC: 0.40 (high solar gain), 0.25 (low solar gain)

Window U-factor can be reduced to 0.25 or below through glazing upgrades (additional glazing layers and/or krypton gas fills) without expensive upgrades of the frame. Depending on the choice of low-E coatings, highly-insulating windows can be designed for high or low solar gain.

Best-case highly-insulating window

- U-factor: 0.20
- SHGC: 0.40 (high solar gain), 0.25 (low solar gain)

Windows with optimized glazing, spacer, and frame performance are available with U-factors below 0.20. Depending on the choice of low-E coatings, highly-insulating windows can be designed for high or low solar gain.

Future highly-insulating window

- U-factor: 0.17
- SHGC: 0.40 (high solar gain), 0.25 (low solar gain)

In its 2007-12 multi-year plan for window research and development, U.S. DOE states the goal of developing and deploying cost-competitive windows with a 0.17 U-factor by 2010. Such performance increases and cost effectiveness can be achieved either through new lower cost window technologies, such as currently researched by LBNL, or through economies of scale for current best-performing technologies.

Selected Analysis Results

The energy-saving technologies used in typical ENERGY STAR windows have found wide acceptance as cost-effective energy-efficiency features. Highly-insulating windows with additional glazing layers, on the other hand, can be substantially more expensive. Therefore it is not surprising that we found the cost-effectiveness of currently available highly-insulating windows to be low when compared to typical ENERGY STAR windows (see Figure 1 in the appendix). However, this finding does not account for the ancillary benefits of highly-insulating windows: reduced heating and cooling peak demand and opportunities for HVAC system downsizing.

If conventional windows instead of ENERGY STAR windows are used as the baseline for comparison, the cost-effectiveness of highly-insulating windows is more significant. However, it is important to note the differences between highly-insulating windows that allow high solar gain (Figures 2 through 5) and those made for low solar gain (Figure 6 and 7), since solar heat gain improves overall annual energy savings in heating dominated climates.

High-solar-gain windows save more energy in the heating-dominated North and are thus more cost effective. However, low-solar-gain windows provide much higher cooling peak load reduction (Figures 8 and 9).

In addition to the energy and peak demand saving benefits that we estimated through simulation, there are other benefits of high-performance windows that are harder to simulate but that could lead to further substantial energy and cost savings:

- If integrated in a well-insulated building envelope, highly-insulating windows make the consideration of alternative duct designs possible. For instance, traditional perimeter heating, which is used to offset discomfort from cold window surfaces, is not necessary for a highly-insulated envelope. By avoiding perimeter heating and reducing duct runs, energy loss from duct leakage as well as first cost for duct installation can be reduced.[2]
- High-performance windows improve the comfort of building occupants. Studies by the Center for the Built Environment at UC Berkeley have found that occupants tend to compensate for thermal discomfort, such as from cold window surfaces or strong solar radiation, by setting their thermostat at more extreme temperatures, thus further increasing energy use.[3] Our savings estimates do not take this effect into account, which leads to somewhat conservative results.

Free Riders vs. Spill-over

Although typical ENERGY STAR windows are currently more cost effective than highly-insulating windows, promotion of highly-insulating windows has the potential to create spill-over effects and lasting market transformation. While continued promotion of ENERGY STAR windows can help further increase the market share of energy-efficient windows where energy codes provide insufficient traction, financial incentives for current ENERGY STAR windows are bound to create free riders. Incentives for highly-insulating windows, on the other hand, would potentially provide a spill-over effect by promoting underutilized high-efficiency options that can become more attractive with increasing awareness and economies of scale.

Incremental cost of High-Performance Windows

It is difficult to make assumptions about the incremental cost of one window option versus another because the market is very diverse and window retailers tend to set prices depending on what customers are willing to pay. Nevertheless, a few general assumptions can be made about the incremental cost of energy-efficient windows compared to more conventional windows. Here, we concentrate on the basic window options used in our simulations:

[2] Building America contractor Ibacos (www.ibacos.com) can serve as a source on compact duct design.
[3] Huizenga et al. 2006. *Window Performance for Human Thermal Comfort*. University of California, Berkeley.

- **Conventional windows.** Windows without low-E coatings, gas fills, or similar energy-efficiency features are our baseline option and thus have no incremental cost.

- **Typical ENERGY STAR Windows (U-factor 0.35).** These windows have low-E coatings, which, according to U.S. DOE's website, typically increase window prices by 10-15 percent.[4] Northeast Energy Efficiency Partnerships surveyed retailers about the incremental cost for their customers to purchase ENERGY STAR Windows instead of conventional double-pane windows and received answers that ranged from 5-15 percent, depending on market saturation. If \$15/ft^2 is assumed as the base cost, an average cost premium of \$1.50/ft^2 could be assumed, which matches closely with observations made by the Southwest Energy Efficiency Project.[5] According to PNNL's Building Energy Codes Resource Center, low-E windows typically retail for only about \$1/ ft^2 more than non-low-E windows.[6] Since we define typical ENERGY STAR windows as having gas fills and low-conductance spacers in addition to low-E coatings, we assume an incremental cost of \$1.50/ft^2.

- **Moderate-cost highly-insulating windows (U-factor 0.25).** Literature is sparser on the incremental cost of windows that exceed ENERGY STAR performance. In its evaluation of windows with a U-factor of less than 0.25, ACEEE assumes a cost increment of \$5/ft^2 over conventional windows.[7] Based on conversations with window retailers and window manufacturers, we conclude that this assumption is too optimistic if used for retail prices. A more realistic assumption is the goal set by DOE of achieving an incremental cost of no higher than \$5/ft^2 for windows with a 0.2-0.25 U-factor by 2007 relative to typical windows used in new construction (which would include low-E windows).[8] In conversations with manufacturers, we learned that window U-factor can be reduced to 0.25 or below through glazing upgrades (additional glazing layers and/or krypton gas fills) without modifications in the frame. This can be achieved at an incremental cost as low as \$2.50/ft^2 wholesale price compared to typical ENERGY STAR windows. For retail, we assume the incremental cost for a 0.25 U-factor window to be \$4.5/ft^2 if compared to a window with a 0.35 U-factor and \$6 per square foot if compared to a conventional window.

- **Best-case highly-insulating windows (U-factor 0.20).** Since windows with a U-factor of 0.25 (moderate-cost HI windows) generally have three glazing layers, improving the U-factor to 0.20 (best-case HI windows) does not require the addition of glazing layers. However, changes in the frame may be necessary to allow for optimum gap width between the glazing layers or to improve frame insulation and stability. Anecdotal price data from window manufacturers suggests that improving the U-factor to 0.20 yields a 50 percent higher incremental cost than going from U-factor 0.35 to 0.25. For our simulations, we therefore assume that the incremental cost of best-case HI windows is \$2.50/ft^2 over moderate-cost HI windows and \$7/ft^2 over typical ENERGY STAR windows.

- **Future highly-insulating windows (U-factor 0.17).** In its 2007-12 multi-year plan for window research and development, U.S. DOE states the goal of achieving an incremental cost by 2010 of no more than \$5/ft^2 for windows with a 0.17 U-factor compared to currently common windows. For our simulations, we assume this to be the incremental cost relative to typical code-compliant windows. Such performance increases coupled with cost reduction can be achieved either through new lower

[4] U.S. Department of Energy. *A Consumers Guide to Energy Efficiency and Renewable Energy: Low-emissivity Window Glazing and Glass.* Accessed November 27, 2007. http://www.eere.energy.gov/consumer/your_home/windows_doors_skylights/index.cfm/mytopic=13430.
[5] Larry Kinney. 2004. *Windows and Window Treatments.* Southwest Energy Efficiency Project.
[6] Pacific Northwest National Laboratory. *Low Solar Heat Gain Windows – Successful Market Transformation in Georgia and Texas.* Last modified January 11, 2006. http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1298.
[7] Sachs, Harvey et al. 2004. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004.* American Council for an Energy Efficient Economy.
[8] U.S. Department of Energy. *Multy Year Program Plan 2007-2012.* Last updated January 2007. http://www.eere.energy.gov/buildings/about/pdfs/mypp_2007/mypreport_ch2.pdf.

cost window technologies, such as currently researched by LBNL, or through economies of scale for current best-performing technologies.

In Europe, windows with a 0.17 U-factor are already becoming more common (for example, windows certified as Passive House windows), while a Swiss market study asserts that due to the maturing triple-pane window market, "the cost for triple glazing (coated and inert-gas-filled) decreases faster than the one of the already well-established double glazing and, therefore, the costs of the two glazing types can be expected to converge in the longer term".[9] The same is likely to happen once the market for triple-glazed windows reaches maturity in the United States.

Presently, there are few incentives for the use of beyond-code windows in the US, so the demand for highly-insulating windows among home-builders remains low. Therefore, most retailers of highly-insulating windows are focusing on niches in the replacement market. To change this situation and enable window manufacturers develop economies of scale for beyond-code windows, market transformation efforts are essential.

Other Basic Assumptions Used in the Analysis

Locations

Since highly-insulating windows provide the most benefits in heating-dominated climates, we mostly focused our savings estimates on locations throughout the northern part of the United States. However, to also assess the potential of windows with special solar-control low-E glass, we included two locations in cooling-dominated climates in the analysis.

Building types

We simulated the performance of windows for both new construction and replacement. We simulated new construction with 2,400 ft^2 floor space and 360 ft^2 window area and existing homes with 2,000 ft^2 floor space and 300 ft^2 window area. For building shell performance and other parameters, the climate-specific settings of the RESFEN software were used. All homes are assumed to be heated with natural gas furnaces (AFUE 0.78) and cooled with central air conditioning (SEER 13 in new construction, SEER 10 in existing buildings).

Energy prices

Natural gas prices used for the analysis were based on ASE (Alliance to Save Energy) projections, which used EIA data of historic winter heating fuel prices and EIA projections of price developments for the winter of 2007 to project state-specific residential retail prices for natural gas used for heating. The electricity prices used in the analysis are average residential retail prices by state for the warm months (May through September) of 2006. EIA has not yet published the complete state-specific residential retail prices for the period of May-September 2007.

Cost per saved therm of natural gas

Modeled after the CEC formula to determine the levelized cost of conserved energy, we used the following formula to determine the cost per saved therm of natural gas as a result of window efficiency increases:

I x CRF / S

I = Incremental cost for higher performing windows

CRF = Capital recovery factor = $r(1+r)^{n-1} / (1+r)^{n-1}$

r = discount rate (we used 5%)

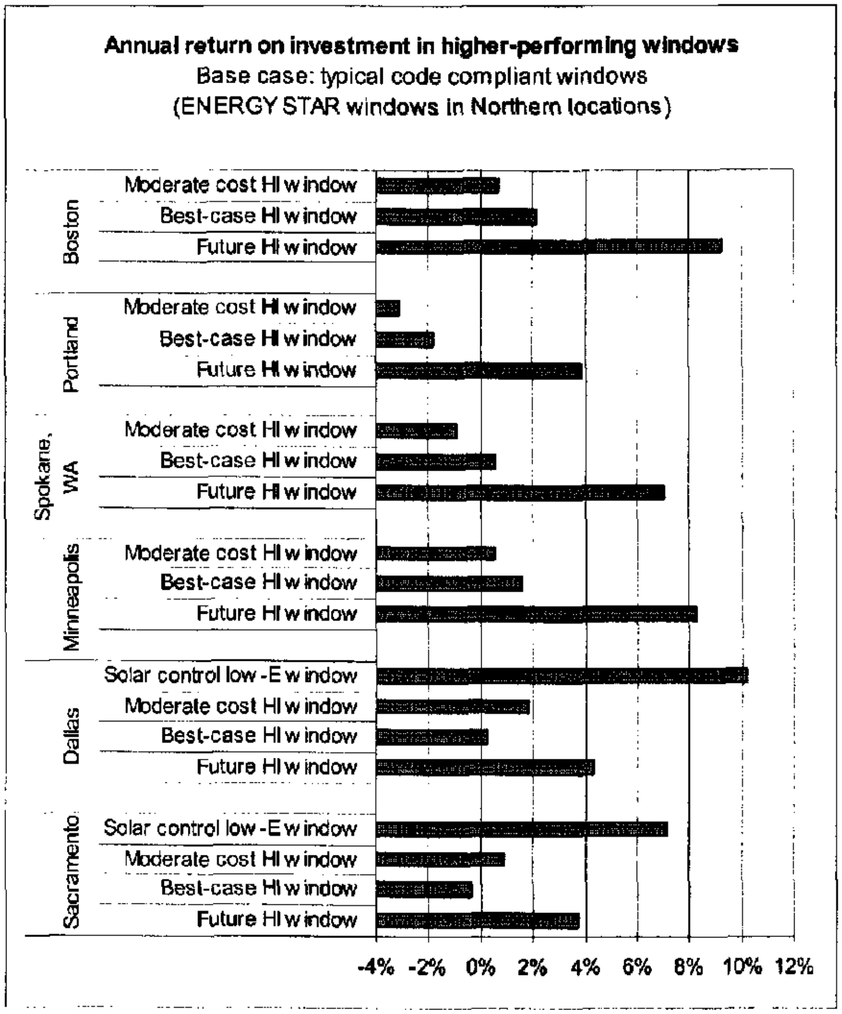
n = planning horizon / measure lifetime: (25 years)[10]

S = annual savings in therms

[9] Martin Jakob and Reinhard Madlener. 2003. *Exploring Experience Curves for the Building Envelope: An Investigation for Switzerland for 1970-2020.* Centre for Energy Policy and Economics, Swiss Federal Institutes of Technology: p. 27.

[10] 25 years is, for example, used by Questar Gas as the measure lifetime for window energy-efficiency measures (see http://www.psc.utah.gov/gas/05docs/05057T01/QGC%20DSM%20Exhibit%201.5%20(Audit%20&%20Wx)12-5-06.doc).

Figure 1: Annual return on investment in higher-performing windows
Base case: Code compliant / ENERGY STAR Windows



If windows meeting prescriptive energy code requirements (ENERGY STAR windows in the North) are used as the base case, the energy savings that can be achieved with current highly-insulating (HI) windows are estimated to provide only low return on their incremental cost. Only the more cost-effective highly-insulating windows that DOE is envisaging for 2010 (highlighted in blue) would provide good return on investment in cold climates. In hot climates, good return on investment can presently be achieved with solar control low-E windows.

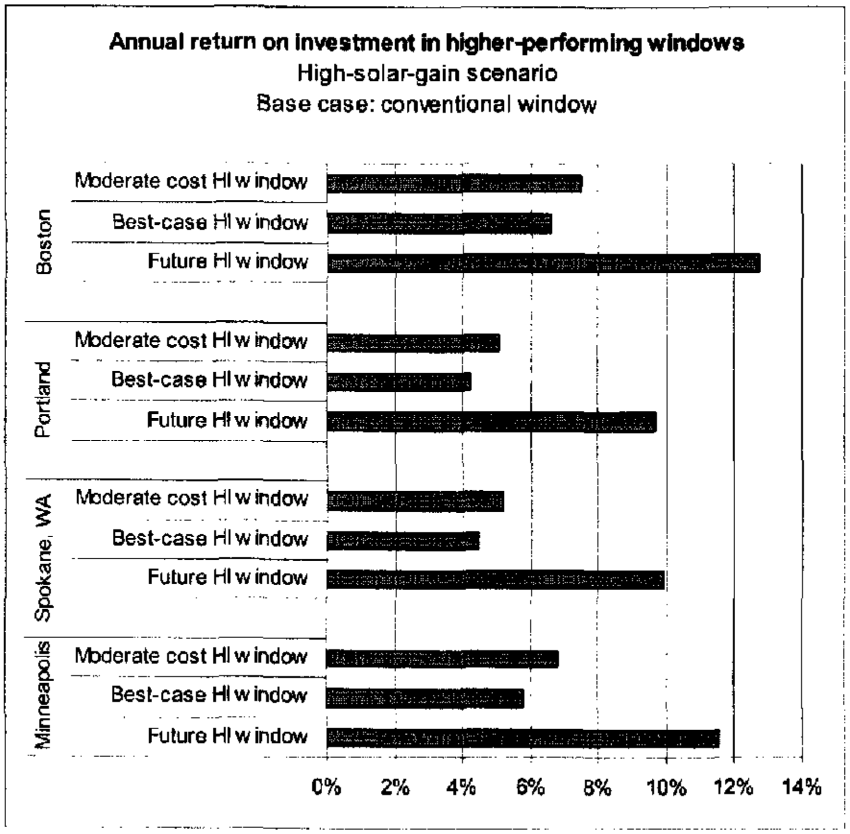


Figure 2: Annual return on investment in high-solar-gain high-performance windows
Base case: Conventional windows

If conventional windows are used as the base case, the energy savings that can be achieved with current highly-insulating (HI) windows designed for high solar gain are estimated to offer significant return on investment in cold climates with high energy prices. Even more cost-effective highly-insulating windows are envisaged by DOE for 2010 (highlighted in blue).

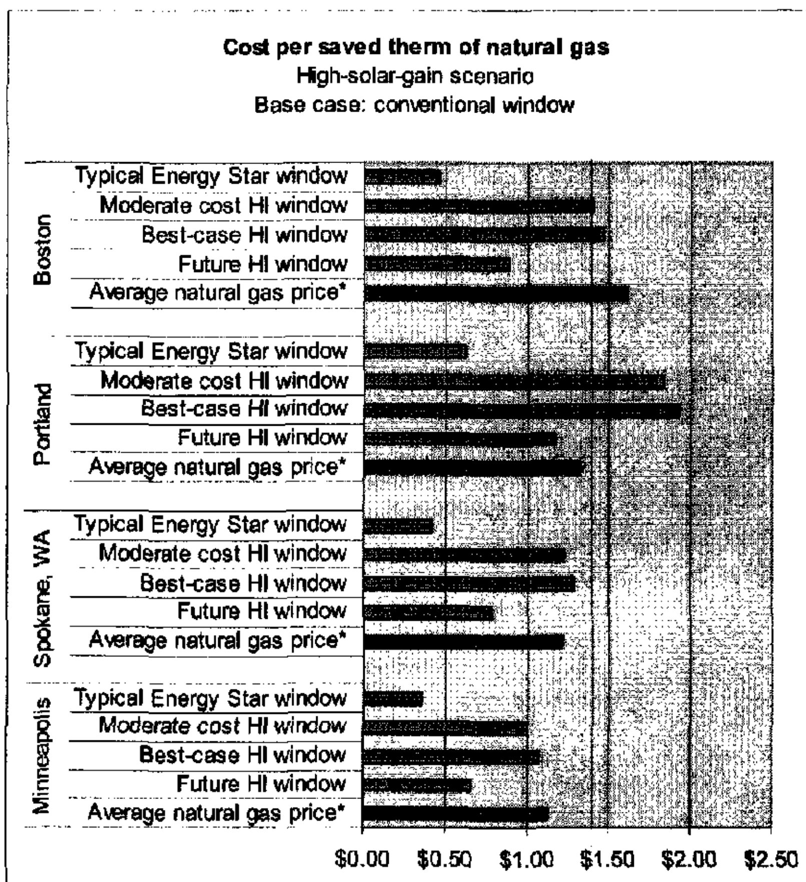


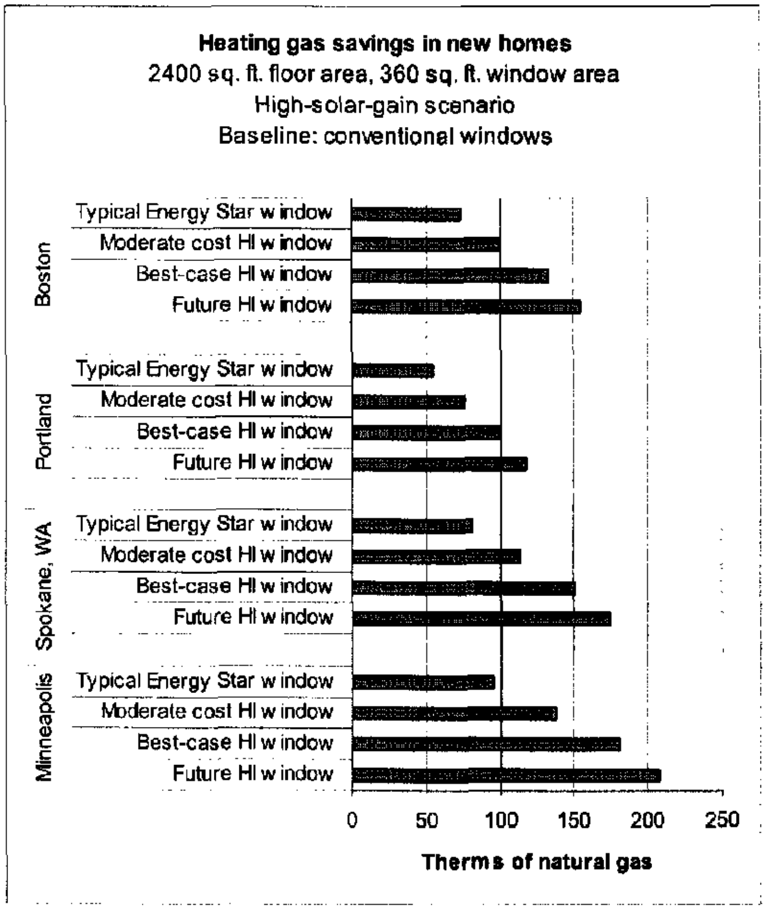
Figure 3: Cost per saved therm of natural gas with high-solar-gain high-performance windows Base case: Conventional window

With highly-insulating windows that allow high solar gain, substantial heating energy use reductions can be achieved. Current highly-insulating windows are still a very expensive option for natural gas savings, but market transformation toward economies of scale and improved performance can lead to very cost-effective options for cold climates.

** Note: the average natural gas price used here is the projected average retail price for natural gas for residential heating in the respective states according to Alliance to Save Energy projections that are based on regional price projections by the Energy Information Administration..*

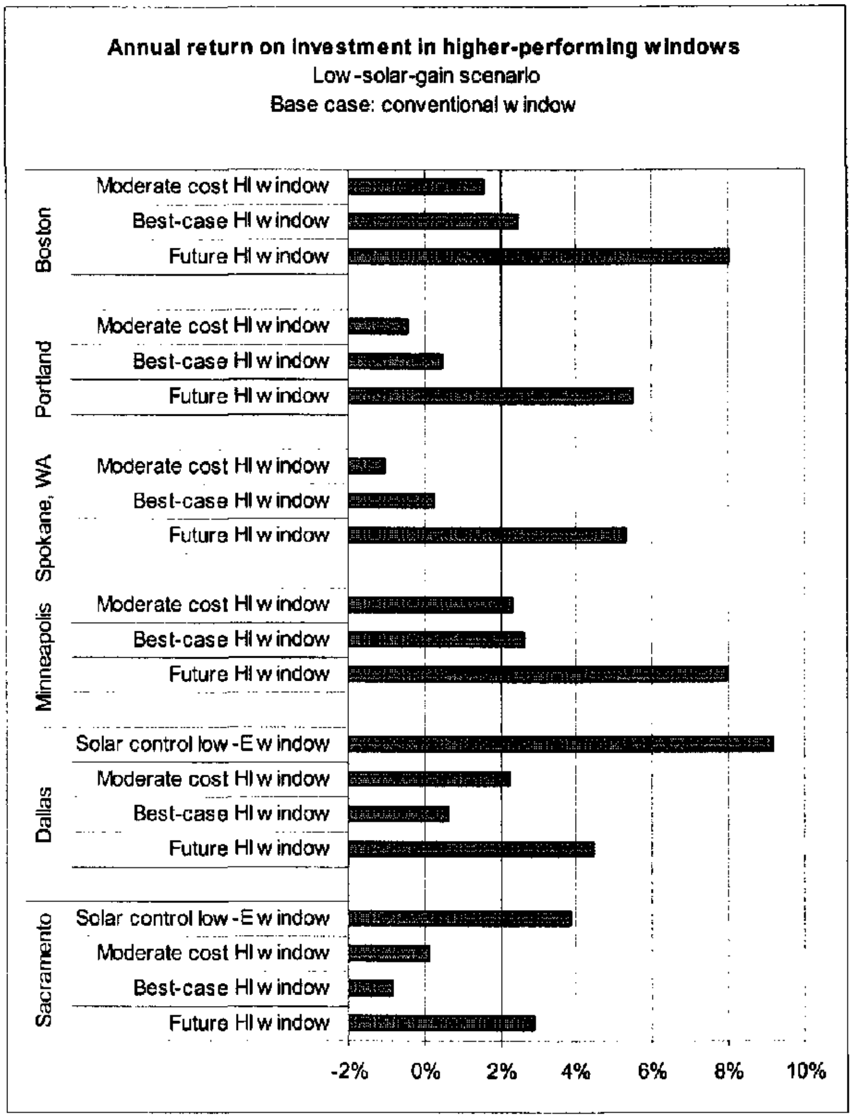
APPENDIX

Figure 4: Heating gas savings in new homes with high-solar-gain high-performance windows
Base case: Conventional windows



In our estimates, average natural gas consumption for heating across the four sample climates is about 18 percent lower in homes with future highly-insulating windows than in homes with conventional windows, and about 11 percent lower than in homes with typical ENERGY STAR windows.

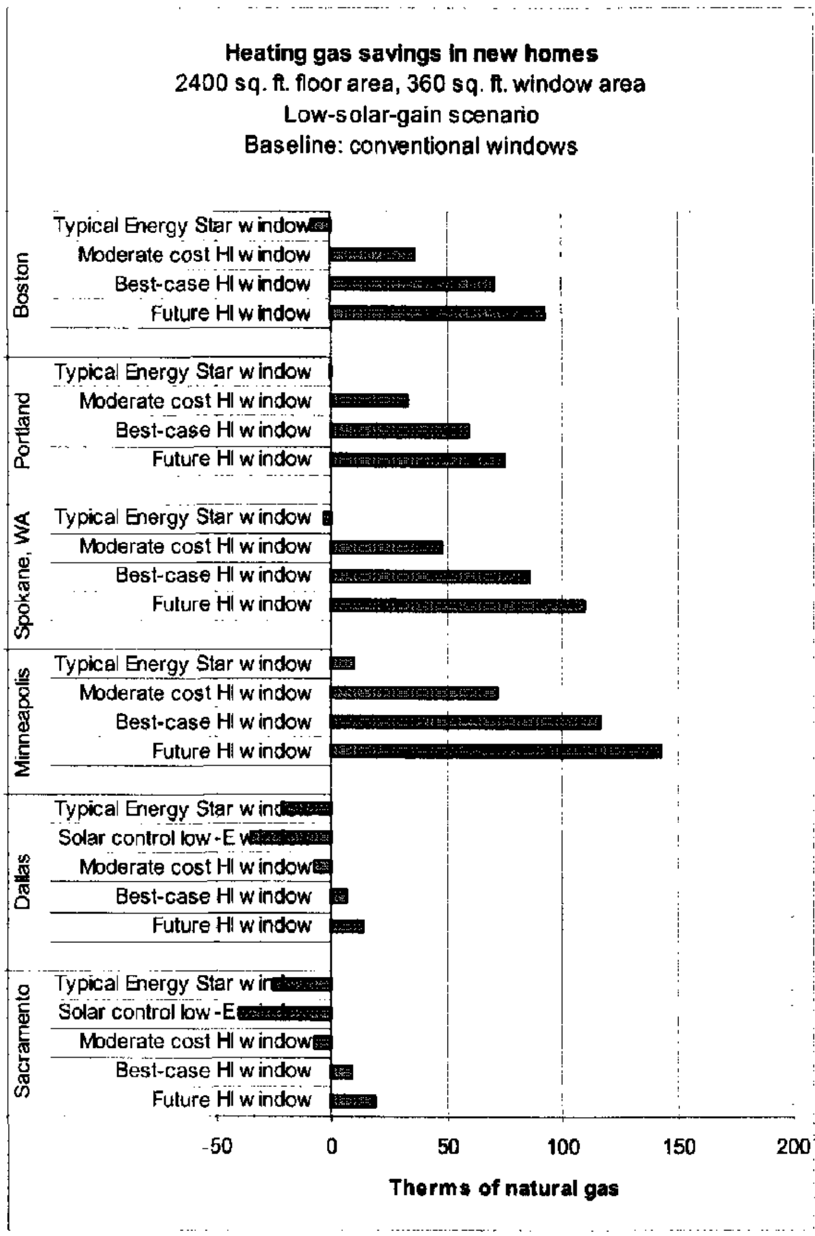
Figure 5: Annual return on investment in low-solar-gain high-performance windows
Base case: Conventional windows



In heating-dominated climates, windows designed for low solar gain are not estimated to provide as high energy savings as windows designed for high solar gain. Nevertheless, low-solar-gain windows can provide substantial cooling peak load reductions and allow for HVAC system downsizing (see Figure 5).

APPENDIX

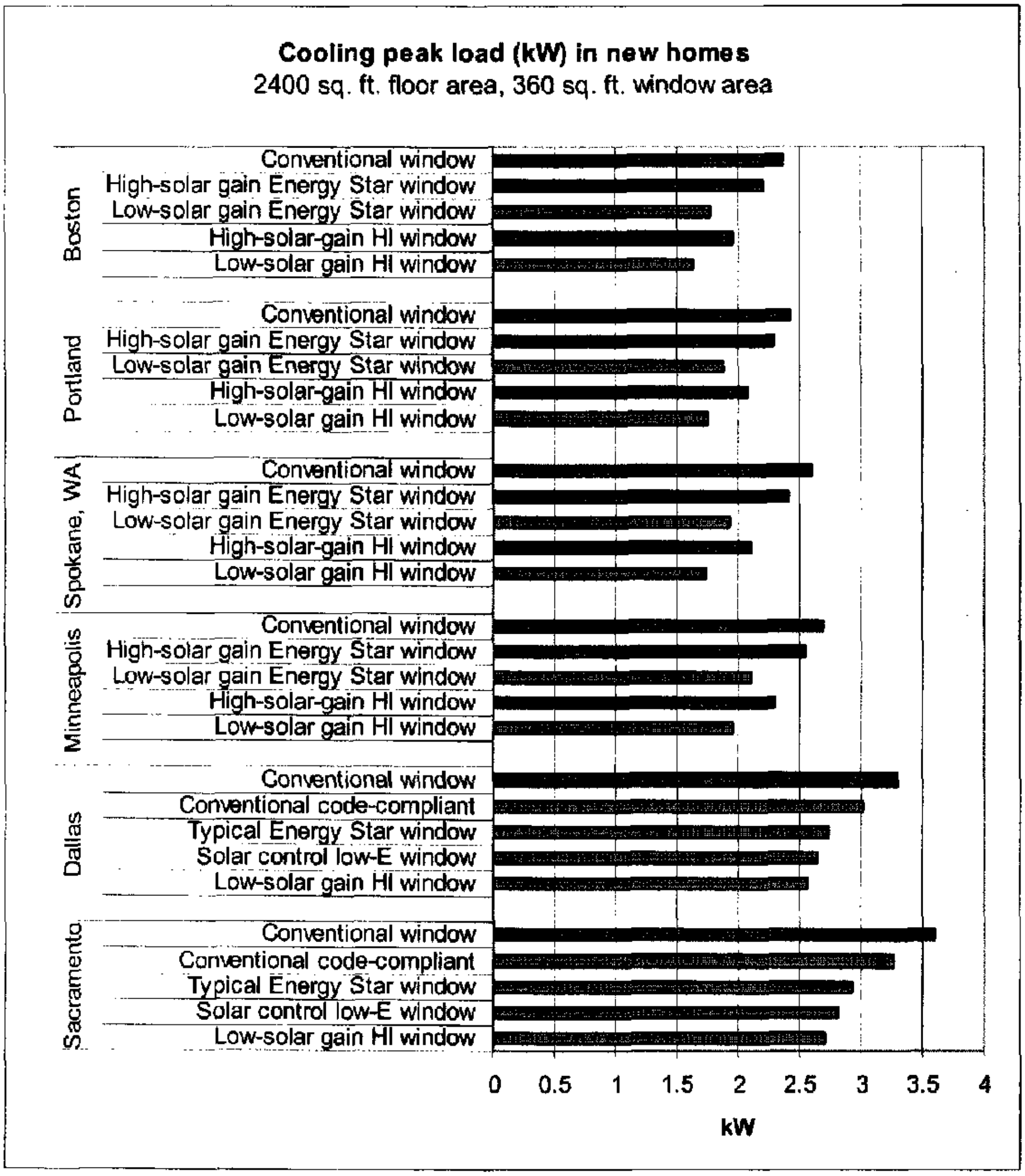
**Figure 6: Heating gas savings in new homes with low-solar-gain high-performance windows
Base case: Conventional windows**



High performance windows can lead to more heating energy use if they block a substantial fraction of solar heat gain. This is particularly obvious in climates with strong solar heat even in wintertime.

APPENDIX

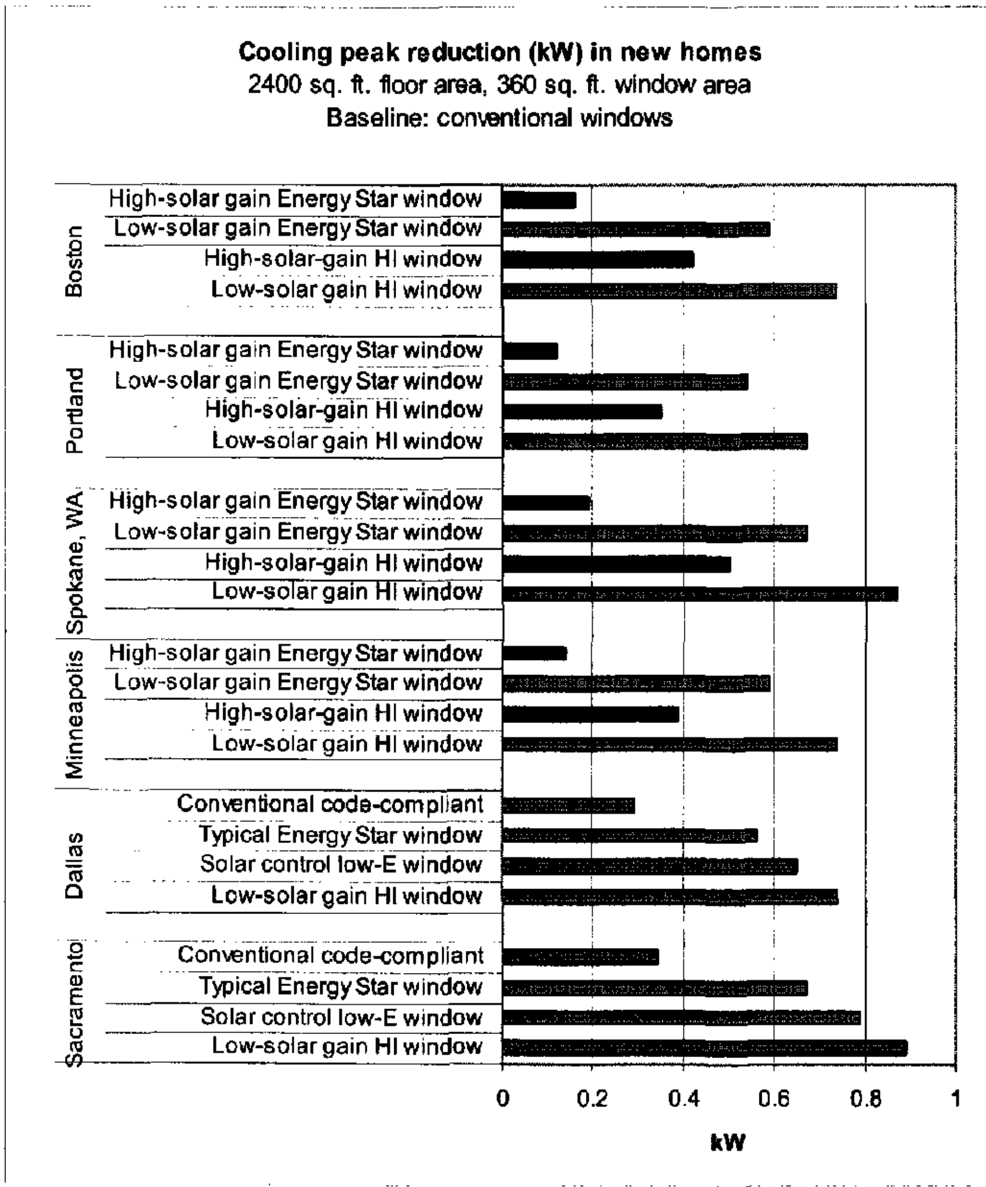
Figure 7: Cooling peak load in new homes depending on window type (low-solar-gain windows marked blue)



According to our estimates, low-solar-gain HI windows reduce peak cooling load by an average 28 percent if compared with conventional windows across different climates. Even high-solar-gain HI windows would achieve an average peak load reduction by 18 percent.

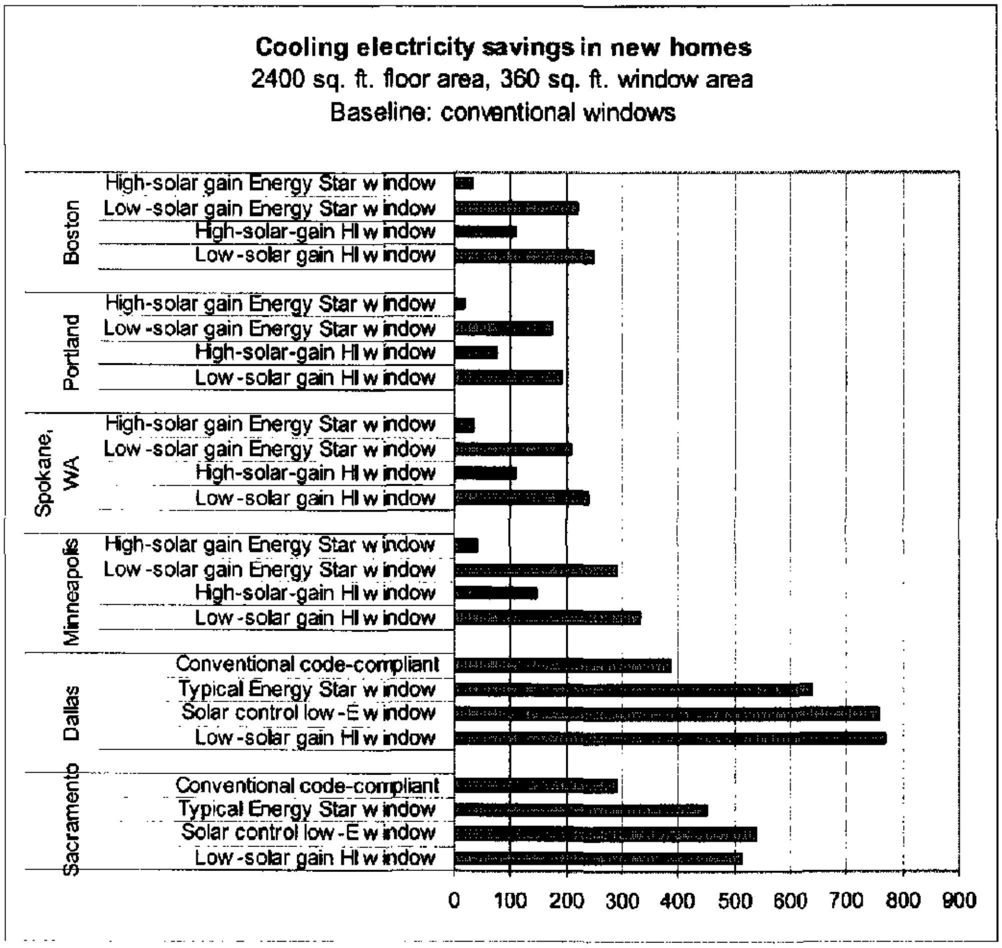
APPENDIX

Figure 8: Cooling peak load reduction in new homes depending on window type (low-solar-gain windows marked blue)



APPENDIX

Figure 9: Cooling electricity savings in new homes depending on window type (low-solar-gain windows marked blue)



Attachment F:

"09-06-30 Pool Pumps Exploration Memo"

CEE
Consortium for Energy Efficiency

98 N. Washington St., Suite 101
Boston, MA 02114
617.589.3949
www.cee1.org

Memorandum

To CEE Residential Appliances Committee
From Eileen Eaton
Date June 30, 2009
Re Pool Pumps Exploration

Background

Starting in 1997, members of the CEE Appliance Committee have been promoting clothes washers, dishwashers, refrigerators, and room air-conditioners in their programs. Over this time period, the market penetration of ENERGY STAR models in these four product categories has increased significantly. As a result, the ENERGY STAR criteria and CEE's high efficiency specifications for these products have been revised many times. Even so, members have communicated difficulty managing free-ridership issues and getting their programs to pass total resource cost (TRC) tests. This combined with the need to deliver even greater energy savings, has led to the Appliance Committee's interest in exploring new technologies.

In the spring of 2008, the Appliance Committee created a list of technologies of interest, established a criterion for evaluating them, and identified their top three priorities. At CEE's June Program Meeting, the Committee discussed the potential for pursuing pool pumps, clothes dryers, and dehumidifiers. Given the existence of the ENERGY STAR program for dehumidifiers, and the significant market barriers associated with clothes dryers, the Committee chose to focus on pool pumps first. [*Unfortunately work in this area was postponed due to revisions to the ENERGY STAR criteria for dishwashers and CEE's residential dishwasher specification during the fall of 2008 and first half of 2009.*]

This memo outlines the potential energy savings, existing pool pump programs, relevant standards, additional information needed, market challenges, and potential next steps with regards to pool pumps. It will be used to inform the Committee's discussion on our July 7 call, during which we'll review the information in sections I-III to ensure it is consistent with current program experience and then focus our discussion on enhancing sections IV-VI.

I. Potential Energy Savings

The following information on potential energy savings was gathered from a 2009 Pool and Spa Marketing study, San Diego Gas & Electric's Pool Motor Brochure dated 9/06/07, and the online Pentair Pool Pump Cost Calculator. If you are currently running a program, please compare these numbers and assumptions to the ones you are using to see if there are significant discrepancies.

Energy use

Standard (single speed) pumps

a. 6 hours/day[i]
b. 13.8 kWh/day[ii]
c. Warm climate (365 days) 5,037 kWh/yr
d. Cool climate (100 days)[1] 1,380 kWh/yr

Two-speed pumps

a. 10 hours/day[iii]
b. 9.4 kWh/day[iv]
c. Warm climate (365 days) 3,431 kWh/yr
d. Cool climate (100 days) 940 kWh/yr

Variable speed pumps

a. 10 hours/day[v]
b. 2.1 kWh/day[vi]
c. Warm climate (365 days) 767 kWh/yr
d. Cool climate (100 days) 210 kWh/yr

Per Unit Energy Savings

These savings were calculated based on the above energy use estimates.

Two-speed savings over standard (single speed)

a. 4.4 kWh/day
b. Warm climate (365 days) 1,606 kWh/yr
c. Cool climate (100 days) 440 kWh/yr
d. Approximately 30% savings

Variable speed savings over standard (single speed)

a. 11.7 kWh/day
b. Warm climate (365 days) 4,270 kWh/yr
c. Cool climate (100 days) 1,170 kWh/yr
d. Approximately 85% savings

Total Energy Savings Potential

The above savings numbers were multiplied by the number of in-ground pools in a particular climate zone to determine aggregate savings. The market regions as defined by Pool & Spa Marketing were grouped as follows: Warm Climate – Southeast, South Central, and Southwest and Cool Climate – Northeast, East Central, West Central, and Northwest.

Two-speed savings over standard (single speed)

a. 5.1 million in-ground pools nationally in 2007[vii]

[1] Assumes pools are open from Memorial Day through Columbus Day in cool climates.

    1. 3.3 million in-ground pools in warm climates (65%)
    2. 1.8 million in-ground pools is cool climates (35%)

b. 6.1 billion kWh/yr saved nationally
    1. Warm climate (365 days) 5.32 billion kWh/yr
    2. Cool climate (100 days) 0.78 billion kWh/yr

Variable speed savings over standard (single speed)

a. 5.1 million in-ground pools nationally in 2007[viii]
    1. 3.3 million in-ground pools in warm climates (65%)
    2. 1.8 million in-ground pools is cool climates (35%)

b. 16.1 billion kWh/yr saved nationally
    1. Warm climate (365 days) 14 billion kWh/yr
    2. Cool climate (100 days) 2.1 billion kWh/yr

II. Existing Programs

The following information was collected by CEE staff as part of its research for the July 7 call. The list of program offerings among CEE members may not be comprehensive but reflects the program details staff were able to find through web research and member outreach.

CALIFORNIA

- Pacific Gas & Electric
    - Rebate:
        - Efficient two-speed pool filtration pump and motor with automatic controller – $100
        - Efficiency variable speed pool filtration pump and motor – $100
    - Requirements: A controller capable of automatically switching speeds must be purchased and installed, if the existing controller does not have this capability.
    - Resources:
        - List of qualified two speed pumps, motors, and controllers and variable pumps and controllers http://www.pge.com/myhome/saveenergymoney/rebates/seasonal/poolpumps/

- San Diego Gas & Electric
    - Rebates: SDG&E provides a $100 rebate for Multi-Speed or Variable-Speed Pool Pump and Motors.
    - Requirements: A qualifying automatic controller is required for most multi-speed pool pump and motor sets.
    - Resources:
        - List of qualifying pool pumps and controllers http://www.sdge.com/residential/poolPumps.shtml

- Southern California Edison
    - Rebate: $200 back for a two-speed pool pump or variable-speed pool pump. This rebate is part of the Home Energy Efficiency Rebate Program (HEER).
    - Requirements: For those models that require an automatic control system capable of controlling both high and low speeds, a controller must be installed.
    - Resources:
        - List of qualifying pool pumps and motor models http://www.sce.com/residential/rebates-savings/pool/pool-pump-motor.htm

Note: Two-speed pumps don't always deliver correct speeds, and so existing programs are experiencing more buy in from contractors with variable pumps. However, calculating savings on variable speeds is more complex. PG&E verified service providers model is being pursued an upstream rebate program. It is important to note that the baseline may be different in CA because of Title-24.

MASSACHUSETTS AND RHODE ISLAND

- Cape Light Compact, NSTAR Electric, National Grid, Western Massachusetts Electric, and Unitil
    - Rebates:
        - Two-speed customer rebate $50, contractor $50
        - Variable speed customer rebate $100, contractor $50
    - Requirements: To be eligible, installations must include a qualifying controller.
    - Resources:
        - List of qualified products http://www.myenergystar.com/documents/RebateForms/MA_and_RI_Qualified_Pool_Pump_List_May_2009.pdf
        - List of qualified controllers http://www.myenergystar.com/documents/RebateForms/MA_and_RI_Qualified_Controller_List_May_2009.pdf

NEW YORK

- Long Island Power Authority
    - Rebates:
        - Two-speed installer rebate $75 and two-speed customer rebate $75
        - Variable speed installer rebate $100 and variable speed customer rebate $200
    - Requirements: The pool pumps must be installed with an eligible controller by a participating dealer in order to qualify for the rebate. Eligible pumps must be 1/2 HP or larger.
    - Resources:
        - List of qualified products http://www.lipower.org/pdfs/cei/qualified-poolv.pdf and http://www.lipower.org/pdfs/cei/qualified-pool2.pdf
        - List of participating dealers/installers http://www.lipower.org/pdfs/cei/retailers-pool.pdf

NEVADA

- NV Energy
    - Rebate: NV Energy is providing instant rebates on energy-efficient residential pool pumps.
        - $100 instant rebate for two-speed pumps
        - $200 instant rebate for variable-speed pumps
    - Requirements: Must use a participating retailer, pool builder, or distributor to receive instant rebate. Pump must be new; rebuilt motors do not qualify.
    - Resources:
        - They have developed a list of participating retailers and pool builders as well as service professionals.
        - http://www.nvenergy.com/saveenergy/home/rebates/poolpumps.cfm

TEXAS

- Austin Energy
    - Rebates: $200 for an Austin Energy qualified variable-speed pump and motor
    - Requirements: Must be Austin Energy qualified and a replacement for an existing pump and motor, or installed with a new in-ground pool (existing pools with solar heating are not eligible)
    - Resources:
        - List of qualified models http://www.austinenergy.com/Energy%20Efficiency/Programs/Rebates/Residential/Pool%20Pump/qualifyingSystems.htm
        - List of participating pool professionals http://web.memberclicks.com/mc/directory/viewSaveSearch.do?saveSearchReturn=3 and http://www.austinenergy.com/Energy%20Efficiency/Programs/Rebates/Residential/Pool%20Pump/index.htm

III. Current Standards

CALIFORNIA

- Title 20 (http://www.energy.ca.gov/2006publications/CEC-400-2006- 002/CEC-400-2006-002-REV2.PDF) addresses pumps, motors, and controls and was adopted in October 2005.
- Title 20 specifies:
    - Service Factor
    - Motor Efficiency
        - Employs standard test procedure to make motor efficiency comparisons
    - Two-Speed Capability
        - Pump Motors

        - Pump Controls

- Title 24 (http://www.energy.ca.gov/title24/index.html) includes information on pump motor selection, pipe design, and filter size selection. The standards are in a 2008 update process now.
- Title 24 Recommendations:
    - Compliance with Title 20
    - Accessible On/Off Switch
    - Posted Instructions for Energy Efficient Pool Operation
    - No Electric Resistance Heating
        - Exceptions for heaters with fully insulated covers/enclosures or 60% of heat from solar or recovery
    - Pump Sizing and Flow Rate Requirements
    - System Piping Requirements
    - Filtration Equipment Sizing Requirements
    - Peak Demand Controls
    - Cover Required for All Pools

IV. Additional Information Needed

This is a list of information needs identified at CEE's June Meeting in 2008. Efficiency programs may have other information needs that aren't included in this list. Please consider what should be added.

- Market channel information
    - Where pumps are purchased
    - Who installs them
- Installation considerations
    - Correct sizing of pump for pool
        - There maybe a study from Ecos on this topic
    - Design of pipes, filters, pump and pool

V. Challenges

Again, this list of challenges is from CEE's 2008 June Meeting. Please consider other challenges that should be included.

- Customer awareness
- Industry support
- Getting pumps installed
- Regional differences
- High cost equipment
- High cost installations
- Complicating factors
    - Efficient pool designs
    - Filtration systems and where filters and pumps are installed

- Pool timers (timers may not be a good for programs because they don't address water quality/filtration requirements and are also based on consumer behavior).
- Pool heaters

VI. Potential Next Steps

The items under each heading are not comprehensive. As in the previous sections, additional inputs are welcome.

- Identify additional resources
    - Progress Energy in Florida as they may have a new standard in place.
    - CA studies (SDG&E pool timers)
    - Pool permit data
    - Real estate data
- Talk with industry
    - International Pool Spa Service Association (IPSSA)
    - Experienced programs stressed that training industry and installers is key.
- Determine Role for CEE
    - Information sharing
    - CEE specification
    - Product lists
    - ENERGY STAR label would help manufacturers be consistent in reporting/testing

---

[i] San Diego Gas & Electric Pool Motor Brochure. Page 2. September 6, 2007. http://www.sdge.com/documents/residential/PoolMotorBrochure.pdf

[ii] San Diego Gas & Electric Pool Motor Brochure. Page 2. September 6, 2007. http://www.sdge.com/documents/residential/PoolMotorBrochure.pdf

[iii] San Diego Gas & Electric Pool Motor Brochure. Page 2. September 6, 2007. http://www.sdge.com/documents/residential/PoolMotorBrochure.pdf

[iv] San Diego Gas & Electric Pool Motor Brochure. Page 2. September 6, 2007. http://www.sdge.com/documents/residential/PoolMotorBrochure.pdf

[v] Pentair Pool Pump Cost Calculator. Accessed June 10, 2009 http://www.pentairpool.com/pool_pump_calc/index.htm.

[vi] Calculated based on Pentair Pool Pump Cost Calculator: $/day divided by utility rate $/kWh. http://www.pentairpool.com/pool_pump_calc/index.htm.

[vii] Hubbard, Richard. U.S. Swimming Pool Industry Experiences Downturn in 2007. Pool & Spa Marketing. March 2009. Pages 12-13. http://www.poolspamarketing.com/public/stats/pdf/2007_US_Swiming_Pool_Stats.pdf

[viii] Hubbard, Richard. U.S. Swimming Pool Industry Experiences Downturn in 2007. Pool & Spa Marketing. March 2009. Pages 12-13. http://www.poolspamarketing.com/public/stats/pdf/2007_US_Swiming_Pool_Stats.pdf

Attachment G:

"PGE Updated Proposal Information Template for Residential Pool Pump Measure Revisions"

Proposal Information Template for: **Residential Pool Pump Measure Revisions**

Submitted to:
California Energy Commission
In consideration for the 2008 Rulemaking Proceeding on Appliance Efficiency Regulations, Docket number 07-AAER-3

Prepared for:
Pacific Gas and Electric Company

Pat Eilert
Gary Fernstrom
Ed Elliot

Pacific Gas and Electric Company

Prepared by:
Leo Rainer
Davis Energy Group

Last Modified: July 23, 2008

This report was prepared by Pacific Gas and Electric Company and funded by the California utility customers under the auspices of the California Public Utilities Commission.

Proposal Information Template – Residential Pool Pump Measure Revisions

2008 Appliance Efficiency Standards

Leo Rainer
Davis Energy Group
July 23, 2008

CONTENTS

Purpose

This document is a report template to be used by researchers who are evaluating proposed changes to the California Energy Commission's (Commission) appliance efficiency regulations (Title 20, Cal. Code Regs,, §§ 1601 – 1608) This report specifically covers revisions to current Residential Pool Pump appliance standards which were adopted by the California Energy Commission on Oct 11, 2006.

This template covers the following 3 pool pump topics:

- Replacement pool pump motors
- High-efficiency multi-speed motor and control clarifications
- New pool pump test curve

Background

There are approximately one million above ground residential swimming pools in California, the vast majority of which use a single-speed motor to drive the filtration pump to circulate and filter swimming pool water in order to remove particulate debris and maintain clarity. Residential pump motors range in size from one half to three horsepower (hp), are operated an average of about 4.6 hours per day, but in some cases up to 10 hours per day, and draw approximately one kW per nominal horsepower.

Using pumps with 2-speed motors offer a significant opportunity for energy savings by taking advantage of pump affinity laws. Operating a pump equipped with a two-speed motor at half speed for twice as long moves the same volume of water, but in theory uses only one-quarter the amount of energy. In reality, currently available two-speed motors are less efficient at the lower speed, so energy savings are closer to 55%. Low speed operation is generally adequate for filtering, but high speed may be needed for operating pool sweeps for a few hours daily, and for reforming DE filters after backwashing.

Residential Pool Pumps were first included in the 2005 Title-20 appliance standards that were adopted at the end of 2005. Residential Swimming Pool standards are included in the 2008 Title-24 building standards which are expected adopted in April, 2008 and will become effective July 1, 2009. The 2005 Title-20 standards regulated pool pump motor types and required testing and listing of pool pump motor combinations effective January 1st, 2006. In addition, multi-speed motors and controls were required for pool pumps of greater than 1 HP effective January 1st, 2008. The 2008 Title-24 standards require pool design standards that include minimum pool turnover times and maximum flow velocities.

Since the implementation of the standards there have been ongoing discussions between PG&E and the pool industry (principally the Association of Pool and Spa Professionals, APSP) in regards to updates and revisions including the following:

- Accommodate new pool equipment such as variable-speed motors
- Clarify whether or not replacement motors are covered
- Add a third pool pump test curve to represent efficient pool piping design.

Overview

Replacement pool pump motors

The current pool pump standards do not refer to pool pumps, pool pump motors, and pool pump motor combinations consistently. In addition, pool pump motors are not explicitly identified in the scope of the standards. Because of this, it is currently the interpretation of the CEC that the standards do not cover replacement pool pump motors, although this was the intent of the those involved in writing the standards.

Description of Standards Proposal	The scope of Residential Pool Pumps should be amended to explicitly include the pump, pump motor, and replacement motors. .
California Stock and Sales	There are approximately 1.1 million private, residential, in-ground swimming pools in California, with annual sales of 34,000. Approximately 113,000 pool pump motors are replaced each year.
Energy Savings and Demand Reduction	Energy savings of replacing an average single-speed pool pump motor with a two-speed motor is estimated to be 1088 kWh/yr which will result in statewide savings of 497 GWh and 132 MW over the first ten years of the standard.
Economic Analysis	Installation of a two-speed replacement motor is estimated to cost an average of $450 more than a single-speed replacement. Net present value of the energy savings over the 10 year lifetime of the motor is $563 with a 2.2 benefit-to-cost ratio.
Non-Energy Benefits	Operating swimming pool filtration equipment at low flow rates greatly reduces noise and can reduce entrapment issues due to high flow velocities.

Environmental Impacts	None
Acceptance Issues	Not all pool service companies have experience with two-speed motors. Increasing the cost of a pool pump motor replacement above $500 may require that it be done by a licensed contractor.
Federal Preemption or other Regulatory or Legislative Considerations	Pool pump motors are definite purpose motors and as such are not presently covered by federal efficiency regulations.

High-efficiency multi-speed motor and control clarifications

When the current standards were written the vast majority of residential pool pump motors were either single-speed or two-speed. Since then manufacturers have brought out an increasing variety of multi-speed and variable-speed motors. These can provide significant energy savings over conventional motors, but their performance is more difficult to characterize. Section 1605.3(g)(5)(B) needs to define what the lowest speed is.

New Pool Pump Test Curve

The 2008 Title-24 pool standards rely on a new pool system curve to size pumps for pools of greater than 25,000 gallons. This curve, referred to as "Curve C", was suggested by pool pump stakeholders and represents the system curve of a well designed, low pressure-drop pool. Adding Curve C to the test and listing requirements of filtration pumps will allow the data to be easily used for Title-24 compliance.

Methodology

The current appliance efficiency data base for pool pumps was used to estimate the efficiency of typical 1.5 hp single- and two-speed pumps. The data base was sorted by pump type and total horsepower and single- and two-speed pumps with close to 1.5 total hp were selected. Average energy factors for each type of pump was used to estimate annual energy use.

Two-speed motors can replace single-speed motors directly in most pumps, but they require a new two-speed controller and wiring which requires additional labor to install. Pool pump motors have an expected lifetime of 10 years, although the pump head can last much longer. We estimate that 113,000 pool pump motors are replaced each year, of these, we estimate:

- 30% will be replaced with a less than 1 hp motor and remain single-speed.
- 20% will replace the whole pump and will be covered by the current standard.
- 50% will be a motor replacement of greater than 1 hp.

Analysis and Results

Three sizes of pool pump motors were evaluated for this analysis: 1.25, 1.65, and 2.2 total hp. 84 pool pumps with these total capacities were selected from the current CEC appliance data base. Single-speed pump operation time was assumed to be the California average of 4.6 hours. High-speed pump operation depends on whether the pool has a filter pump powered automatic pool cleaner and whether there is a sand or DE filter that needs backwashing and high-speed start-up. An average of 1.3 hours per day was assumed. Low-speed operation was set to the number of hours required to filter the same amount of water as the single-speed system. Operating assumptions based on Curve A characteristics are summarized in the Table 1.

Table1: Pool Pump Operation

Total HP	Motor	Flow (gpm)	Power (W)	EF (gal/Wh)	Run Time (hrs/day)	Energy (kWh/yr)
1.25	Single-speed	57.0	1360	2.51	4.6	2286
	Two-speed High	58.1	1488	2.34	1.3	680
	Two-speed Low	32.1	334	5.77	5.9	720
1.65	Single-speed	60.7	1637	2.22	4.6	2753
	Two-speed High	61.3	1814	2.03	1.3	829
	Two-speed Low	33.0	427	4.64	6.1	958
2.2	Single-speed	63.0	1958	1.93	4.6	3291
	Two-speed High	65.6	1913	2.06	1.3	874
	Two-speed Low	33.0	414	4.79	6.3	953
Weighted Average Savings			**1246**			**1088**

The two-speed pumps operate an average of 7.4 hours per day, but due to the significantly lower power use on low-speed the average savings is 1088 kWh/yr. Average demand savings on low-speed is 1.2 kW.

Economic calculations are shown in Table 2. Average incremental cost of a two-speed motor is $210, but an additional $160 is required for the controller and $80 for the added installation labor.

Table 2: Life Cycle Economics

Design Life (years)	*Annual Energy Savings (kWh)*	*LCC ($/kWh)*	*Present Value of Energy Savings*	*Incremental Cost*	*Net Customer Present Value*	*BCR*
10	1088	0.931	$1013	$450	$563	2.25

Statewide savings estimates are shown in Table 3. 30% of motor replacements are assumed to be with less than one hp single-speed motors, and 20% are assumed to be whole pump change-outs, resulting in on one-half of required motor replacements being two-speed replacements. Full savings are realized in 2019 after all existing single-speed motors have been replaced. Demand savings are based on one-third of pool pumps operating on-peak.

Table 3: Statewide Energy and Demand Savings

Annual Motor Replacements	Fraction Replaced with 2-speed	Energy Savings (GWh/year)		Demand Savings (MW)	
		First Year	2019	First Year	2019
113,000	50%	61	615	23	232

Recommendations

Replacement pool pump motors

Make the following changes in sections 1602 and 1604 to explicitly include replacement pool pump motors in the regulations:

1602(g)

"Residential pool pump" means a pump-motor combination used to circulate and filter pool water in order to maintain clarity and sanitation, and includes the centrifugal pump and the pump motor.

1604(g)

(3) Test Method for Residential Pool Pumps and Replacement Motors

(B) ANSI/HI 1.6-2000 shall be used for the measurement of pump ~~and motor combinations~~ efficiency.

High-efficiency multi-speed motor and control clarifications

Add the following definition to section 1602(g):

"Auxiliary pool load" means a feature or device that circulates pool water, in addition to that required for pool filtration, including, but not limited to, solar pool heating systems, filter backwashing, pool cleaners, waterfalls, fountains, and spas.

Make the following changes in section 1605.3(g)(5) to better accommodate high-efficiency multi-speed motors and to clarify control specifications as they relate to multi-speed products:

(B) ~~Two~~Multi-**Speed Capability**.

(i) **Pump Motors**. Pool pump motors with a capacity of greater than 1 total HP ~~or more~~ which are manufactured on or after January 1, 2008, including but not limited to those installed in existing residential pool pumps as replacement residential pool pump motors, shall have the capability of operating at two or more speeds with ~~a low~~ the lowest speed having a rotation rate that is no more than one-half of the motor's maximum rotation rate.

(ii) **Pump Controls**. Pool pump motor controls manufactured on or after January 1, 2008 that are sold for use with a two- or more speed pump shall have the following minimum capabilit~~y~~ies:

(a) The ability to operate the pool pump at two or more speeds.

(b) A filtration speed that is the default when no auxiliary pool loads are operating and is no more than one-half of the motor's maximum rotation speed.

(c) A high-speed override capability that returns to the filtration speed within twenty four hours.

New Pool Pump Test Curve

1604 (g) (3) Test Method for Residential Pool Pumps

(C) ~~Two~~ Three curves shall be calculated:

Curve A: H = 0.0167 x F2

Curve B: H = 0.050 x F2

Curve C: H = 0.0082 x F2

Where:

H is the total system head in feet of water.

F is the flow rate in gallons per minute (gpm).

(D) For each curve (A~~&~~,B&C), the pump head shall be adjusted until the flow and head lie on the curve. The following shall be reported for each curve and pump speed (two-speed pumps shall be tested at both high and low speeds). See Table V.

1606 Table V Data Submittal Requirements

	Appliance	*Required Information*	*Permissible Answers*
G	Residential Pool Pumps	Motor Construction	PSC, Cap Start-Cap Run, ECM, Cap Start-induction run, split-phase
		Motor Design	Single-speed, two-speed, multiple-speed, variable-speed
		Frame	
		Speed (rpm)	
		Motor has Capability of Operating at Two or More Speeds with the Low Speed having a Rotation Rate that is No More than One-Half of the Motor's Maximum Rotation Rate	Yes, no
		~~Pool Pump~~ Motor Service Factor	
		Motor Efficiency (%)	
		Nameplate Horsepower	
		Flow for Curve 'A' (in gpm)	
		Power for Curve 'A' (in watts)	
		Energy Factor for Curve 'A' (in gallons per watt-hour)	
		Flow for Curve 'B' (in gpm)	
		Power for Curve 'B' (in watts)	
		Energy Factor for Curve 'B ' (in gallons per watt-hour)	
		Flow for Curve 'C' (in gpm)	
		Power for Curve 'C' (in watts)	
		Energy Factor for Curve 'C ' (in gallons per watt-hour)	

Bibliography and Other Research

ANSI/NSPI – 1 2003. *American National Standard for Public Swimming Pools*, American National Spa & Pool Institute, March 2003.

ANSI/NSPI – 5 2003. *American National Standard for Residential In-ground Swimming Pools*, American National Spa & Pool Institute, December 2002.

APSP 2007. Association of Pool & Spa Professionals, *Portable Electric Spa Stand-by Energy Test Protocol (Draft)*, APSP-14-200X, October 2007.

DEG 2005. Davis Energy Group, *CASE Initiative for Title 20 Standards Development: Analysis of standards options for residential pool pumps, motors, and controls.* Prepared for PG&E, March 2005.

DEG 2007. Davis Energy Group, *CASE Initiative for Title 24 Standards Development: Draft Report on Residential Swimming Pools.* Prepared for PG&E, March 2007.

IAPMO 1997. *Uniform swimming pool, spa and hot tub code.* International Association of Plumbing & Mechanical Officials, 1997 Edition.

NSF/ANSI 50 – 2005. *Circulation system components and related materials for swimming pools, spas/hot tubs.* NSF International Standard/American National Standard.

Hydraulics and Filtration Manual, P1-700, Pentair Pool Products, 2002 Edition.

PK Data 2006. *California Swimming Pool and Hot Tub Information*, P.K. Data, April 2006.

STA-RITE Commercial Pool/Spa Engineering Design Manual

Attachment H:

"28 - Pump and Motor Single Speed"

Residential Swimming Pool Pumps

Measure Name	Residential Swimming Pool Pump
Target Sector	Single Family Residential Establishments
Measure Unit	Pool Pump
Unit Energy Savings	694 kWh
Unit Peak Demand Reduction	0.357kW
Measure Life	10 years

1.1 Introduction

Residential pool pumps ranging from 0.75 hp to 3 hp are often oversized, have inefficient motors and operate at higher flow rates than necessary. This work paper documents the calculation methodology and the assumptions regarding baseline equipment, high efficiency equipment, and usage patterns used to estimate annual energy savings expected from the replacement of a standard pool pumps with high efficiency pool pumps.

1.2 Measure Applicability

This work paper documents the energy savings attributable to efficient pool pumps in small residential applications. The most likely areas of application are swimming pools in single family establishments. There are two energy efficient scenarios described in this paper. The first scenario replaces a standard efficiency 1.5 HP pump with a premium efficiency 1.5 HP pump. The second scenario, called the "right-sizing" scenario, replaces a standard efficiency 1.5 HP pump with a premium efficiency 1.0 HP pump. In this scenario, the smaller pump runs slightly longer hours but filters approximately the same number of gallons per day.

1.3 Savings Calculations

The DSMore Michigan Database of Energy Efficiency Measures[1] refers to the California Energy Commissions' extensive field study for the energy savings analysis. The energy savings and demand reduction obtain through the following calculations:

Energy Usage:

$$E_{Base} = (HP_{Base} \times LF_{Base} \times .746) \times \left(\frac{1}{PME_{Base}}\right) * HrD_{Base} \times DY = 2,121\ kWh$$

$$E_{Eff} = (HP_{Eff} \times LF_{Eff} \times .746) \times \left(\frac{1}{PME_{Eff}}\right) * HrD_{Eff} \times DY = 1,467\ kWh$$

$$E_{RS} = (HP_{RS} \times LF_{RS} \times .746) \times \left(\frac{1}{PME_{RS}}\right) * HrD_{RS} \times DY = 1,386\ kWh$$

Peak Demand:

$$D_{Base} = \left\{ HP_{Base} \times \left(\frac{LF_{Base}}{PME_{Base}}\right) \times 0.746\frac{kW}{HP} \times CF \right\} = 2.272\ kW$$

$$D_{Eff} = \left\{ HP_{Eff} \times \left(\frac{LF_{Eff}}{PME_{Eff}}\right) \times 0.746\frac{kW}{HP} \times CF \right\} = 0.799\ kW$$

$$D_{RS} = \left\{ HP_{RS} \times \left(\frac{LF_{RS}}{PME_{RS}}\right) \times 0.746\frac{kW}{HP} \times CF \right\} = 0.697\ kW$$

Energy Savings:

The energy savings are taken as the difference between the baseline energy usage and the average energy usage for the two efficient scenarios.

$$E_{Savings} = E_{Base} - \frac{1}{2}(E_{Eff} + E_{RS}) = 694kWh$$

Demand Reduction:

The demand reductions are taken as the difference between the baseline peak coincident demand and the average peak coincident remand for the two efficient scenarios.

$$D_{Savings} = D_{Base} - \frac{1}{2}(D_{Eff} + D_{RS}) = 0.357\ kWh$$

1.4 Definition of Variables

The parameters in the above equations are listed in **Table 1** below.

Table 1: Calculation Assumptions

Component	Type	Value	Source
HP_{base} : Baseline Pump HP	Fixed	1.5	i
HP_{Eff} : Efficient Pump HP	Fixed	1.5	i
HP_{RS} : Right-Sized Pump HP	Fixed	1.0	i
PME_{B} : Baseline Pump-Motor Efficiency	Fixed	0.325	i
PME_{Eff} : Efficient Pump-Motor Efficiency	Fixed	0.455	i
PME_{RS} : Efficient Right-Sized Pump-Motor Efficiency	Fixed	0.455	i
LF_{Base} : Load Factor	Fixed	0.66	i
LF_{Eff} : Load Factor	Fixed	0.65	i
LFRS : Right Sized Pump Load Factor	Fixed	0.85	i
HrD_{Base} : Baseline Operating Hours/ day	Fixed	6.10	i
HrD_{Eff} : Baseline Operating Hours/ day	Fixed	6.00	i
HrD_{RS} : Baseline Operating Hours/ day	Fixed	6.50	i

DY: Days per Year	Fixed	153	i
D_{Base}: Baseline pump demand (kW)	Calculated	2.27	i
D_{Eff}: Efficient pump demand (kW)	Calculated	1.60	i
D_{RS}: Efficient, right-sized pump demand (kW)	Calculated	1.39	i
CF: Coincidence Factor	Fixed	0.50	i

1.5 Prescriptive Deemed Savings

The deemed savings for the installation of a residential pool pump compared to a standard efficiency pool pump is **694 kWh per year** with a demand savings of **.357 kW.**

Measure Life

The Database for Energy Efficiency Resources estimates the measure life at 10 years[ii] which also matches with the DSMore useful life used in the energy savings analysis.

1.6 Evaluation Protocols

The most appropriate evaluation protocol for this measure is verification of installation coupled with assignment of stipulated energy savings.

References

[i] Please find original documentation from DSMore MI DB attached herein:

Microsoft Office Word 97 - 2003 Docu   Microsoft Office Excel 97-2003 Worksl

[ii]DEER EUL values, updated October 10, 2008
http://www.deeresources.com/index.php?option=com_content&view=article&id=65&Itemid=57

Attachment I:

"LED Refrig Lighting ERCO Talking Pointsv3"

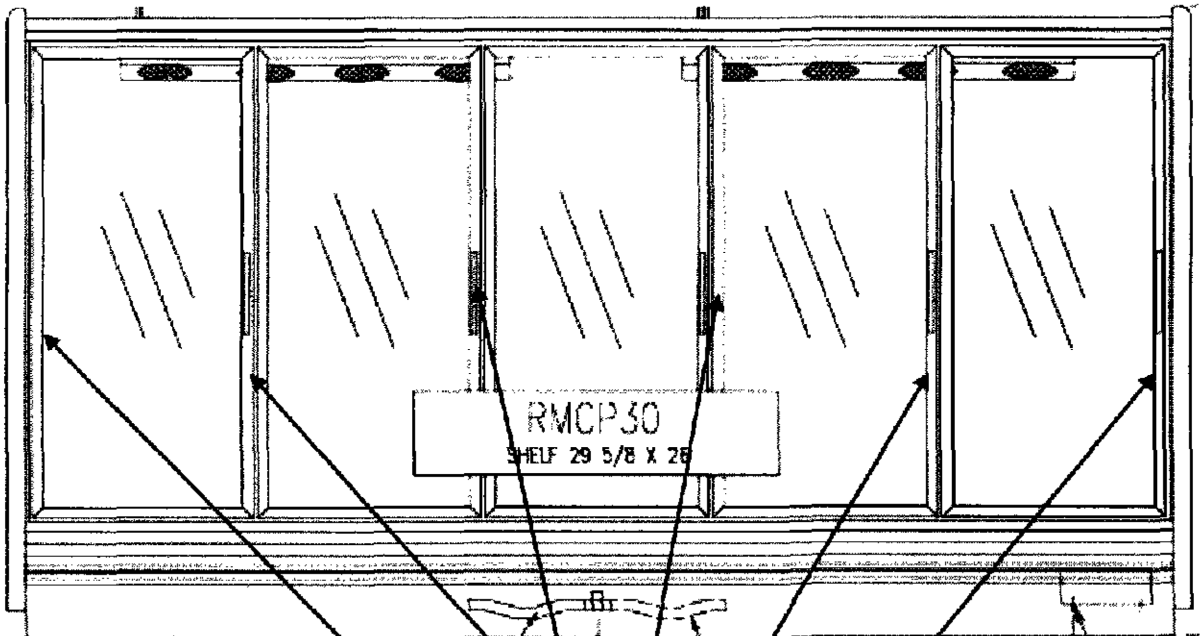
Efficient Refrigerated Case Options (ERCO)

Summary of Program

Pacific Gas and Electric Company®

Traditional Case Lighting

Frozen Food & Refrigerated cases are typically illuminated by fluorescent lighting



Lamps are located here

The lighting is located on either side of the door behind a mullion

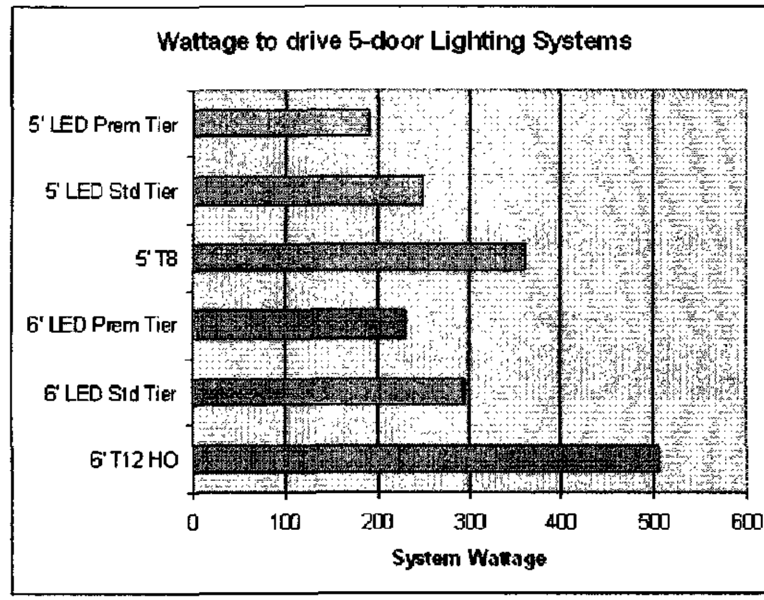
Rows or aisles of doors are built in modules ranging from 2-door modules to 6-door modules

If we look at a 5-door module we will find 6-lamps per module, one lamp at each end and one lamp between each door.

Cases also are differentiated by Low temperature (freezer) and Medium temperature (beverage).

Benefits of LED Case Lighting

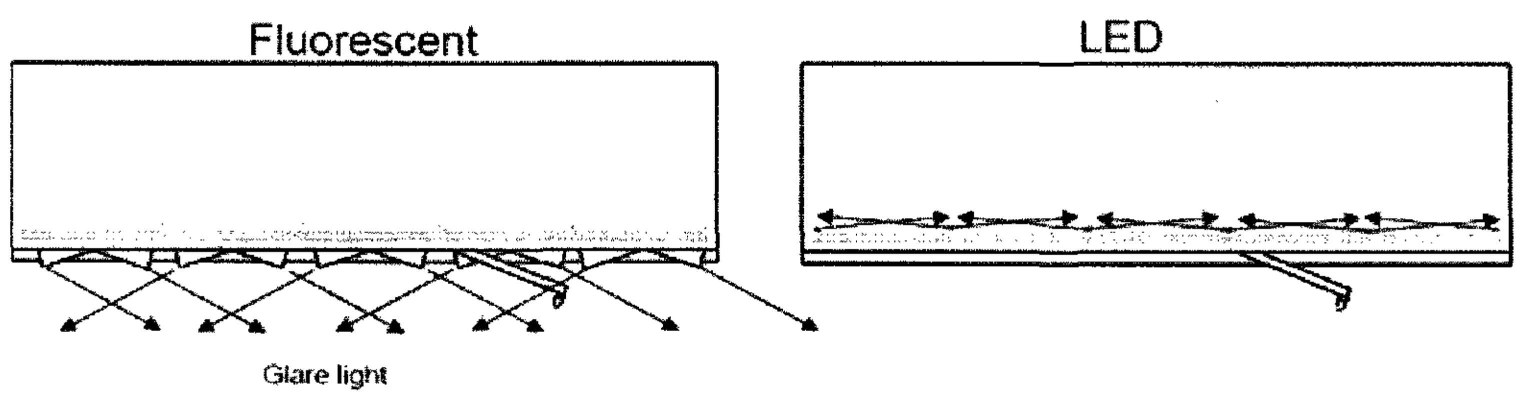
1. **Energy Savings** – depending on the existing light, LED refrigerated case lighting can save 30-60% of the energy usage as compared to the existing fluorescent lighting.



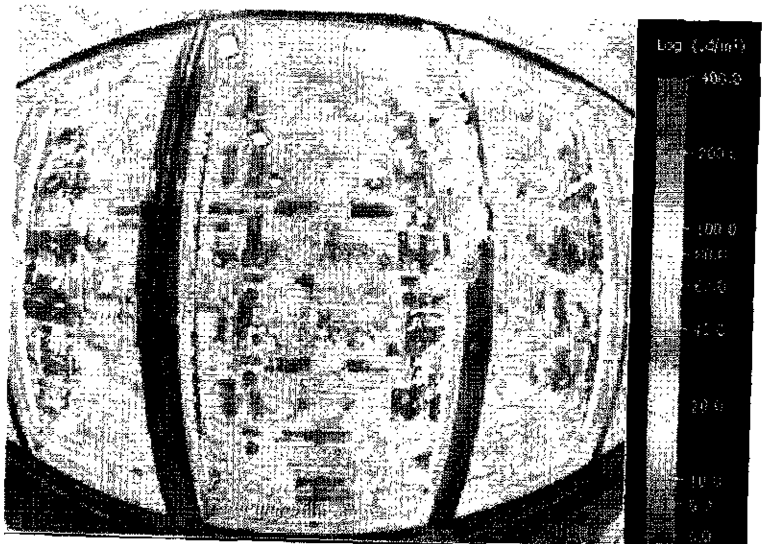
2. **Reduced Maintenance Costs** – 5 year warrantee and estimated 50,000 hour useful life (significantly longer than fluorescents) can dramatically reduce costs associated with maintenance over the lifetime of the product.

Benefits of LED Case Lighting

3. **Better for the Environment** – apart from the energy savings and long life, LEDs are highly durable and contain no mercury.
4. **Improved Product Visibility** – LEDs have directional lighting which limits glare and light loss. Converse to fluorescent operation, LEDs function better at cooler temperatures.

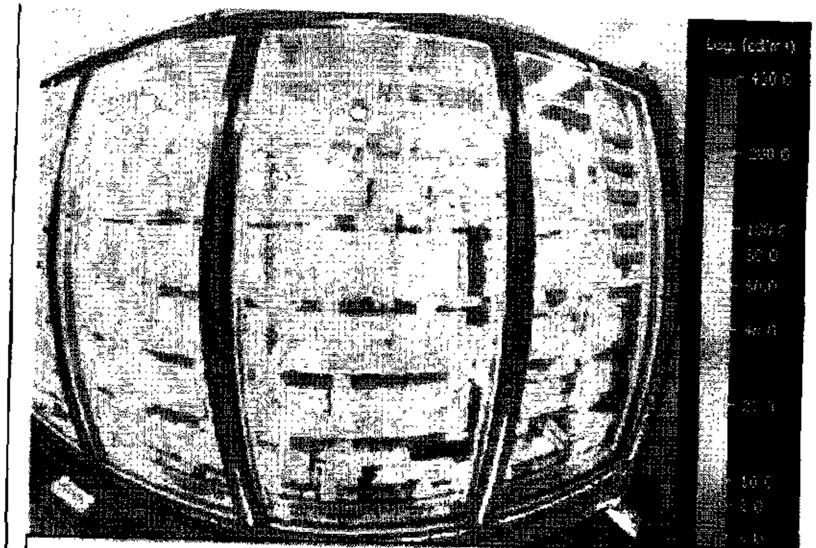


Benefits of LED Case Lighting



T8 Lighting

Door Average: 93.61
Center Average: 55.13
Left Side Average: 106.31
Right Side Average: 114.53
Both Sides Average: 112.97



LED Lighting

Door Average: 44.13
Center Average: 40.01
Left Side Average: 50.15
Right Side Average: 39.75
Both Sides Average: 45.54

Tiered Performance Levels

Product category	Lumens Per Watt	System Wattage	Incentive Amount
Premium LED Case Light replacing 6' Fluorescent	≥ 35	≤ 46	$100
Standard LED Case Light replacing 6' Fluorescent	≥ 25	≤ 59	$75
Premium LED Case Light replacing 5' Fluorescent	≥ 35	≤ 38	$65
Standard LED Case Light replacing 5' Fluorescent	≥ 25	≤ 50	$45

CRI = >70; Color <5700k; Power Supply Efficiency >85%;
PF >.90; THD <20%;
4 year Warranty

Lamp Wattage Options

Lighting Options - Input Wattage Per Frame Section							
Lighting System	Nom. Fixture Length	1-Door Watts	2-Door Watts	3-Door Watts	4-Door Watts	5-Door Watts	6-Door Watts
Fluorescent T8	72"	144.0	228.0	300.0	372.0	444.0	528.0
Fluorescent T8	**60"**	**120.0**	**180.0**	**228.0**	**288.0**	**348.0**	**408.0**
Fluorescent T12/HO	**72"**	**168.0**	**252.0**	**336.0**	**420.0**	**504.0**	**588.0**
Fluorescent T12/HO	60"	156.0	234.0	312.0	390.0	468.0	546.0
Fluorescent T10/VHO	72"	174.0	270.0	348.0	444.0	522.0	618.0
Fluorescent T10/VHO	60"	162.0	246.0	324.0	408.0	486.0	570.0
Average watts per door, 5' T8		120	90	**76**	72	70	68
Average watts per door, 6' T12HO		168	126	**112**	105	101	98
Best in class watts per door, 5' LED		42	40	39	39	39	38
Best in class watts per door, 6' LED		48	45	44	43	43	42
Max watts per door, 5' LED Premium Tier		38	38	38	38	38	38
Max watts per door, 5' LED		50	50	50	50	50	50
Max watts per door, 6' LED Premium Tier		46	46	46	46	46	46
Max watts per door, 6' LED		59	59	59	59	59	59

LED Refrigerated Case Work Paper
Summary Calculations

Base Case Lighting Energy Consumption				Proposed Case Lighting Energy Consumption			
System	W/ door	Annual operation (hrs/yr	Lighting kWh/Yr	System	W/ door	Annual operation (hrs/yr	kWh/Yr
5' fluorescent	76	6,570	499	5', premium efficiency	38	6,570	250
				5', standard efficiency	50	6,570	329
6' fluorescent	112	6,570	736	6', premium efficiency	46	6,570	302
				6', standard efficiency	59	6,570	388

Refrigerated Case Savings, Lighting and Compressor							
	Lighting			Refrigeration		Total	
System	Lighting load per door (W)	Annual operation (hrs/yr	Lighting Savings kWh	Refrigeration W saved per door	Refrigeration Savings kWh	Total load (kW)	Total kWh Savings
5', premium efficiency	38	6,570	249	13	84	0.051	333
5', standard efficiency	26	6,570	170	9	57	0.035	227
6', premium efficiency	66	6,570	434	22	143	0.088	577
6', standard efficiency	53	6,570	348	18	115	0.071	463

What has worked

- Manufacturers have stepped up
  - Hussmann, GE, Phillips, Electraled, 1Source Electric, Efficient Lights, Energy Solutions
- Door Method is working
  - Easy to count and inspect
- LM-79 at LTL and ITL have meet our needs
  - However we are seeing some inconsistencies between labs
- We are seeing advancements in the products
  - Lm/W has increased and wattage has dropped
  - Color is settling at 35k and 41k
  - Attention to uniformity and wider distribution
  - Control options available
  - Cost is coming down

What has come up

- Manufacturers and Labs aren't on the same page
  - Missing information
  - Increased testing costs
  - Inconsistencies in test procedures

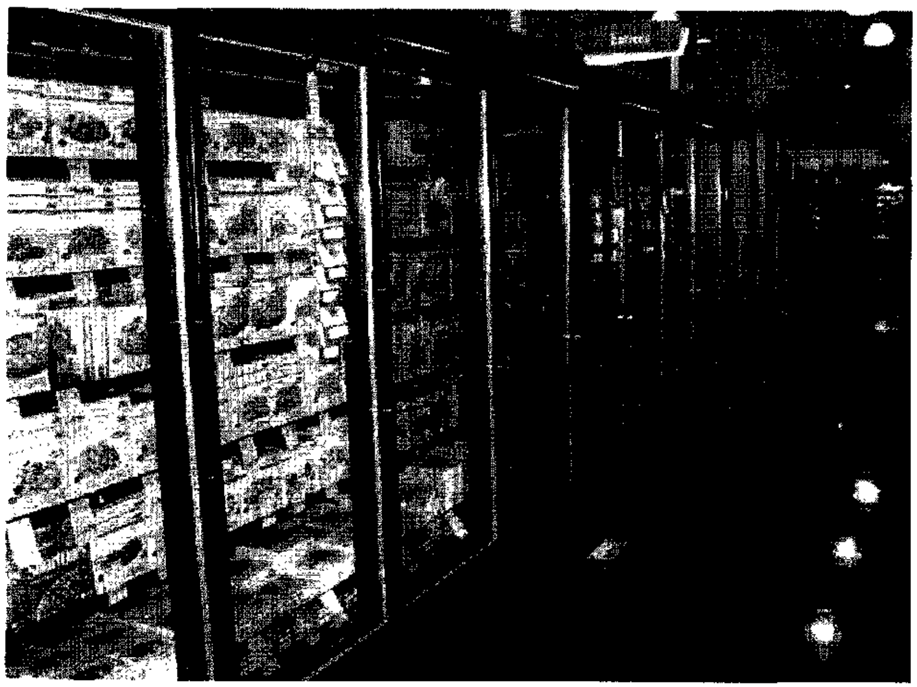
- Constant Voltage Power Supply loading has impact on efficiency
  - PER THE PG&E ERCO PROCEDURE FOR CONSTANT VOLTAGE LED RODUCTS,THE LUMINAIRE WAS TESTED WITH THE LED DRIVER OPERATING UNDER A SIMULATED FULL LOAD CONDITION, SPECIFIED BY THE LUMINAIRE MANUFACTURER AS TWO CENTER AND ONE END LUMINAIRE. IN ORDER TO DETERMINE EFFICACY, THE FULL LOAD LUMENS WERE EXTRAPOLATED BY MULTIPLYING THE MEASURED LUMEN OUTPUT OF THIS CENTER LED LUMINAIRE x 2 AND ADDED THE LUMEN OUPUT FROM ITL61639. THE SYSTEM EFFICACY WAS THEN CALCULATED BY DIVIDING THE EXTRAPOLATED FULL LOAD LUMENS BY THE MEASURED INPUT WATTAGE TO THE FULLY LOADED LED DRIVER.

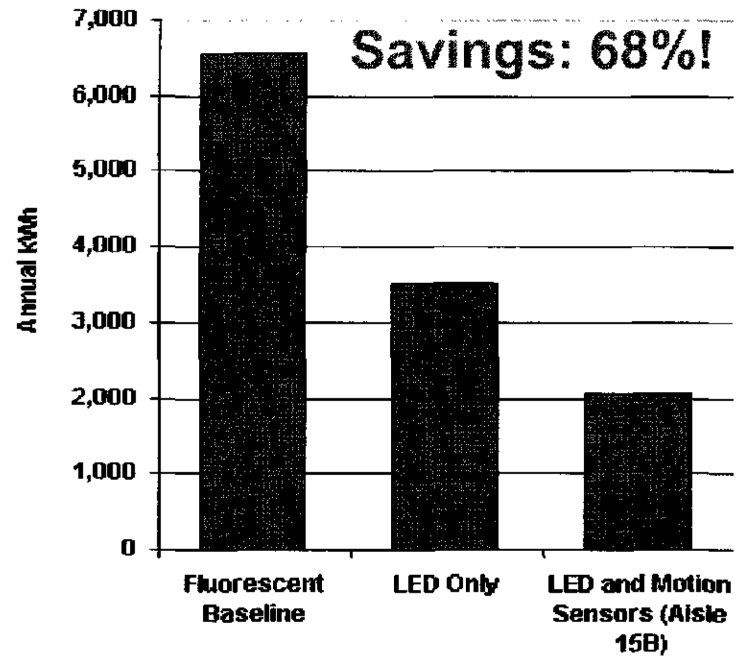
- Leading Power Factor
  - One manufacturer has been adamant that a leading PF of .50 should be preferred to lagging of >.90

- Trophy built products,

Lessons from the Field

- LEDs + motion sensors – a great application!

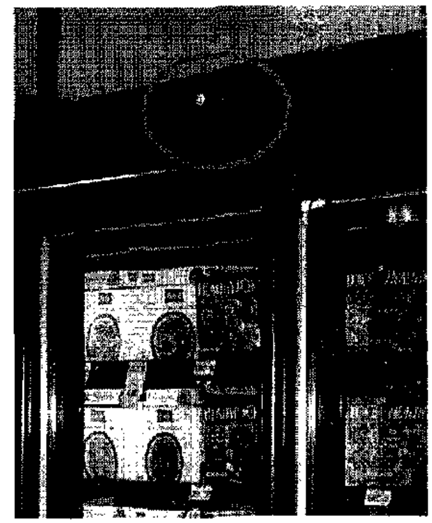




Lessons from the Field

About sensors:

- Dimming preferable to on/off systems.
- Ramping time should be ≤ 1 second.
- Sensors need to be specifically designed for food cases.
- Sensor location & adjustments impact savings potential & customer reaction.

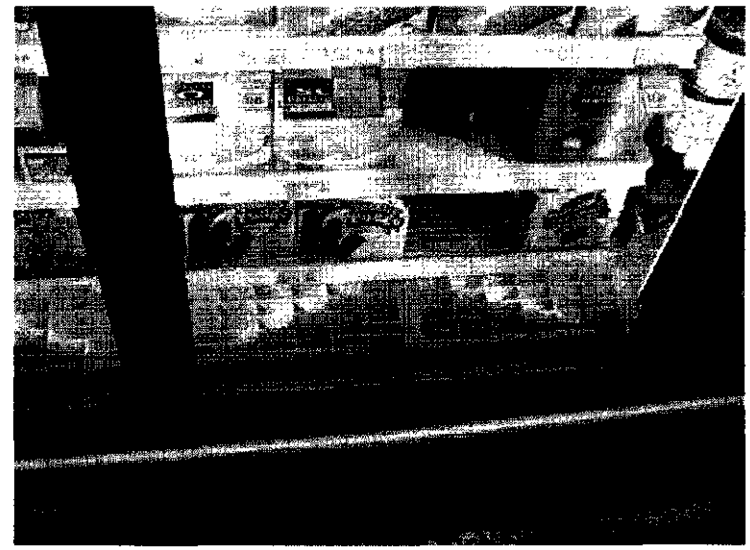


"SMUD survey found that 85% of customers in a grocery store are 'definitely not likely' or 'probably not likely' to buy products from a frozen food case with its light out because they were concerned about food safety."

Lessons from the Field

Optics: one size does not fit all

- Size, shape and shelving systems of food cases vary significantly – even cases from the same manufacturer.
- Even well-designed fixtures from respected manufacturers may not be right for every application.
- Recommend customers install a sample before making a major commitment.



Whole Foods Market, Sacramento, CA

Where were at

- Time to review specifications
  - Drop standard tier ?
  - Is 35 Lm/W the standard or Raise to 40 Lm/w?
  - Include Controls option
  - Require 5-year system warranty or,L_{70} at 50,000 hours
  - Is there LM-80 and In-situ testing available?
  - Is Power Supply Efficiency Necessary?

- Revise Qualification process
  - Drop Thermal Chamber test and rely on 25c LM-79
  - Develop better method to measure light bars and power supply in typical loaded conditions
    - Possible solution measure as 2-door system
      - One Center and Two End Bars

More information

- Links to our programs can be found at
- www.cainstantrebates.com/erco
- www.pge.com/led
- http://www.smud.org/en/business/rebates/Documents/2009LEDLightingSpecs.pdf

Thank you

Dave Alexander
Sr. Program Manager
Customer Energy Efficiency
Pacific Gas & Electric Company
DJAJ@pge.com

Dave Bisbee, CEM
Project Manager
Customer Advanced Technologies Program
Sacramento Municipal Utility District
dbisbee@smud.org

Attachment J:

"Compressed Air Analysis"

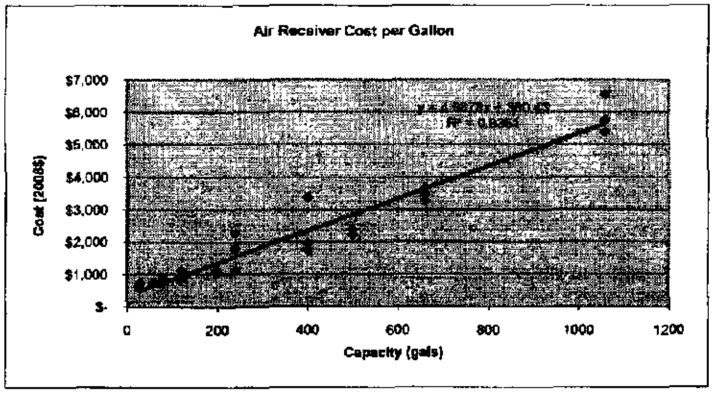
Air Receivers for Load/No Load Compressors

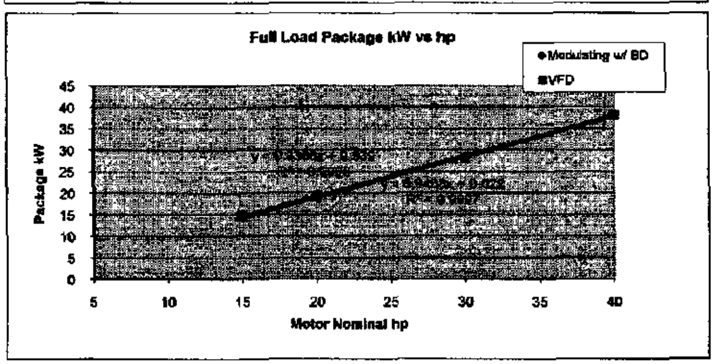
Approx. compressor capacity/hp: 4 cfm/hp

Assumptions:
1) Baseline: Rotary screw compressor with load/no load and 1 gal/cfm air receiver, or modulating w/ BD control
2) High Efficiency: Rotary screw compressor with load/no load control and 3 gal/cfm air receiver or greater
3) Full Load Package kW is nearly equal for compressors of the same nominal hp (regardless of control type)

Capacity (gals)	Price
30	$ 731.00
30	$ 567.00
60	$ 767.00
80	$ 905.00
80	$ 767.00
120	$ 1,132.00
120	$ 823.00
200	$ 1,130.00
240	$ 2,282.00
240	$ 1,781.00
240	$ 1,142.00
400	$ 3,371.00
400	$ 1,955.00
400	$ 1,770.00
500	$ 2,374.00
500	$ 2,222.00
660	$ 3,677.00
660	$ 3,464.00
660	$ 3,278.00
1060	$ 6,535.00
1060	$ 5,756.00
1060	$ 5,393.00
1550	$ 7,599.00

Source:
http://hansontank.us/airtanks.html
<accessed on 1/11/2008>





Source: "Compiled Data Request Results.xls"

Control System	Compressor Factors (CF)
Modulating w/ BD	0.890
Load/No Load w/ 1 gal/CFM	0.909
Load/No Load w/ 3 gal/CFM	0.831
Load/No Load w/ 5 gal/CFM	0.806

Source: "BHP Weighted Compressor Load Profiles.xls"

Algorithms:

Incremental Cost

Incremental Cost ($) = 5 x ($TANK_e$ - $TANK_b$) (see graph at left)

Where

5 = slope from linear regression
$TANK_e$ = Efficient tank size (gal)
$TANK_b$ = Existing tank size

kWh Savings

ΔkWh = (0.94 x Compressor Motor Nominal hp + 0.54) x HOURS x (CF_b - CF_e)
≈ 0.94 x Compressor Motor Nominal hp x HOURS x (CF_b - CF_e)

Where

0.95 and 0.54 = Compressor hp to Full Load kW conversion factor and offset, respectively (see graph at left)
HOURS = Total compressor operating hours
CF_e = Efficient Compressor Factor
CF_b = Baseline Compressor Factor

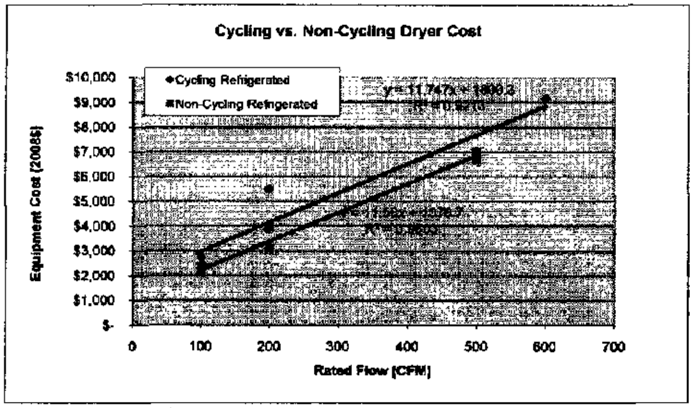
ΔkW = ΔkWh / HOURS

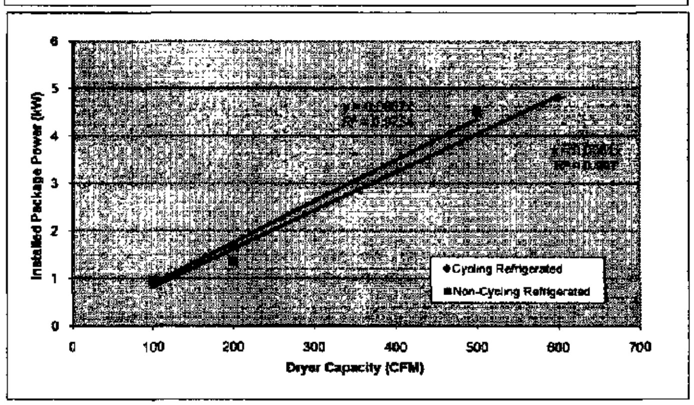
Savings Calculator:		
Compressor Nominal hp		25
HOURS		4160
CF_b		0.909
CF_e		0.806
$TANK_e$		500
$TANK_b$		100
ΔkWh:		10057
ΔkW:		2.42
Incremental Cost:	$	2,000
Cost per kWh Saved:	$	0.20

Cycling Refrigerated Air Dryers

Assumptions:

1) Baseline: Non-cycling refrigerated air dryer
2) High Efficiency: Cycling refrigerated air dryer
3) Installed Package kW is nearly equal for cycling and non-cycling refrigerated air dryers
4) Air dryers are sized to accommodate maximum compressor capacity





Source: "Compiled Data Request Results.xls"

Algorithms:

Incremental Cost (from graph at left)

Incremental Cost = 0.167 x Dryer Rated CFM + 732.6

= 0.167 x (Compressor Nominal hp x Compressor CFM/hp) + 732.6

= 750

kWh Savings

ΔkWh = [(Baseline Dryer kW x $HOURS_b$) - (Cycling Dryer kW x $HOURS_c$)] x Chilled Coil Response Time Derate

Where

$HOURS_b$ = Baseline Dryer hours of operation, same as compressor hours

$HOURS_c$ = Cycling Dryer hours of operation = $HOURS_b$ x Average %Capacity

Chilled Coil Response Time Derate = 0.925 (from Air Dryer Calc.xls)

Simplified kWh Savings

ΔkWh = (Compressor hp x Compressor CFM/hp) x 0.0087 x HOURS x (1 - Average %Capacity) x Chilled Coil Response Time Derate

Where

0.0087 = CFM to Baseline Dryer kW conversion factor (see graph at left)

Average %Capacity = 65% (from "BHP Weighted Compressed Air Load Profiles.xls")

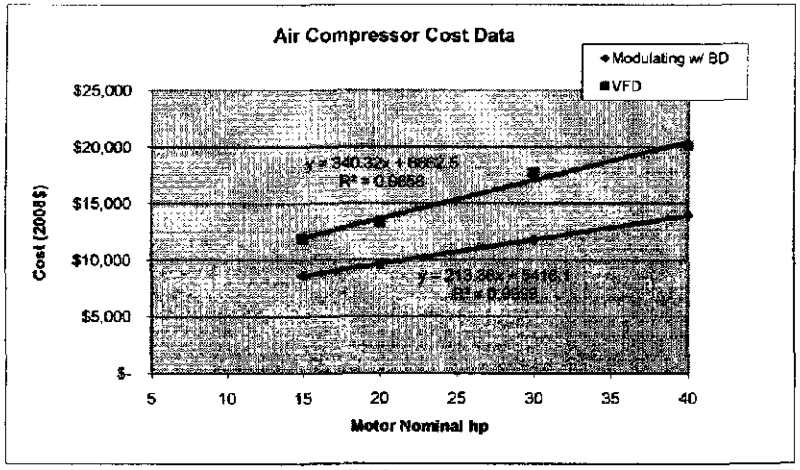
HOURS = Total compressor operating hours

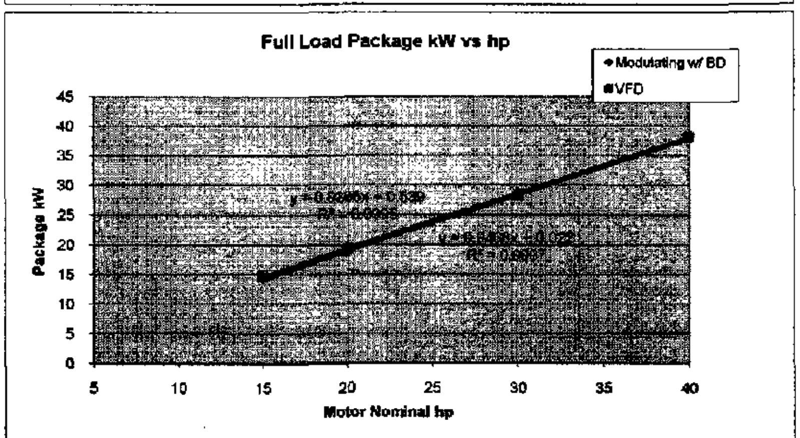
ΔkW = ΔkWh / HOURS

Savings Calculator:	
Compressor Nominal hp:	25
HOURS	4160
Baseline Dryer kW:	0.87
Average %Capacity:	65%
Chilled Coil Response Time Derate:	0.925
ΔkWh:	1171.716
ΔkW:	0.281663
Incremental Cost:	$ 750.00
Cost per kWh Saved:	$ 0.64

Efficient Compressors 40 hp and Below

Assumptions:
1) Baseline: Rotary screw compressor with modulating w/BD control
2) High Efficiency: Variable speed control
3) Full Load Package kW is nearly equal for compressors of the same nominal hp (regardless of control type)





Control System	Compressor Factors (CF)
Modulating w/ BD	0.890
Variable Speed Control	0.675

Source: "BHP Weighted Compressor Load Profiles.xls"

Algorithms:

Incremental Cost

Incremental Cost ($) = 127 x Compressor Motor Nominal hp + 1446 (see graph at left - incremental cost equation is tr

kWh Savings

ΔkWh = (0.94 x Compressor Motor Nominal hp + 0.54) x HOURS x (CF_b - CF_e)

= 0.94 x Compressor Motor Nominal hp x HOURS x (CF_b - CF_e)

Where

0.95 and 0.54 = Compressor hp to Full Load kW conversion factor and offset, respect
HOURS = Total compressor operating hours
CF_e = Efficient Compressor Factor
CF_b = Baseline Compressor Factor

ΔkW = ΔkWh/HOURS

Savings Calculator:		
Compressor Nominal hp		25
HOURS		4160
CF_b		0.890
CF_e		0.675
	ΔkWh:	21022
	ΔkW:	5.05
	Incremental Cost:	$ 4,621
	Cost per kWh Saved:	$ 0.22

ıe difference of the two linear regressions)

ively (see graph at left)

Air-Entraining Air Nozzles

Assumptions:

1) Baseline: Open copper tube or inefficient air gun @ 26 CFM (1/8" hole at 100 PSI)
2) High Efficiency: Air nozzles capable of amplifying the air stream 25 fold, blowgun mounted or stationary. Assume 14 CFM max.

Algorithms:

Incremental Cost
Incremental Cost = $14 per unit

kWh Savings
ΔkWh = (Baseline Nozzle CFM - Efficienct Nozzle CFM) x Compressor kW/CFM x HOURS x %USE
Where

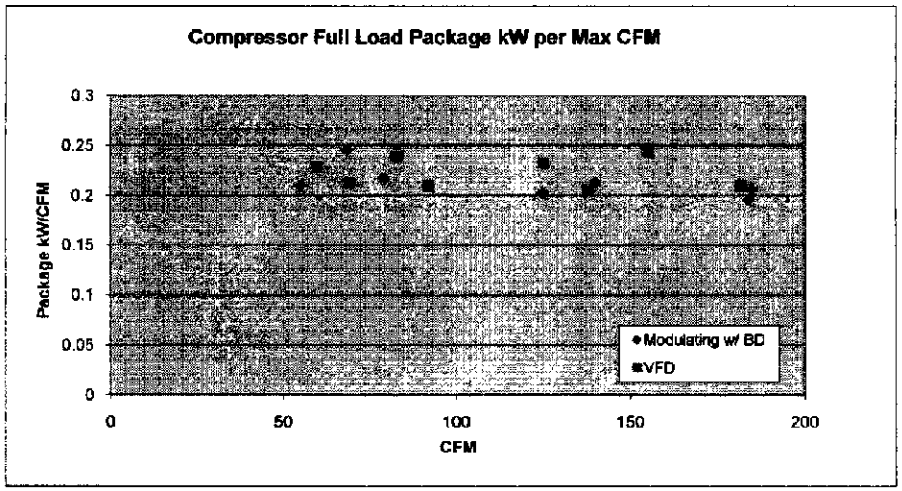
Baseline Nozzle CFM = 26
Efficient Nozzle CFM = 14
Compressor kW/CFM = 0.32 (assumes modulating w/BD compressor - see calculations below)
HOURS = compressor total operating hours
%USE = 5% (assume 3 second of operation per minute or 5% of total compressor operating hours)

ΔkW = ΔkWh / HOURS

Savings Calculator:		
Baseline Nozzle CFM:		26
Efficient Nozzle CFM:		14
Compressor kW/CFM:		0.32
HOURS:		4160
%USE:		5.0%
ΔkWh:		798.72
ΔkW:		0.19
Incremental Cost:	$	14.00
Cost per kWh Saved:	$	0.02

Equipment Cost			
Manufacturer	Model		Cost
AirTX	48008	$	15
ExAir	1009	$	13
Vortec	1200	$	13

Average Compressor kW/CFM Calculations:



Source: "Compiled Data Request Results.xls"

Compressor Full Load Package kW/Max CFM = 0.225
Average %Capacity = 65% (from "BHP Weighted Compressed Air Load Profiles.xls")
Modulating w/ BD Compressor %Full Load kW @ 65% Capacity = 92% (from "BHP Weighted Compressed Air Load Profiles.xls")
Average Compressor kW/CFM = "Full Load Package kW/Max CFM" x "%Full Load kW @ Average %Capacity" / "Average % Capacity" = 0.225 x (92%/65%) = 0.32

Calculations for other compressor types:

Compressor Full Load Package kW/Max CFM	0.225
Average %Capacity	65%

Compressor Control Type	%Full Load @ 65% Capacity	Average Compressor kW/CFM
Modulating w/ BD	92%	0.32
Load/No Load w/ 1 gal/CFM	94%	0.32
Load/No Load w/ 3 gal/CFM	86%	0.30
Load/No Load w/ 5 gal/CFM	82%	0.28
Variable Speed w/ Unloading	67%	0.23

No Loss Condensate Drains

Assumptions:

1) Baseline: Timer controlled valve to the atmosphere with set frequency and duration
2) High efficiency: Operate by sensing the condensate level and opening when necessary, and closing before any compressed air escapes

Algorithms:

Incremental Cost

Incremental Cost = $200 (see "Compiled Data Request Results.xls" for details)

kWh Savings

ΔkWh = Air Loss Rate x Compressor kW/CFM x OPEN x % Not Condensate

Where

Air Loss Rate = An hourly average rate dependent on the Drain Orifice Diameter and Pressure, expressed in CFM (see table below)
Compressor kW/CFM = The average amount of electrical demand in kW required to produce one cubic foot of air at 100 psi
OPEN = Hours per year the timed drain is open
% Not Condensate = Percentage of time compressed air escapes instead of condensate

Simplified kWh Savings

ΔkWh = Air Loss Rate x Compressor kW/CFM x OPEN x AF x % Not Condensate

Where

Air Loss Rate = 25.22 (analysis assumes 1/8" orifice diameter @ 100 psi)
Compressor kW/CFM = 0.32 (assumes modulating w/ BD compressor - see analysis in the "Nozzles" sheet for additional compressor types)
OPEN = 146 (assumes timed drain vents 10 seconds every 10 minutes)
AF = [(Total compressor operating hours + 8760) / 2] / 8760 (Assume timed drain operates 8760, but the actual number of hours that compressed a
% Not Condensate = 75% (EVT assumption)

ΔkW = ΔkWh / HOURS

Where

HOURS = compressor total operating hours

Savings Calculator:	
Air Loss Rate (CFM):	25.22
Compressor kW/CFM:	0.32
OPEN:	146.0
AF	0.74
% Not Condensate	75%
HOURS:	4160
ΔkWh:	645.0
ΔkW:	0.16
Incremental Cost:	$ 200.00
Cost per kWh Saved	$ 0.31

Compressor Control Type	%Full Load @ 65% Capacity	Average Compressor kW/CFM
Modulating w/ BD	92%	0.32
Load/No Load w/ 1 gal/CFM	94%	0.32
Load/No Load w/ 3 gal/CFM	86%	0.30
Load/No Load w/ 5 gal/CFM	82%	0.28
Variable Speed w/ Unloading	67%	0.23

Source: "Nozzles" sheet in this workbook

Leakage Rates (CFM)

Pressure (psig)	Orifice Diameter (inches)						
	1/64	1/32	1/16	1/8	1/4	3/8	
70	0.29	1.16	4.66	18.62	74.4	167.8	
80	0.32	1.26	5.24	20.76	83.1	187.2	
90	0.36	1.46	5.72	23.10	92.0	206.6	
95	0.38	1.51	6.02	24.16	96.5	216.8	*interpolated from original table*
100	0.40	1.55	6.31	25.22	100.9	227.0	
105	0.42	1.63	6.58	26.31	105.2	236.7	*interpolated from original table*
110	0.43	1.71	6.85	27.39	109.4	246.4	*interpolated from original table*
115	0.45	1.78	7.12	28.48	113.7	256.1	*interpolated from original table*
120	0.46	1.86	7.39	29.56	117.9	265.8	*interpolated from original table*
125	0.48	1.94	7.66	30.65	122.2	275.5	

Source: "Compressed Air Systems Analysis Tool v2a.xls"

›nting and leakage when the compressor is dowr

Measure	ΔkWh	ΔkW	Incremental Cost
Air Receiver	10057	2.42	$ 2,000.00
Dryers	1172	0.28	$ 750.00
Compressors	21022	5.05	$ 4,621.00
Nozzles	799	0.19	$ 14.00
Condensate Drains	645	0.16	$ 200.00

Attachment K:

"deeminglighting13nov09 evaluationreport"

Recommended Values

Building Use	Hours	CF
Food Sales	5,544	92%
Food Service	4,482	84%
Health Care	3,677	78%
Hotel/Motel	3,358	35%
Office	3,526	77%
Public Assembly	2,729	67%
Public Services	3,425	64%
Retail	4,226	84%
Warehouse	3,404	79%
School	2,302	52%
College	3,900	68%
Dormitory	986	7%
Industrial	4,745	77%
Agricultural	4,[illegible]	67%
Other	3,672	67%

Developing hours of use weighting factors

	PG&E 1996	DOE	RLW Schools	PG&E RightLig	SDG&E TOU	SDG&E 2006
Meters	0	0	600	184	431	150
Surveys	1,276	5,430	0	0	0	0
Sample Size	127	543	600	184	431	150
Weight	6%	27%	29%	9%	21%	7%

Hours values and weighted averages

Building Use	PG&E 1996*	DOE	RLW Schools	PG&E RightLig	SDG&E TOU	SDG&E 2006	Weighted Average
Food Sales	5,600	5,258		4,636	6,390	5,066	5,544
Food Service	4,600	4,589		4,278	4,450	4,305	4,482
Health Care	4,400	4,617			2,689	2,504	3,677
Hotel/Motel	5,500	5,857			2,307		3,358
Office	4,000	3,780		2,668	3,792	2,698	3,526
Public Assembly		2,885				2,861	2,729
Public Services (non-food)	3,400	3,431					3,425
Retail	4,450	4,258		1,421	5,436	3,840	4,228
Warehouse	3,580	3,705			3,211	3,250	3,404
School	2,150	2,774	2,147		1,795	2,785	2,302
College	3,900						3,900
Industrial		5,056		3,547	5,512	2,888	4,745
Other	4,500	3,723			3,667	2,804	3,672
Weight	6%	27%	29%	9%	21%	7%	100%

* PG&E Public Service is an average of the values reported for Personal and Community Service

Dormitory hours of use and coincidence factor are based on the values used by the Residential deemed savings.

Hours of use	986
Coincidence Factor	7%

CF values and weighted averages

Building Use	PG&E 1996	RLW Schools	RLW CF	SDG&E Time of Use	Weighted Average*
Food Sales	81%		95%	90%	92%
Food Service	68%		81%	96%	84%
Health Care	74%		77%	82%	78%
Hotel/Motel	67%			23%	35%
Office	61%		75%	78%	77%
Public Assembly					67%
Public Services (non-food)	64%				64%
Retail	86%		82%	86%	84%
Warehouse	84%		78%	79%	79%
School	42%	33%	63%	53%	52%
College	68%		68%		68%
Industrial			73%	85%	77%
Other	70%		54%	88%	67%
Weighting Factor	9%	21%	46%	24%	100%

* The "Other" value was assigned to Public Assembly because there were no sources for that building type.

Coincidence Factor weighting system

	PG&E 1996	RLW Schools	RLW CF	SDG&E Time of	Focus
Peak Months	May-Oct	Jun-Sept	Jun-Aug	May-Sept	Jun-Aug
Peak hours	12 - 6 pm	3 - 5 pm	1 - 5 pm	1 - 4 pm	1 - 4 pm
Total Peak Hours	1,104	244	368	459	276
Hours in Focus Peak	276	92	276	276	276
Percent in Focus Peak	25%	38%	75%	60%	100%
Peak Period Weighting Factor	13%	19%	38%	30%	
Sample Size	127	600	1,415	431	
Sample Size Weighting Factor	5%	23%	55%	17%	
Overall Weighting Factor	9%	21%	46%	24%	

Development of agriculture values

Sample of Agriculture Customers from Impact Evaluations

Project/Lamp Type	Hours per Day	Quantity	CF	ToD
1/1	12	7	0.00	Night
2/1	3.5	13	0.29	Day
3/1				
4/1	5	5	0.28	?
5/1	17.5	26	1.00	Day
6/1	3	3	0.17	?
1/2	12	8	0.00	Night
2/2	3.5	12	0.29	Day
3/2				
4/2	6	20	0.28	?
5/2	17.5	38	1.00	Day
6/2	3	9	0.17	?
1/3	4	35	0.00	Night
2/3				
3/3	12	10	0.00	Night
4/3	8	12	0.44	?
5/3	17.5	82	1.00	Day
6/3	16	84	0.89	?
Total/Avg	12.9	362	67%	
Avg Hours/yr	4,[illegible]			
CF	67%			

Coincidence factor multipliers		
Day	divide hours by:	12
Unknown (?)	divide hours by:	18
Night	divide hours by:	n/a (CF=0)

Recommended Savings

Building Use	Hours	CF	Proposed Deemed Savings			
			2.0810.170		2.0811.170	
			kW	kWh	kW	kWh
Food Sales	5,544	82%	0.0214	129	0.1085	651
Food Service	4,452	84%	0.0190	104	0.1001	534
Health Care	3,677	78%	0.0182	88	0.0931	436
Hotel/Motel	3,356	35%	0.0081	78	0.0416	400
Office	3,526	77%	0.0178	82	0.0912	420
Public Assembly	2,729	67%	0.0155	64	0.0794	326
Public Services	3,425	64%	0.0148	80	0.0757	408
Retail	4,226	84%	0.0197	98	0.1006	503
Warehouse	3,464	79%	0.0184	81	0.0941	413
School	2,302	52%	0.0122	54	0.0625	274
College	3,900	68%	0.0159	91	0.0810	465
Dorms	986	7%	0.0016	23	0.0083	117
Industrial	4,745	77%	0.0180	111	0.0918	565
Agricultural	4,698	67%	0.0156	110	0.0797	560
Other	3,672	67%	0.0155	86	0.0794	438

Tech Code	Measure Description	Existing Watts	New Watts	change in watts
2.0810.170	T8 4L-4ft High Performance Replacing T12 2L-8ft	123	100	23
2.0811.170	T8 4L-4ft High Performance Replacing T12HO/VHO 2L-8 ft	226	107	119

Lighting Rep. Conversations on VHO vs. HO

Interview:	Location	Installed Fixtures % VHO	Installed Fixtures % HO
Gene Scholler with Sylvania Lighting Services	Milwaukee	8%	92%
Neher Lightbulbs (sales representative)	Milwaukee	15%	85%
Brian with Gexpro Lightbulbs	Wauwatosa	10%	90%
	Average	11%	89%

Proposed Values for Existing Watts

Fixture Type	Input Wattage	Weighting	Measure	Input Watts
T12	123	N/A	2.0180.170	123
T12HO	207	89%	2.0181.170	226
T12VHO	380	11%		

T12 Fixture Watts (updated May 2009)

Fixture Type	Watts
(1) 4' Lamp	42
(2) 4' Lamp	72
(3) 4' Lamp	115
(4) 4' Lamp	144
(1) 8' HO Lamp	122
(1) 8' VHO Lamp	205
(2) 8' Lamp	123
(2) 8' HO Lamp	207
(2) 8' VHO Lamp	380

new wattages

Average ballast factors from WiSeerts

Measure	Projects Reviewed	% of Total Projects	Avg. Ballast Factor
2.0810.170	6	22%	0.80
2.0811.170	25	46%	0.87

Proposed New Fixture Wattages

BF Category	Ballast Factor	Input Watts at BF=1.00	Proposed Input Wattage
Low	0.80	125	100
Normal	0.87	123	107

Input Watts at BF=1.00 above are calculated from CEE data that gives values for Ballast Efficacy Factor (BE
BEF is used to convert CEE average fixture wattages to average input wattages, as if the BF is 1.00.
Qualifying Products - High-Performance 120 and 277V T8 Ballasts CEE High-Performance Commercial Lighting Systems Initiative. Updated 03/31/09.

Recommended Savings

Building Use	Hours	CF	2.5170.170		2.5180.170		2.5182.170		2.5185.170		2.5186.170	
			kW	kWh	kW	kWh	kW	kWh	kW	kWh	kW	kWh
Food Sales	5,544	92%	0.1388	837	0.2265	1,366	0.0952	574	0.6592	3,975	0.5016	3,025
Food Service	4,482	84%	0.1269	677	0.2070	1,104	0.0870	464	0.6025	3,214	0.4584	2,445
Health Care	3,677	78%	0.1180	555	0.1925	906	0.0809	381	0.5604	2,636	0.4264	2,006
Hotel/Motel	3,356	35%	0.0528	507	0.0861	827	0.0362	347	0.2505	2,406	0.1906	1,831
Office	3,526	77%	0.1156	532	0.1886	869	0.0793	365	0.5489	2,528	0.4177	1,923
Public Assembly	2,729	67%	0.1006	412	0.1641	672	0.0690	283	0.4776	1,956	0.3634	1,489
Public Services	3,425	64%	0.0959	517	0.1564	844	0.0657	355	0.4552	2,456	0.3464	1,869
Retail	4,226	84%	0.1275	638	0.2081	1,041	0.0875	438	0.6056	3,030	0.4608	2,305
Warehouse	3,464	79%	0.1192	523	0.1945	853	0.0818	359	0.5661	2,484	0.4306	1,890
School	2,302	52%	0.0792	347	0.1292	567	0.0543	238	0.3760	1,650	0.2861	1,256
College	3,900	68%	0.1026	589	0.1676	961	0.0704	404	0.4875	2,796	0.3710	2,128
Dormitory	986	7%	0.0106	149	0.0172	243	0.0072	102	0.0502	707	0.0382	538
Industrial	4,745	77%	0.1163	716	0.1898	1,169	0.0798	491	0.5523	3,402	0.4203	2,589
Agricultural	4,698	67%	0.1010	709	0.1648	1,157	0.0693	486	0.4797	3,368	0.3650	2,563
Other	3,672	67%	0.1006	554	0.1641	905	0.0690	380	0.4776	2,633	0.3634	2,003

Tech Code	Measure Description	New Watts	Old Watts
2.5170.170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	295
2.5180.170	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	458
2.5182.170	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	462
2.5185.170	T8/T5HO <= 500 Watts Replacing >=1000 W HID	363	1,080
2.5186.170	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	1,080

Existing Fixture Wattages

Fixture Type	Watts	to 2/4 lamp	to 4/6 lamp	to 6/8 lamp	<=500W	501-800W
1000W HPS	1,100	0%	0%	0%	2%	2%
400W HPS	465	0%	3%	3%	0%	0%
250W HPS	295	3%	0%	0%	0%	0%
400W MV	455	0%	1%	1%	0%	0%
250W MV	290	1%	0%	0%	0%	0%
1000W MH	1,080	0%	0%	0%	98%	98%
750W MH	850	0%	0%	1%	0%	0%
400W MH	458	0%	96%	95%	0%	0%
250W MH	295	96%	0%	0%	0%	0%
750W PS MH	816	0%	0%	0%	0%	0%
320W PS MH	365	0%	0%	0%	0%	0%
250W PS MH	288	0%	0%	0%	0%	0%
Total:		100%	100%	100%	100%	100%
Average Watts:		295 W	458 W	462 W	1080 W	1080 W

* Watts taken from SPC. Percentages are based on a sample from WISeerts.

New Fixture Wattages

Fixture Type	Watts	250-399W to 2/4 lamp	400-999W to 4/6 lamp	400-999W to 6/8 lamp	1000W+ to <=500W	1000W+ to 501-800W
4L F32T8 HBF	144	100%	2%	0%	0%	0%
6L F32T8 HBF	222	0%	48%	0%	7%	0%
8L F32T8 HBF	288	0%	0%	2%	13%	0%
16L F32T8 HBF	576	0%	0%	0%	0%	28%
2L F54T5 HO	119	0%	13%	0%	0%	0%
4L F54T5 HO	237	0%	37%	0%	3%	0%
6L F54T5 HO	360	0%	0%	98%	54%	0%
(2) 4L F54T5 HO	474	0%	0%	0%	2%	0%
8L F54T5 HO	474	0%	0%	0%	21%	0%
10L F54T5 HO	593	0%	0%	0%	0%	63%
(2) 6L F54T5 HO	720	0%	0%	0%	0%	9%
Total:		100%	100%	100%	100%	100%
Average Watts:		144 W	212 W	359 W	363 W	535 W

* Watts taken from Advance Atlas, percentages from a WISeerts sample.

Recommended Savings

		Space Type					
		kWh Savings					
Building Type	Hours	Gymnasium	Industrial	Retail	Warehouse	Public Assembly	Other
Food Sales	5,544	517	591	197	701	618	525
Food Service	4,482	418	478	159	567	499	424
Health Care	3,677	343	392	131	465	410	348
Hotel/Motel	3,356	313	358	119	424	374	318
Office	3,526	329	376	125	446	393	334
Public Assembly	2,729	254	291	97	345	304	258
Public Services	3,425	319	365	122	433	382	324
Retail	4,226	394	451	150	534	471	400
Warehouse	3,464	323	370	123	438	386	328
School	2,302	215	246	82	291	256	218
College	3,900	364	416	139	493	434	369
Dormitory	988	92	105	35	125	110	93
Industrial	4,745	442	506	169	600	529	449
Agriculture	4,698	438	501	167	594	523	445
Other	3,672	342	392	131	464	409	348
Percent Off		39%	45%	15%	53%	47%	40%
Coincidence Factor		15%	18%	6%	18%	12%	14%
kW Savings		0.0344	0.0427	0.0142	0.0427	0.0284	0.0325

Wattage from High Bay Fluorescent Measure

Tech Code	Measure Description	New Watts	Old Watts
2.5170.170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	295
2.5180.170	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	458
2.5182.170	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	462
2.5185.170	T8/T5HO <= 500 Watts Replacing >=1000 W HID	363	1,080
2.5186.170	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	1,080

Developing Average Wattage from WISeerts Data

			Ag		Com		Ind		S&G		Total	
Tech Code	Measure Description	Watts	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent
2.5170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	196	13.9%	1,230	5.1%	5,080	9.7%	1,062	18.5%	7,568	9.0%
2.5180	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	1,038	73.5%	14,739	61.4%	39,381	74.9%	4,043	70.4%	59,199	70.7%
2.5182	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	177	12.6%	7,290	30.4%	5,440	10.3%	531	9.2%	13,438	16.0%
2.5185	T8 or T5HO <= 500W, Replacing >=1000 W HID	363	-	0.0%	601	2.5%	2,327	4.4%	63	1.1%	2,991	3.6%
2.5186	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	-	0.0%	150	0.6%	381	0.7%	43	0.7%	574	0.7%
	Total/Average Watts:		1,409	221	24,010	259	52,609	230	5,742	217	83,770	237

* Extraction from WISeerts 04/2009

Recommended Savings

Building Use	Hours*	CF	CFL <33 W kW	CFL <33 W kWh	CFL Reflector Flood kW	CFL Reflector Flood kWh
Food Sales	5,544	92%	0.0512	309	0.0449	273
Food Service	4,442	84%	0.0468	250	0.0410	219
Health Care	3,677	78%	0.0435	205	0.0382	180
Hotel/Motel	3,356	35%	0.0195	167	0.0171	164
Office	3,528	77%	0.0426	196	0.0374	172
Public Assembly	2,729	67%	0.0371	152	0.0325	133
Public Services	3,425	64%	0.0354	181	0.0310	167
Retail	4,226	84%	0.0470	236	0.0412	208
Warehouse	3,464	79%	0.0440	193	0.0386	169
School	2,302	52%	0.0292	128	0.0256	112
College	3,900	68%	0.0378	217	0.0332	190
Dormitory	986	7%	0.0039	55	0.0034	48
Industrial	4,745	77%	0.0429	264	0.0376	232
Agricultural	2,450	67%	0.0373	136	0.0327	120
Other	3,472	67%	0.0371	206	0.0326	179

* Ag hours of use from CATI Analysis below. All others are standard hours of use

Tech Code	Measure Description	New Watts	Old Watts
2.0300.1650	CFL <= 32W, replacing incandescent <= 100W	20.0	75.7
2.0307.1650	CFL reflector flood lamps <=30W replacing incandescent reflector flood lamps <=100W	17.5	66.3

* Wattages are the average of those from CATI surveys for 18MCP, FY06, and FY04

Recommended Savings for Related Measures, kW

WISerts Tech Code	Measure Description	New Watts	Old Watts	Food Sales	Food Service	Health Care	Hotel/Motel	Office	Public Assembly	Public Services (Non food)	Retail	Warehouse	School	College	Industrial	Agriculture	Other	Dorms
2.0301.165	CFL High Wattage 31-115 Watts, replacing incandescent	65.0	200.0	0.124	0.113	0.106	0.047	0.108	0.090	0.088	0.114	0.107	0.071	0.092	0.104	0.090	0.090	0.009
2.0305.060	CFL Cold Cathode Screw-in, replacing incandescent	4.0	36.0	0.019	0.018	0.016	0.007	0.016	0.014	0.013	0.018	0.017	0.011	0.014	0.016	0.014	0.014	0.001
2.0310.165	CFL Direct install, replacing incandescent, WPS Hometown Checkup	20.0	75.7	0.051	0.047	0.044	0.019	0.043	0.037	0.035	0.047	0.044	0.029	0.038	0.043	0.037	0.037	0.004
2.0400.165	CFL Fixture, replacing incandescent fixture																	
n/a	Replace incandescent lamps with 14 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent lamps with 20 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent lamps with 23 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent spotlight lamps with 18 Watt spotlight compact fluorescent lamps, WPS Hometown Checkup																	
	Coincidence Factor			92%	84%	78%	35%	77%	67%	64%	84%	79%	52%	68%	77%	67%	67%	7%

Recommended Savings for Related Measures, kWh

WISerts Tech Code	Measure Description	New Watts	Old Watts	Food Sales	Food Service	Health Care	Hotel/Motel	Office	Public Assembly	Public Services (non food)	Retail	Warehouse	School	College	Industrial	Agriculture	Other	Dorms
2.0301.165	CFL High Wattage 31-115 Watts, replacing incandescent	65.0	200.0	749	605	496	453	476	366	482	570	468	311	527	641	331	498	133
2.0305.060	CFL Cold Cathode Screw-in, replacing incandescent	4.0	25.0	116	94	77	70	74	57	72	89	73	48	82	100	51	77	21
2.0310.165	CFL Direct install, replacing incandescent, WPS Hometown Checkup	20.0	75.7	309	250	205	157	196	152	181	236	193	128	217	264	136	205	35
2.0400.165	CFL Fixture, replacing incandescent fixture																	
n/a	Replace incandescent lamps with 14 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent lamps with 20 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent lamps with 23 Watt compact fluorescent lamps, WPS Hometown Checkup																	
n/a	Replace incandescent spotlight lamps with 18 Watt spotlight compact fluorescent lamps, WPS Hometown Checkup																	
	Hours of Use			5,544	4,442	3,677	3,356	3,528	2,729	3,425	4,226	3,464	2,302	3,900	4,745	2,450	3,472	986

CATI Survey Analysis

period	program	_FREQ_	withn	without	avg_deltaw	avg_weekly_ophrs	Annual Hours
18 MCP	1	36	20.6	79.4	60.0	55.7	2,892
FY04	1	25	19.2	70.6	54.9	35.6	1,856
FY06	1	5	18.3	71.3	52.0	44.8	2,327
	2	60	19.5	74.4	54.9	64.0	3,337
18 MCP							
FY04	2	23	20.0	71.1	51.1	49.9	2,604
FY06	5	101	20.2	77.5	57.3	61.7	3,216
18 MCP	overall	96	19.9	78.5	58.6	60.6	3,158
FY04	overall	48	19.6	70.6	50.9	43.6	2,271
FY06	overall	109	20.2	77.1	57.0	60.8	3,170

program	sector	FREQ	withn	without	avg_deltaw	avg_ophrs	Annual Hours
1	Ag	69	19.9	75.1	55.2	47.1	2,450
2	Comm	83	19.7	73.5	53.8	60.1	3,125
5	Channel	101	20.2	77.6	57.3	61.7	3,207
	Overall	253	20.0	75.7	55.7	57.4	2,987

Reflector Flood Lamp Analysis

Sector	Sample	Total	Percent	Avg. Watts
Agriculture	6	6	100%	15
Commercial	7,160	26,471	27%	18.4
Industrial	162	281	58%	14.1
Schools & Gov't	6,420	7,350	87%	14.4
Total/Average	13,778	34,108	40%	17.8

WISerts data used to produce average CFL flood wattage [illegible]

Alternate Recommended Hours and CF by Sector

Sector	Hours	CF
Agriculture	4,698	67%
Commercial	3,730	77%
Industrial	4,745	77%
Schools-Gov't	3,238	64%

hours and cf by building type

Building Use	Hours	CF
Food Sales	5,544	92%
Food Service	4,482	84%
Health Care	3,677	78%
Hotel/Motel	3,356	35%
Office	3,526	77%
Public Assembly	2,729	67%
Public Services	3,425	64%
Retail	4,226	84%
Warehouse	3,484	79%
School	2,302	52%
College	3,900	68%
Dormitory	986	7%
Industrial	4,745	77%
Agricultural	4,698	67%
Other	3,672	67%

commercial hours weighted average

Building Use	Weight	Average Hours
Food Sales	3.60%	5,544
Food Service	3.60%	4,482
Health Care	8.50%	3,677
Hotel/Motel	6.00%	3,356
Office	25.30%	3,526
Public Assembly	7.30%	2,729
Public Services (non-food)	6.00%	3,425
Retail	24.00%	4,226
Warehouse	15.70%	3,484
Average	**100%**	**3,730**

* Weights based on DOE study

commercial CF weighted average

Building Use	Weight	Average CF
Food Sales	3.90%	92%
Food Service	3.90%	84%
Health Care	9.20%	78%
Hotel/Motel	6.50%	35%
Office	27.30%	77%
Public Services (non-food)	6.50%	64%
Retail	25.80%	84%
Warehouse	16.90%	79%
Average	**100%**	**77%**

* Weights based on DOE study

S&G weighted average

Building Use	Weight	Average Hours	Average CF
Office	23%	3,526	77%
School	36%	2,302	52%
College	41%	3,900	68%
Average	**100%**	**3,238**	**64%**

* Weights based on WISeerts analysis

Alternate Recommended Savings Using CF/Hours by Sector

Sector	Hours	CF	Proposed Deemed Savings			
			2.0810.170		2.0811.170	
			kW	kWh	kW	kWh
Agriculture	4,698	67%	0.0160	110	0.0797	550
Commercial	3,730	77%	0.0179	67	0.0912	[illegible]
Industrial	4,345	77%	0.0180	111	0.0918	[illegible]
Schools-Gov't	3,238	64%	0.0150	75	0.0767	388

Tech Code	Measure Description	Existing Watts	New Watts	change in watts
2.0810.170	T8-4L-4ft High Performance Replacing T12 2L-8ft	123	100	23
2.0811.170	T8-4L-4ft High Performance Replacing T12HO/VHO 2L-8ft	226	107	119

Lighting Rep. Conversations on VHO vs. HO

Interview:	Location	Installed Fixtures % VHO	Installed Fixtures % HO
Gene Scholler with Sylvania Lighting Services	Milwaukee	8%	92%
Neher Lightbulbs (sales representative)	Milwaukee	15%	85%
Brian with Gexpro Lightbulbs	Wauwatosa	10%	90%
	Average	11%	89%

Proposed Values for Existing Watts

Fixture Type	Input Wattage	Weighting	Measure	Input Watts
T12	123	N/A	2.0180.170	123
T12HO	207	88%	2.0181.170	226
T12VHO	380	11%		

T12 Fixture Watts (updated May 2009)

Fixture Type	Watts
(1) 4' Lamp	42
(2) 4' Lamp	72
(3) 4' Lamp	115
(4) 4' Lamp	144
(1) 8' HO Lamp	122
(1) 8' VHO Lamp	205
(2) 8' Lamp	123
(2) 8' HO Lamp	207
(2) 8' VHO Lamp	380

new wattages

Average ballast factors from WISeerts

Measure	Projects Reviewed	% of Total Projects	Avg. Ballast Factor
2.0810.170	8	22%	0.80
2.0811.170	28	46%	0.87

Proposed New Fixture Wattages

BF Category	Ballast Factor	Input Watts at BF=1.00	Proposed Input Wattage
Low	0.80	125	100
Normal	0.87	123	107

Input Watts at BF=1.00 above are calculated from CEE data that gives values for Ballast Efficacy Factor (BEF).

BEF is used to convert CEE average fixture wattages to average input wattages, as if the BF is 1.00.

Qualifying Products - High-Performance 120 and 277V T8 Ballasts, CEE High-Performance Commercial Lighting Systems Initiative. Updated 03/31/09.

Alternate Recommended Savings Using CF/Hours by Sector

Sector	Hours	CF	2.5170.170		2.5180.170		2.5182.170		2.5185.170		2.5186.170	
			kW	kWh	kW	kWh	kW	kWh	kW	kWh	kW	kWh
Agriculture	4,898	67%	0.1010	709	0.1648	1,157	0.0693	486	0.4797	3,368	0.3650	2,563
Commercial	3,730	77%	0.1156	563	0.1886	919	0.0793	386	0.5490	2,674	0.4178	2,035
Industrial	4,745	77%	0.1163	718	0.1898	1,169	0.0798	491	0.5523	3,402	0.4203	2,589
Schools-Gov't	3,238	64%	0.0972	489	0.1586	798	0.0666	335	0.4615	2,322	0.3512	1,767

Tech Code	Measure Description	New Watts	Old Watts
2.5170.170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	295
2.5180.170	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	458
2.5182.170	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	462
2.5185.170	T8/T5HO <= 500 Watts Replacing >=1000 W HID	363	1,080
2.5188.170	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	1,080

Existing Fixture Wattages

Fixture Type	Watts	to 2/4 lamp	to 4/6 lamp	to 6/8 lamp	<=500W	501-800W
1000W HPS	1,100	0%	0%	0%	2%	2%
400W HPS	465	0%	3%	3%	0%	0%
250W HPS	295	3%	0%	0%	0%	0%
400W MV	455	0%	1%	1%	0%	0%
250W MV	290	1%	0%	0%	0%	0%
1000W MH	1,080	0%	0%	0%	98%	98%
750W MH	850	0%	0%	1%	0%	0%
400W MH	458	0%	96%	95%	0%	0%
250W MH	295	96%	0%	0%	0%	0%
750W PS MH	818	0%	0%	0%	0%	0%
320W PS MH	365	0%	0%	0%	0%	0%
250W PS MH	288	0%	0%	0%	0%	0%
Total:		100%	100%	100%	100%	100%
Average Watts:		295 W	458 W	462 W	1080 W	1080 W

* Watts taken from SPC. Percentages are based on a sample from WISeerts.

New Fixture Wattages

Fixture Type	Watts	250-399W to 2/4 lamp	400-999W to 4/6 lamp	400-999W to 6/8 lamp	1000W+ to <=500W	1000W+ to 501-800W
4L F32T8 HBF	144	100%	2%	0%	0%	0%
6L F32T8 HBF	222	0%	48%	0%	7%	0%
8L F32T8 HBF	288	0%	0%	2%	13%	0%
16L F32T8 HBF	576	0%	0%	0%	0%	28%
2L F54T5 HO	119	0%	13%	0%	0%	0%
4L F54T5 HO	237	0%	37%	0%	3%	0%
6L F54T5 HO	360	0%	0%	98%	54%	0%
(2) 4L F54T5 HO	474	0%	0%	0%	2%	0%
8L F54T5 HO	474	0%	0%	0%	21%	0%
10L F54T5 HO	593	0%	0%	0%	0%	63%
(2) 6L F54T5 HO	720	0%	0%	0%	0%	9%
Total:		100%	100%	100%	100%	100%
Average Watts:		144 W	212 W	359 W	363 W	535 W

* Watts taken from Advance Atlas, percentages from a WISeerts sample.

Alternate Recommended Savings Using CF/Hours by Sector

		Space Type					
		kWh Savings					
Sector	Hours	Gymnasium	Industrial	Retail	Warehouse	Public Assembly	Other
Agriculture	4,698	438	501	167	594	523	445
Commercial	3,730	348	398	133	472	416	353
Industrial	4,725	441	504	168	597	526	447
Schools-Gov't	3,239	302	346	115	409	361	307
Percent Off		39%	45%	15%	53%	47%	40%
Coincidence Factor		15%	18%	6%	18%	12%	14%
kW Savings		0.0344	0.0427	0.0142	0.0427	0.0284	0.0325

Wattage from High Bay Fluorescent Measure

Tech Code	Measure Description	New Watts	Old Watts
2.5170.170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	295
2.5180.170	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	458
2.5182.170	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	462
2.5185.170	T8/T5HO <= 500 Watts Replacing >=1000 W HID	363	1,080
2.5186.170	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	1,080

Developing Average Wattage from WISeerts Data

			Ag		Com		Ind		S&G		Total	
Tech Code	Measure Description	Watts	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent	Number of Fixtures	Percent
2.5170	T8 4 lamp or T5HO 2 lamp Replacing 250-399 W HID	144	196	13.9%	1,230	5.1%	6,080	8.7%	1,062	18.5%	7,568	9.0%
2.5180	T8 6 lamp or T5HO 4 lamp Replacing 400-999 W HID	212	1,036	73.5%	14,739	61.4%	39,381	74.9%	4,043	70.4%	59,199	70.7%
2.5182	T8 8 lamp or T5HO 6 lamp Replacing 400-999 W HID	359	177	12.6%	7,290	30.4%	5,440	10.3%	531	9.2%	13,438	16.0%
2.5185	T8 or T5HO <= 500W, Replacing >=1000 W HID	363	-	0.0%	601	2.5%	2,327	4.4%	63	1.1%	2,991	3.6%
2.5186	T8 or T5HO <= 800W, Replacing >=1000 W HID	535	-	0.0%	150	0.6%	381	0.7%	43	0.7%	574	0.7%
	Total/Average Watts:		1,409	221	24,010	259	52,606	230	5,742	217	83,770	237

* Extraction from WISeerts 04/2009

Alternate Recommended Savings Using CF/Hours by Sector

Building Use	Hours	CF	Savings by Measure: CFL <32 W kW	kWh	CFL Reflector Flood kW	kWh
Agriculture	2,430	61%	0.0373	134	0.0327	120
Commercial	3,730	77%	0.0427	208	0.0374	182
Industrial	4,745	77%	0.0429	264	0.0376	232
Schools-Govt	3,236	64%	0.0389	168	0.0314	156

* Ag hours of use from CATI Analysis below. All others are standard hours of use

Tech Code	Measure Description	New Watts*	Old Watts
2.0300.1650	CFL <= 32W, replacing incandescent <=100W	20.0	75.7
2.0307.1650	CFL reflector flood lamps <=30W replacing incandescent r	17.5	66.9

* Wattages are the average of those from CATI surveys for 18MCP, FY06 and FY04

Recommended Savings for Related Measures, kW

WISeerts Tech Code	Measure Description	New Watts	Old Watts	Agriculture	Commercial	Industrial	Schools and Government
2.0301.165	CFL High Wattage 31-115 Watts, replacing incandescent	65.0	200.0	0.0803	0.1034	0.1040	0.0860
2.0805.060	CFL Cold Cathode Screw-in, replacing incandescent	4.0	25.0	0.0141	0.0161	0.0162	0.0135
2.0310.165	CFL Direct Install, replacing incandescent, WPS Hometown Checkup	20.0	75.7	0.0373	0.0427	0.0429	0.0389
2.0400.165	CFL Fixture, replacing incandescent fixture						
n/a	Replace incandescent lamps with 14 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent lamps with 20 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent lamps with 23 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent spotlight lamps with 15 Watt spotlight compact fluorescent lamps, WPS Hometown Checkup						
			Coincidence Factor	61%	77%	77%	64%

Recommended Savings for Related Measures, kWh

WISeerts Tech Code	Measure Description	New Watts	Old Watts	Agriculture	Commercial	Industrial	Schools and Government
2.0301.165	CFL High Wattage 31-115 Watts, replacing incandescent	65.0	200.0	331	508	641	437
2.0805.060	CFL Cold Cathode Screw-in, replacing incandescent	4.0	25.0	51	78	100	68
2.0310.165	CFL Direct Install, replacing incandescent, WPS	20.0	75.7	136	208	264	186
2.0400.165	CFL Fixture, replacing incandescent fixture						
n/a	Replace incandescent lamps with 14 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent lamps with 20 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent lamps with 23 Watt compact fluorescent lamps, WPS Hometown Checkup						
n/a	Replace incandescent spotlight lamps with 15 Watt spotlight compact fluorescent lamps, WPS						
			Hours of Use	2,430	3,730	4,745	3,236

CATI Survey Analysis

period	program	FREQ	wattsin	wattsout	avg_deltaw	avg_weekly	Annual
18 MCP	1	36	20.5	79.4	58.9	35.7	2,603
FY04	1	25	19.2	70.0	50.8	35.6	1,856
FY06	1	8	19.3	71.3	52.8	44.8	2,327
18 MCP	2	60	19.5	74.4	54.9	64.0	3,337
FY04	2	23	20.0	71.1	51.1	49.9	2,604
FY06	5	101	20.2	77.5	57.3	61.7	3,216
18 MCP	overall	96	19.9	76.3	56.8	60.6	3,159
FY04	overall	48	19.6	70.4	50.9	43.6	2,271
FY06	overall	109	20.2	77.1	57.0	60.8	3,170

program	sector	FREQ	wattsin	wattsout	avg_deltaw	avg_ophrs	Annual Hours
1	AG	69	19.9	75.1	55.2	47.1	2,430
2	Comm	63	19.7	73.5	53.8	60.1	3,136
5	Channel	101	20.2	77.6	57.3	61.7	3,217
	Overall	233	20.0	75.7	55.7	57.4	2,987

Reflector Flood Lamp Analysis

Sector	Sample	Total	Percent	Avg. Watts
Agriculture	6	6	100%	15
Commercial	7,180	26,471	27%	18.4
Industrial	182	361	50%	14.4
Schools & Gov't	6,439	7,459	87%	14.4
Total/Average	13,778	34,108	40%	17.5

WISeerts data used to produce average CFL flood wattage supplied

Attachment L:

"Strip curtains for walk-in units"

Strip Curtains for Walk-In Freezers and Coolers

Measure Name	Strip Curtains for Walk-In Coolers, Freezers
Target Sector	Commercial Refrigeration
Measure Unit	Walk-in unit door
Unit Energy Savings	Variable: 2,974 kWh for Freezers, 422 for coolers, **1,118 kWh weighted average for all walk-ins**
Unit Peak Demand Reduction	Variable 0.35 kW for freezers, 0.05 kW for coolers **0.14 kW weighted average for all walk-ins**
Measure Life	4 years

1.1 Introduction

Strip curtains are used to reduce the refrigeration load associated with the infiltration of non-refrigerated air into the refrigerated spaces of walk-in coolers or freezers. This paper quantifies the savings that result from using strip curtains as energy efficiency measures for walk-in freezers.

The air density difference between two adjacent spaces of different temperatures is the primary cause of air infiltration into walk-in coolers and freezers. The total refrigeration load due to infiltration through the main door into the unit depends on the temperature differential between the refrigerated and non-refrigerated airs, the door area and height, and the duration and frequency of door openings. The avoided infiltration depends on the efficacy of the newly installed strip curtains as infiltration barriers[i], and on the efficacy of the supplanted infiltration barriers, if applicable. The calculation of the refrigeration load due to air infiltration, and the energy required to meet that load, is rather straightforward, but, relies on critical assumptions regarding the aforementioned operating parameters. For all the above assumptions, this paper uses values that were determined by direct measurement and monitoring of over 100 walk-in units in a recent evaluation for the CA Public Utility Commission. Some weather dependent parameters, such as the temperature and humidity of the infiltrating air, and the average annual coefficient of performance (COP) of the refrigeration system, are modified to reflect the climate in PA.

1.2 Measure Applicability

This work paper documents the energy savings attributable to strip curtains applied on walk-in freezer doors in many commercial applications. The most likely areas of application are large and small grocery stores, supermarkets and restaurants.

1.3 Savings Calculations

The energy savings due to infiltration barriers in refrigeration are described by the following equation, which is based on Tamm's equation[ii] (an application of Bernoulli's equation), and the ASHRAE handbook[iii]

$$\boxed{kWh = 365\ x\ t_{open}(\eta_{new} - f_{old}\eta_{old})20C_D A\{(T_i - T_r)/T_i)gH\}^{0.5} \times 60 \times (\rho_i h_i - \rho_r h_r)\ \times 3413^{-1} \times COP^{-1}}$$

1.4 Definition of Variables

The variables in the above equation are defined below:

t_{open} =minutes of time walk-in door is open

η_{new} = the efficacy of the new strip curtain – an efficacy of 1 corresponds to the strip curtain thwarting all infiltration, while an efficacy of zero corresponds to the absence of strip curtains.

η_{old} = the efficacy of the old strip curtain

f_{old} = the fraction of customers that have old strip curtains

20 is the product of 60 minutes per hour and an integration factor of 1/3[iv]

C_D = Discharge Coefficient: empirically determined scale factors that account for differences between infiltration as rates predicted by application Bernoulli's law and actual observed infiltration rates

A = doorway area, ft^2

T_i = drybulb temperature of infiltrating air, Rankine

T_r = drybulb temperature of refrigerated air, Rankine

g = gravitational constant = 32.174 ft/s^2

H = doorway height, ft

h_i = enthalpy of the infiltrating air, Btu/lb

h_r = enthalpy of the refrigerated air, Btu/lb

ρ_i = density of the infiltration air, lb/ft^3

ρ_r = density of the refrigerated air, lb/ft^3

3413 = the number of BTUs in one kWh

COP = the time-dependent (weather dependent) coefficient of performance of the refrigeration system

The parameters in the above equations are listed in **Table 1** below. The equation above and the values for the input parameters are taken from the 2006-2008 California Public Utility Commission's evaluation of strip curtains[v]. The original work included 8760-hourly bin calculations. The values used herein represent annual average values. For example, the differences in the temperature between the refrigerated and infiltrating airs are averaged over all times that the door to the walk-in unit is open. The value for the baseline curtain efficacy of 0.26 is taken from CA. It assumes that approximately 50% of customers are replacing old, degraded strip curtains, and the remaining customers are installing strip curtains for the first time.

Table 1: Calculation Assumptions

Component	Type	Value: Restaurants	Value: Convenience Stores	Value: Chain Supermarkets	Source (Endnote)
η_{new}	Fixed	.85	.85	.85	v
η_{old}	Fixed	.58	.58	.58	v
f_{old}	Fixed	.5	.5	.5	v
C_D	Fixed	0.48 (freezer) 0.43 (cooler)	0.45 (freezer) 0.44 (cooler)	0.56 (freezer) 0.38 (cooler)	v
t_{open} (minutes/day)	Fixed	38 (freezer) 45(cooler)	9 (freezer) 39 (cooler)	102 (freezer) 132 (cooler)	v
A (ft^2)	Fixed	21	21	35	v
H (ft)	Fixed	7	7	7	v
T_i (°F)	Fixed	67	64	67	v
T_r (°F)	Fixed	10 (freezer) 39 (cooler)	7 (freezer) 39 (cooler)	9 (freezer) 37 (cooler)	v
RH_i (%)	Fixed	50	50	50	v
RH_r (%)	Fixed	80	80	80	v
COP	Fixed	2.0 (freezers) 3.8 (coolers)	2.0 (freezers) 3.8 (coolers)	2.0 (freezers) 3.8 (coolers)	v

<u>Demand Savings</u>

The demand savings are taken to be the annual energy savings divided by 8760 – essentially, a flat load shape is assumed, which, for commercial refrigeration in PA, is slightly conservative.

$$Demand\ Savings\ (kW) = Energy\ Savings \div 8760$$

1.5 Deemed Savings

The partially deemed savings for the installation of strip curtains can be calculated using the equation above with the parameters specified in Table 1. Calculated energy and demand savings are shown in Table 2 below[vi].

Table 2: Deemed Energy Savings and Demand Reductions

Application	Energy Savings (kWh)	Demand Savings (kW)
Supermarket-Freezer	7,412	0.85
Convenience Store-Freezer	294	0.03
Restaurant-Freezer	1,216	0.14
Average Freezer[a]	**2,974**	**0.34**
Supermarket -Cooler	959	0.11
Convenience Store - Cooler	143	0.02
Restaurant – Cooler	165	0.02
Average Cooler[a]	**422**	**0.05**
Average Walk-In Unit[b]	**1,188**	**0.14**
a: Unweighted average across all sectors		
b: weighted average – assumes 30% freezers, 70% coolers		

1.6 Measure Life

The measure life is estimated to be four years[v].

1.7 Evaluation Protocols

The most appropriate evaluation protocol for this measure is verification of installation coupled with assignment of stipulated energy savings according to store type. The strip curtains are not expected to be installed directly. As such, the program tracking / evaluation effort must capture the following key information:

- Fraction of strip curtains installed in each of the eight categories (e.g. freezer / cooler and store type, including one type for "other")
- Fraction of customers that had pre-existing strip curtains

The rebate forms should track the above information. During the M&V process, interviews with site contacts should track this fraction, and savings should be adjusted accordingly.

References

[i] We define *curtain efficacy* as the fraction of the potential airflow that is blocked by an infiltration barrier. For example, a brick wall would have an efficacy of 1.0, while the lack of any infiltration barrier corresponds to an efficacy of 0.

[ii] *Kalterveluste durch kuhlraumoffnungen.* Tamm W,.**Kaltetechnik-Klimatisierung** 1966;18;142-144

[iii] American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). 2006. *ASHRAE Handbook,* Refrigeration: 13.4, 13.6

[iv] In the original equation (Tamm's equation) the height is taken to be the difference between the midpoint of the opening and the 'neutral pressure level' of the cold space. In the case that there is just one dominant doorway through which infiltration occurs, the neutral pressure level is half the height of the doorway to the walk-in refrigeration unit. The refrigerated air leaks out through the lower half of the door, and the warm, infiltrating air enters through the top half of the door. We deconstruct the lower half of the door into infinitesimal horizontal strips of width W and height dh. Each strip is treated as a separate window, and the air flow through each infinitesimal strip is given by $60C_D A\{(T_i - T_r)/T_i)g\Delta H_{NPL}\}^{0.5}$ where ΔH_{NPL} represents the distance to the vertical midpoint of the door. In effect, this replaces the implicit wh1.5 (one power from the area, and the other from ΔH_{NPL}) with the integral from 0 to h/2 of wh'0.5 dh' which results in wh1.5/($3\times2^{0.5}$). For more information see: *Are They Cool(ing)?:Quantifying the Energy Savings from Installing / Repairing Strip Curtains*, Alereza, Baroiant, Dohrmann, Mort, Proceedings of the 2008 IEPEC Conference.

[v]http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V/2006-2008+Energy+Efficiency+Evaluation+Report.htm

The scale factors have been determined with tracer gas measurements on over 100 walk-in refrigeration units during the California Public Utility Commission's evaluation of the 2006-2008 CA investor owned utility energy efficiency programs.

The door-open and close times, and temperatures of the infiltrating and refrigerated airs are taken from short-term monitoring of over 100 walk-in units

The temperature and humidity of the infiltrating air and the COP of the units have been modified to reflect the PA climate.

Strip Curtains.xlsb

[vi] The supporting calculations are in the embedded spreadsheet:

Attachment M:

"BHP Weighted Compressed Air Load Profiles - OH TRM"

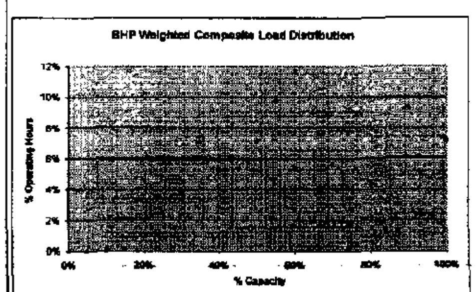
Introduction:

The load profile data in the "Compressor Factors" tab was collected from 50 facilities on Long Island, NY employing air compressors less thar or equal to 40 hp. The number of compressor run hours at a given capacity from a typical work day was recorded and tabulated in the following sheet.

These load profiles were weighted by compressor motor bhp and used to determine theaverage percent capacity for a small air compressor.

DOE part load curves for various compressor types were used in conjunction with the collected data to develop "compressor factors."
The percent full load compressor kW from DOE data was multiplied against the percent total compressor operating hours for each percent capacity bin.
The results were then added to obtain the "compressor factors" for each of the given compressor types. Therefore, the "compressor factors" incorporate average demand curves and part load curves. When multiplied against total operating hours and full load kW for a given compressor, the result is a reliable estimate of a small compressor's annual kWh consumption.

Customer Name	Flowrate (CFM)	Pressure (psi)	BHP	Total Package Full Load Input kW	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%	0%	TOTAL HOURS
					% Capacity																					
Customer ID 1	123	100	29.4	23.58					0.5	0.5	0.5	1				0.5	1	1	1	1	2.5	1				10.5
Customer ID 2	123	100	29.4	23.58	0	0	0	2	1	1	2	1	2	0	2	0	2	1	2	0	0	0	0	0	0	16
Customer ID 3	81	100	21.8	17.68	0	0	0	6	6	6	3	3	3	3	3	3	3	0	0	0	0	0	0	0	0	18
Customer ID 4	123	100	29.4	23.58		1	2	1	1	1			2	2	2	2	2	1	1	1						20
Customer ID 5	123	100	29.4	23.58	0	0	0	0	0	1	1.5	0	0	0	1.5	1.5	1.5	1.5	1.5	0	0	0	0	0	0	10
Customer ID 6	123	100	29.4	23.58	0	0	0	0	0	1	2	0	0	4	3	0	0	2	0	0	0	0	0	0	0	12
Customer ID 7	108	100	27	22.13	0	0	0	0	0	3.5	0	4.5	0	0	0	1	1	0	0	0	0	0	0	0	0	10
Customer ID 8	127	100	25	20.34	0	0	0	0	0	0	1	1.5	0	5	1.5	0	0	0	1.5	0	0	0	0	0	0	10.5
Customer ID 9	127	100	25	20.34	0	0	0	0	0	0	1	1.5	0	5	1.5	0	0	0	1.5	0	0	0	0	0	0	10.5
Customer ID 10	115	125	27.8	22.63	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	11
Customer ID 11	115	125	27.6	22.63	0	0	0	0	4	0	0	0	0.5	0	0	4	0	0	0.5	0	4	0	0	0	0	13
Customer ID 12	115	125	27.6	22.63	0	0	0	0	4	0	0	0	0.5	0	0	4	0	0	0.5	0	4	0	0	0	0	13
Customer ID 13	103	125	24.9	19.75	0	0	0	14	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
Customer ID 14	103	125	27.5	23.18	0	0	0	0	0	0	3	5	2	1	1	0	0	0	0	0	0	0	0	0	0	8
Customer ID 15	123	100	29.4	23.58					1	1									2	3	2					9
Customer ID 16	40	100	10.1	8.42	0	0	0	0	0	0	1	1	2.5	1	0	1	2	1.5	3	1	0	0	0	0	0	14
Customer ID 17	93	125	28.3	20.43	0	1.5	1.5	1	2	0	1	1	1	0	2	0	0	0	2	1	0	0	0	0	0	14
Customer ID 18	123	100	29.4	23.58						0.75	1.5	1.25	1.5	1.5	1.5	1	2			2	1					14
Customer ID 19	125	125	30	24.22			10					2														12
Customer ID 20	125	125	30	24.22			10					2														12
Customer ID 21	125	125	30	24.22			10					2														12
Customer ID 22	126	125	30	24.22			10					2														12
Customer ID 23	126	125	30	24.22			10					2														12
Customer ID 24	127	100	27	22.13	0	0	0	0	0	0	0	4	0	3	0	0	0	3	0	0	0	0	0	0	0	12
Customer ID 25	127	100	27	22.13	0	0	0	0	0	0	0	4	0	3	0	0	0	3	0	0	0	0	0	0	0	12
Customer ID 26	127	100	27	22.13	0	0	0	0	0	0	0	4	0	3	0	0	0	3	0	0	0	0	0	0	0	12
Customer ID 27	105	100	27	22.13	0	0	0	0	1.5	0	0	3.5	0	3	0	0	0	0	0	0	0	0	0	0	0	8
Customer ID 28	81	100	21.8	17.68	0	0	0	0	0	0	1	1.5	0.5	1	1	1	1	4	1	0	0	0	0	0	0	12
Customer ID 29	40	150	11	8.92	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.5	0	0	0	0	0	11
Customer ID 30	43	100	10.1	8.42	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	6
Customer ID 31	123	100	29.4	23.58	0	0	0	4	4	0	0	4	3	3	4	0	0	0	0	0	0	0	0	0	0	24
Customer ID 32	56	125	16.5	13.78	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0	0	0	12
Customer ID 33	123	100	29.4	23.58	0	0	0	0	1	0	1.5	6	0	0	1.5	1	1.5	0	1.5	1	0	0	0	0	0	9
Customer ID 34	123	100	29.4	23.58					1		0.5	0.5				1	1.5	2.5	1.5	1.5						10
Customer ID 35	123	100	29.4	23.58	0	0	0	0	0	1	1	0	2	0	1	1	3	1	1	1.5	0	0	0	0	0	12.5
Customer ID 36	123	100	29.4	23.58	0	0	0	2	5	5	2	6	1	3	0	2	2	2	0	0	0	0	0	0	0	24
Customer ID 37	120	140	33	24.47	0	0	0	0	0	0	4	0	0	0	12.5	0	0	0	0	0	0	0	0	0	0	12.5
Customer ID 38	108	100	27	22.13	0	0	0	0	0	3	0	4.5	0	0	0	1	1	0	0	0	0	0	0	0	0	9.5
Customer ID 39	131	100	33.4	26.57	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
Customer ID 40	131	100	33.4	26.57	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4
Customer ID 41	116	125	27.8	22.85	2	0	0	0	0	6	2	0	0	0	0	0	0	4	0	0	0	0	0	0	0	16
Customer ID 42	56	125	16.5	13.05	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	11
Customer ID 43	115	125	26.4	21.84	0	0	0	0	0	0	5	0	0	0	2	0	0	1	0	0	0.5	0	0	0	0	8.5
Customer ID 44	128	125	32.4	26.52	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0.5	0	0	0	0	8.5
Customer ID 45	81	125	18.2	12.46	0	0	0	0	1	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 46	112	100	27.9	22.70	0	0	0	0	0	0	0	5	0	2	0	0	1	0	0	0	0	0	0	0	0	10
Customer ID 47	140	175	40	35.11	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 48	43	100	10.1	8.42	0	0	0	0	2	2	2	0	1.5	2.5	2.5	2.5	2.5	2.5	2.5	0	0	0	0	0	0	22.5
Customer ID 49	81	100	21.8	17.68	0	0	0	0	0	0	1	1	0	1	1	1	2	2	1	0	0	0	0	0	0	12
Customer ID 50	43	100	10.1	8.42	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	1	1	2	2	1	1	0	0	0	0	10
Customer ID 51	127	100	27	22.13	0	0	0	0	0	0	0	0	0	5	0	0	0	2	0	0	0	0	0	0	0	9
Customer ID 52	43	100	10.1	8.42	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1	2	2.5	2	0	0	0	0	0	9
Customer ID 53	123	100	29.4	23.58	0	0	0	0	0.5	0.5	0.5	0.5	0	0	1	4	1.5	2.5	1	1	0	0	0	0	0	13
Customer ID 54	145	125	28.7	23.35	4	0	0	0	0	4	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	12
Customer ID 55	56	125	16.5	13.75	0	0	0	0	0	6	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 56	105	125	20.7	16.84	0	0	0	0	2	0	0	3	0	3	0	3	0	0	0	0	0	0	0	0	0	17
Customer ID 57	68.5	125	16.2	12.46	0	0	0	0	1	2	2	2	3	1	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 58	98.3	125	26	22.01	0	0	0	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
Customer ID 59	96	125	26.8	21.40	0	0	0	0	0	0	0	0	1	3	0	1	0	0	2	0	0	0	0	0	0	7
Customer ID 60	173	140	38.1	30.90	1	2	2					2	0		2		1									16
Customer ID 61	127	100	27	22.13	0	0	0	0	0	0	0	0	0	5	0	0	0	2	0	0	0	0	0	0	0	10
Customer ID 62	134	125	31.1	25.50	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Customer ID 63	134	125	31.097	25.27	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 64	134	125	31.097	25.27	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Customer ID 65	134	125	31.1	25.50	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8
				Total BHP * HOURS	1456.54	419.75	1096.18	630.5	924.9	2049.85	1140.1	1630.7	1111.66	1886.56	1454.25	1666.8	1072.46	1517.1	785.2	508.9	422.1	29.4	0	0	0	96315.56
				Composite Load Distribution	7%	2%	5%	3%	5%	10%	6%	8%	5%	10%	7%	8%	5%	7%	4%	2%	2%	0%	0%	0%	0%	1.000



Air Compressor Part Load Power Curves (% Full Load kW vs. % Capacity)
Source: U.S. Department of Energy, Compressed Air Challenge
Cross-hatch cells denote interpolated values

	100%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%	0%	
Modulating w/ IGV	100%	98%	96%	93%	90%	88%	93%	92%	90%	88%	86%	84%	82%	78%	70%	68%	54%	47%	40%	58%	29%	0.853
Load/No Load w/ 1 gal/CFM	100%	100%	100%	99%	98%	97%	95%	94%	92%	90%	87%	85%	83%	78%	74%	69%	64%	56%	47%	47%	28%	0.902
Load/No Load w/ 3 gal/CFM	100%	98%	96%	96%	94%	91%	88%	86%	83%	80%	75%	72%	68%	63%	58%	53%	46%	40%	36%	32%	20%	0.810
Variable Speed w/ Unloading	100%	95%	90%	85%	80%	75%	70%	67%	64%	58%	54%	50%	46%	42%	38%	35%	30%	28%	21%	18%	15%	0.656
Load/No Load w/ 5 gal/CFM	100%	98%	95%	93%	91%	90%	86%	83%	78%	76%	71%	68%	67%	63%	60%	58%	45%	41%	38%	51%	28%	0.793
Variable Displacement	100%	95%	92%	88%	84%	80%	77%	75%	69%	67%	64%	58%	41%	57%	52%	44%	43%	39%	38%	31%	26%	0.731

Load/No Load w/ 1 gal/CFM	-2%
Load/No Load w/ 3 gal/CFM	7%
Variable Speed Drive	24%
Load/No Load w/ 5 gal/CFM	10%
Variable Displacement	17%

TEM Table

Variable Speed Drive	24%
Load/No Load	14%
Variable Displacement	17%

Attachment N:

"ECM-Pigg"

State of Wisconsin
Department of Administration
Division of Energy

Residential Programs

Electricity Use by New Furnaces

A Wisconsin Field Study

October 2003

Contractor: Energy Center of Wisconsin

focus on energy

The power is within you.

230-1

Technical Report

Electricity Use by New Furnaces

A Wisconsin Field Study

October 2003

Prepared by

Scott Pigg
Energy Center of Wisconsin
455 Science Drive, Suite 200
Madison, WI 53711
608.238.4601

Prepared for

focus on energy

The power is within you.

Project Manager

Scott Pigg
Energy Center of Wisconsin

Acknowledgements

This publication was funded by the State of Wisconsin, Wisconsin Department of Administration, Division of Energy, and was funded through the Focus on Energy program.

Focus on Energy is a public-private partnership offering energy information and services to energy utility customers throughout Wisconsin. The goals of this program are to encourage energy efficiency and renewable energy, enhance the environment and ensure the future supply of energy for Wisconsin.
(800.762.7077, focusonenergy.com)

A number of individuals and organizations contributed to this effort. The project was commissioned by Wisconsin Energy Conservation Corporation, in its role as the administrator of residential programs under Focus on Energy. In particular, Ed Carroll was instrumental in making the study possible. Field work for the study was conducted by Greg Dalhoff (Dalhoff and Associates), George Penn (Global Energy Options) and Scott Pigg (Energy Center of Wisconsin). Brett Bergee (Energy Center of Wisconsin) recruited and scheduled participants in the study, and took the lead in managing the monitoring data—a task that required mailing out and subsequently downloading more than 750 data loggers over the course of the study. Steve Buss (Energy Center of Wisconsin) compiled the voluminous testing data for the 31 sites. Alex Weisheim (Auer Steel Corporation) and Dan Naidan (TSI, Inc.) provided useful technical sleuthing for two sites in the study. Scott Pigg (Energy Center of Wisconsin) managed the project, conducted the primary data analysis, and wrote the report.

The following individuals provided useful comments on draft versions of this report:

Wayne Deforest, Wisconsin Energy Conservation Corporation
George Edgar, Wisconsin Energy Conservation Corporation
Skip Hayden, Advanced Combustion Technologies
Stephanie Jones, Consortium for Energy Efficiency
Alex Lekhov, Lawrence Berkeley Laboratory
Jim Lutz, Lawrence Berkeley Laboratory
Harvey Sachs, American Council for an Energy Efficient Economy

Needless to say, the final report does not necessarily reflect the views of these individuals or organizations.

Finally, this study would not have been possible without the cooperation of the 31 families that participated in the study. These families not only allowed multiple intrusions into their homes, but also actively assisted with the monitoring effort by swapping data loggers through the mail over a seven-month period.

This report is the property of the State of Wisconsin, Wisconsin Department of Administration, Division of Energy, and was funded through the Focus on Energy program.

Technical Report 230-1

Contents

Figures

Tables

Appendices

The appendices are bound separately under report number 230-2.

Appendix A: Furnace and Site Details

Appendix B: Test Results and Heating Cycle Plots

Appendix C: Modeling Approach

Appendix D: Indoor Temperature and Heating Cycle Length Analysis

Appendix E: Duct Resistance Characteristics

Appendix F: Daily Summary Scatterplots

Abstract

Field tests and monitoring of 31 new Wisconsin furnaces showed that multi-stage furnaces with electronically commutated blower motors (ECMs) use significantly less electricity than conventional new condensing furnaces, especially when operated in year-round continuous-fan mode. The data suggest that a typical Wisconsin home will save about 465 kWh of electricity per year for heating and cooling operation, with the median ECM furnace using about half the electricity per therm for heating compared to the median non-ECM furnace. These savings increase significantly to more than 3,000 kWh when continuous-fan operation is included. Electricity use for heating operation was higher on average than standard rating data would indicate for ECM furnaces; this is most likely due to generally higher static pressures encountered in the field compared to rating test conditions. The study suggests that there are opportunities to further reduce electricity use by ECM furnaces through careful attention to filter static pressure drop. In addition, several ECM furnaces were found to be field configured for continuous-fan airflow well above the factory defaults; fan-only savings would be mitigated or non-existent in homes where this occurs. The ECM furnaces with two-stage heating capability typically operated more than 80 percent of the time at the low stage, with high-fire mainly invoked for setback recovery—but two sites operated mostly in high-fire. The study showed that most of the furnaces were oversized to the point that low-fire operation alone could meet design heating loads for the homes; setback recovery appears more to be the limiting factor in heating system sizing.

Report Summary

This study examines electricity consumption by new Wisconsin furnaces, particularly with regard to differences between furnaces with multi-stage firing and electronically commuted blower motors (ECMs) versus single-stage furnaces with standard blower motors. The study also quantifies some basic furnace operational parameters such as annual operating hours and heating cycle length.

To conduct the study, 31 new furnaces were tested for electrical consumption, static pressure and airflow in various operating modes. The furnaces were also monitored over the latter part of the 2001/02 heating season and the entire 2002 cooling season. A model of furnace operation was developed for each site to standardize the results to typical weather conditions. Fourteen of the furnaces in the study used ECM blower motors, and most of these featured multi-stage firing operation.

From a technology perspective, the study provides basic confirmation that multi-stage ECM furnaces do provide substantial electricity savings over conventional condensing furnaces. Top findings from the study are as follows:

1. **The multi-stage ECM furnaces in the study used significantly less electricity than the standard single-stage furnaces with permanent-magnet split capacitor (PSC) blower motors.** Though the study could not control for differences from home to home in factors such as duct resistance, the results tend to confirm claims that ECM blower motors are inherently more efficient than standard blowers. The test results also demonstrate that furnaces equipped with ECM blowers are capable of operating over a much wider airflow range than standard PSC blowers. Since air handler power requirements increase with the cube of airflow, the ability to reduce airflow when appropriate—such as when providing background air circulation in continuous-fan mode—can mean dramatically lower air handler energy.

2. **The results suggest that an ECM furnace in a typical Wisconsin home will use about 465 kWh per year less electricity than a non-ECM furnace.** The majority of these estimated savings derive from heating mode electricity savings: the median ECM furnace in the study used about half the electricity for heating (0.5 kWh per therm of gas) compared to median non-ECM furnaces (1.0 kWh per therm). The data also showed lower blower power draw in cooling mode, which would also reduce the load on the air conditioning compressor. These savings far offset the finding that the ECM furnaces in the study averaged about 30 additional kWh per year in standby mode compared to the non-ECM furnaces.

3. **The study results indicate electricity savings in excess of 3,000 kWh when year-round continuous-fan operation is practiced.** Most of the ECM furnaces in the study used less than 200 Watts in this operating mode (and about half used less than 100 Watts), compared to 400 to 800 Watts for the non-ECM furnaces, which typically delivered air in continuous-fan mode at the heating speed. Over the 7,000-plus hours of operation in this mode that the data suggest would be typical of a furnace in Madison, Wisconsin, an ECM furnace using 100 Watts would use nearly 3,000 fewer kWh than a non-ECM furnace drawing 500 Watts in this mode. With the above heating- and cooling-mode savings, this would bring the total annual electricity savings to about 3,400 kWh for a typical Wisconsin home.

4. **Most of the two-stage ECM furnaces in the study operated in low stage for the majority of the time.** Eleven of the furnaces were two-stage ECM models, and the data suggest that nine of these would operate in low-fire mode for 80 percent or more of the time for typical Madison, Wisconsin weather. Although these furnaces run for more hours over the course of a heating season, their total electricity consumption is substantially less than a conventional single-stage furnace. Similarly, the two fully modulating furnaces in

the study appear to operate at or near their lowest firing rate for about half of the time. For all of these furnaces, high-fire is mainly invoked only to recover from periods of thermostat setback. Two furnaces operated mainly in high fire; these were both smaller furnaces with long heating cycles.

5. **On average, ECM furnaces in the study used more electricity per therm for heating than would be indicated by standard rating data.** The Gas Appliance Manufacturer's Association (GAMA) publishes standard ratings for annual gas and electricity consumption (in addition to gas efficiency) for furnaces based on standardized test procedures. The ECM furnaces in the study averaged nearly twice the electricity use per therm of gas than their GAMA ratings would indicate, and only three out of 14 furnaces used less than the rated kWh per therm. Static pressure appears to be a general factor: static pressure drop across the furnace and evaporator coil averaged about twice the value typically used in the standard rating test procedure, and ECM sites with higher static pressure drop tended to have higher deviation from the rated electricity use per therm. This is consistent with the fact that most ECM furnaces compensate for high static pressure by increasing the blower speed. (Note, however, that despite using more electricity than the rating data would indicate, the ECM furnaces still used considerably less electricity than the non-ECM furnaces in the study.) In addition, faulty field configuration was clearly a factor in one case, and substantial use of high-fire operation came into play for several other sites. The study suggests that heating electricity use of 0.6 kWh per therm of gas consumed could serve as a useful demarcation line between electrically efficient and less-efficient furnaces: this value neatly separates the ECM and non-ECM furnaces in the study both in terms of rating data and observed electricity use in the field.

6. **Additional electricity savings for ECM furnaces could be realized through careful attention to filter (and duct) pressure drop.** Static pressure drop across the filter varied widely among the sites, and no obvious correlations were found between type of filter or filter condition. Because ECM furnaces generally compensate for higher static pressure by boosting the blower speed to maintain a consistent airflow, additional savings could be realized by minimizing the static pressure that the system sees. This includes selecting filters with low pressure-drop characteristics, and (for new homes) minimizing duct friction. The data from the study suggest additional electricity savings may be obtained with ECM furnaces by using filters with low static pressure drop and by changing or cleaning filters regularly, since filters were found to represent about half of the total static pressure drop seen by the furnace on average. More research is needed to better understand the pressure drop characteristics of various types and brands of furnace filters, however.

7. **Field configuration of continuous-fan airflow was an issue at some sites.** Although ECM furnaces have an advantage of being capable of delivering continuous airflow at much lower electricity cost, this will occur only if the systems are configured properly. Fortunately, most of the furnaces in the study appear to be factory-set to operate at the lowest possible speed setting in continuous-fan mode—and are left that way by the installer. However, four of the 14 ECM furnaces were found to be set to a higher airflow for continuous-fan operation (including one furnace that was actually used in this mode). Non-ECM furnaces generally operated at the heating speed when called upon for continuous-fan operation, so the ability to modify the continuous-fan airflow is limited. However, at least one line of furnaces can be set to a separate lower fan speed for continuous-fan operation, though none of the four such furnaces in the study were configured in this way.

8. **Nearly all of the furnaces in the study were considerably oversized in terms of meeting design heating loads—but setback recovery may be more of a limiting factor.** The data suggest that at a 90F° indoor/outdoor temperature difference, the majority of the furnaces will operate at only 40 to 60 percent of

their full output capacity on a daily basis. In fact, nearly all of the multi-stage furnaces could meet these design conditions using only the lowest firing rate. At the same time, analysis of setback recovery length indicates that about a third of the furnaces will have a setback recovery period that exceeds three hours at design conditions. Even under typical winter conditions, about a third of the homes had setback recovery periods of an hour or more. This raises interesting questions about whether the savings from thermostat setback outweigh the penalties of needing an oversized furnace for quick setback recovery.

9. **The ECM furnaces in the study had lower power factors on average than non-ECM furnaces.** Power factor can be an issue for utilities, because distribution equipment such as transformers must be sized to accommodate current flows, which are proportionally larger for loads with low power factors. The ECM furnaces generally had operating power factors in the range of 0.6 to 0.8, though individual tests sometimes showed far lower values at low operating speeds. Nearly all of the non-ECM furnaces in the study had power factors between 0.8 and 0.9. Since the ECM furnaces draw considerably less power than non-ECM furnaces, the displacement of a non-ECM furnace with an ECM model would still reduce the overall utility system capacity requirements.

It should be noted that the furnaces included in the study were deliberately chosen to include a variety of models, and may not be representative of the distribution of furnaces sold in the state each year. Energy savings figures above are couched in terms of what a typical Wisconsin homeowner might experience. In this sense, the study results do not necessarily reflect the savings attributable to program efforts to promote ECM furnaces: program participants may differ in their gas usage and furnace operational characteristics from the group of homeowners studied here, and this study does not deal with causal linkages between sales of ECM furnaces and program efforts to promote such sales.

Introduction

Background

Space heating and cooling are by far the largest energy expenditure in most Wisconsin homes; energy use for space conditioning is estimated to constitute more than half of the total energy use in the typical home (Pigg and Nevius, 2000). This gives the warm-air furnace—which is found in more than three fourths of Wisconsin single-family homes—a central role in consumer energy costs.

In the 1980s and 1990s, energy efficiency programs geared toward residential furnaces concentrated on the gas efficiency of these devices. These efforts have been successful; recent studies have shown that high efficiency condensing furnaces are currently present in about half of all single-family homes (Pigg and Nevius, 2000), and represent nearly eight out of every ten furnaces sold in the state each year.[1]

The Wisconsin success in creating a sustained market for high efficiency furnaces has led to a refocusing of program efforts to target electrical consumption by furnaces. While the benefits of high gas efficiency are generally understood, it is probably safe to say that many consumers do not realize that furnaces use a substantial amount of electricity, especially when the air handler is operated continuously (typically for air filtration or mitigation of temperature differences in the home). Moreover, standard ratings of furnace energy use, such as those published by the Gas Appliance Manufacturers Association (GAMA) show a tremendous variation in furnace electrical consumption, from less than 100 kWh per year to more than 1000.

To promote the installation of furnaces that are electrically efficient as well as efficient in terms of combustion, the Wisconsin statewide Focus on Energy program began offering a $150 reward for the installation of furnaces that use electronically commutated motors (ECM) in 2002. These ECMs (also sometimes referred to as brushless DC motors) have several advantages over the typical permanent-magnet split capacitor (PSC) blower motors found in most furnaces sold in the state each year. First, ECMs are claimed to be 20 to 30 percent more efficient than standard blower motors (Bryne, 2000; Sachs et al., 2002). Because the air handler represents a large proportion of the total electrical draw by the furnace, using an ECM in place of a standard PSC motor for this application offers an immediate boost in electrical efficiency. Some furnace models also use ECMs for the much smaller blower that moves combustion air through the venting system for power-vented and sealed combustion systems.

Second, the typical ECM blower can produce a much wider range of airflow than the PSC blower used in most furnaces, which typically have only three or four set speeds over a fairly narrow range. This can have a large impact on electrical draw, because power consumption by an air handler rises with the cube of airflow. Furnaces that can produce less airflow when appropriate (such as during continuous background circulation) will use substantially less electricity.

Furnace manufacturers have taken advantage of this fact by bundling ECM-based air handlers with multi-stage firing capability. The idea behind this approach is that the furnace can operate at a lower firing rate and less airflow for the majority of the heating season when heating loads are far below the design maximum. This results in quieter and less drafty operation in addition to reduced electrical consumption. Also—in contrast to most PSC-based furnaces—ECM furnaces also have a separately configurable continuous-fan settings and better ability to fine-tune

[1] Data on Wisconsin furnace sales comes from the Energy Center of Wisconsin's Furnace and A/C Sales Tracking Project.

airflow in cooling mode. In terms of the latter, ECM furnaces in theory provide better ability to maximize the efficiency of central air conditioning systems that use the furnace air handler.

Finally, the dominant ECM blower used in the market (manufactured by General Electric) uses a patented approach to monitor airflow and dynamically adjust the motor speed to deliver the target airflow over a wide range of static pressures. This eliminates most of the uncertainty surrounding whether a furnace is delivering the appropriate airflow for the task at hand. Standard blower motors simply run at a constant speed in any given operating mode. Differences in static pressure from home to home—or over time for a given home as the filter becomes loaded with dirt—means that airflow from these furnaces will vary, with potential adverse effects on performance.

Research Objectives

Despite the market presence of ECM furnaces since the late 1980s, little publicly available data exist to document the claimed performance advantages of these models. For example, do these furnaces indeed run most of the time at a reduced firing rate during the heating season? How much electricity do they draw compared to standard PSC furnaces in various operating modes?

Moreover, there is a general lack of field data on furnace operation in general. The number of hours that a furnace operates in a year—and the number of heating cycles it goes through—affects overall electricity use, but little field data exist on these parameters.

This study was therefore undertaken with the main objective of gathering field data on the operation of new ECM and non-ECM furnaces. The underlying premise is that the primary point of comparison should be between a new multi-stage ECM furnace and a single-stage non-ECM furnace, representing the choice faced by the consumer considering a furnace purchase.

A secondary objective of the research was to look at sizing and field configuration issues with these furnaces, with an eye towards efforts to improve installation practices.

Methods

Recruitment and Site Selection

To implement the study, a total of 31 sites were recruited, representing a mix of new ECM and non-ECM furnaces and a variety of models. The sites were recruited from three sources:

- Participants in a previous study of energy use in new Wisconsin homes who responded to a solicitation of interest in participating in a field study of furnaces. These homes were a mix of homes in the Wisconsin Energy Star® Homes program and comparable non-participants.

- A sample of participants from the Wisconsin Energy Star® Homes program for which program records showed the make and model of the furnace that was installed.

- A sample of participants in a previous state-funded rewards program for owners of older homes who purchased a new furnace.

Despite an effort to balance the study between new homes and older homes, all but five of the recruited sites ended up being new homes. All of the furnaces in the study were sealed combustion, condensing units with 90 percent or better combustion efficiency, and all were upflow "northern" models. The furnaces ranged from 50,000 to 120,000 Btu/hour input, and were all less than three years old at the start of the study. More detail about the furnaces and the sites can be found in Appendix A.

With a few exceptions, the furnaces in the study fall into two main categories: single-stage furnaces with PSC blower motors (14 sites) and two-stage furnaces with ECM blower motors (12 sites). The study also included:

- two sites with fully modulating (ECM) furnaces;

- one site with a two-stage, non-ECM furnace; and,

- one site with a (discontinued) single-stage, pulse-combustion furnace with an ECM blower.

Testing and Monitoring

The study involved a combination of short-term tests on each furnace and monitoring of operation over time. The rationale was that short-term measurements of electricity use could be combined with information about how long the furnaces operated to estimate total seasonal and annual electricity consumption. The timing of the study also precluded monitoring over an entire heating season, so the ability to extrapolate to a standard heating season was required.

Testing Approach

Two rounds of testing were conducted on each furnace. These corresponded with site visits to install and remove monitoring equipment. The first round was conducted in the latter part of February 2002; the second round was mostly conducted between September and November of 2002 (though two sites were tested in August).

Each round of testing involved putting the furnace through various operating modes while recording data on electricity use, static pressure, and temperature. Monitored parameters are summarized below:

Electrical Data

- Amperage, wattage, and power factor for the furnace, as well as the separate measurements for these parameters for the air handler blower and the combustion blower
- Voltage at the furnace electrical connection

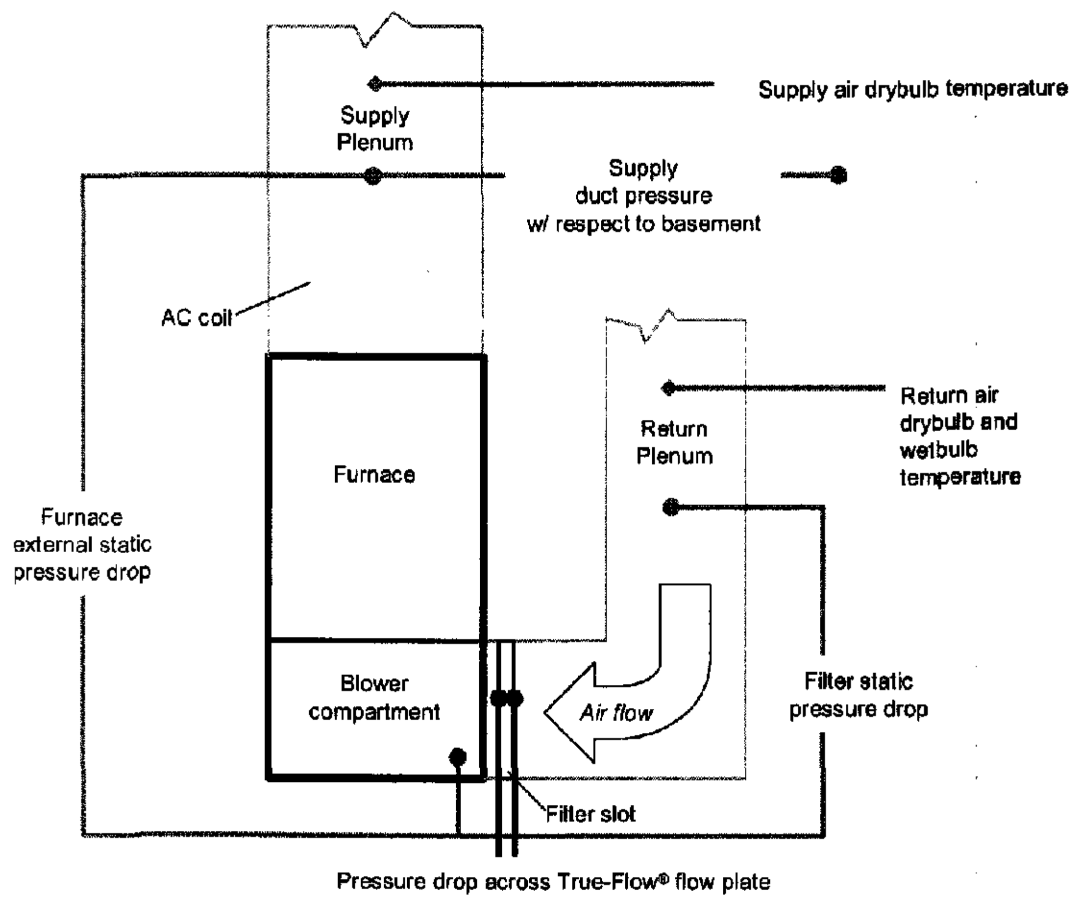
Static Pressure Drop (see figure 1)

- Between the supply ductwork (just after the AC coil) and furnace blower compartment
- Across the filter
- Between the furnace supply ductwork (at the location described above) and the basement (second round only)
- Across the Trueflow® airflow meter (used to determine airflow in the second round of testing only)

Temperature (see figure 1)

- Supply air dry-bulb temperature
- Return air dry-bulb temperature
- Return air wet-bulb temperature (second round of testing only)

Figure 1: Static pressure and temperature monitoring points.



Instrumentation

Power measurements were made using Dent instruments ElitePro® loggers with 15 Amp CTs connected to the overall electrical connection to the furnace, as well as the power leads to the air handler and combustion blowers (to allow disaggregation of these loads). A single voltage measurement was made at the service entrance to the furnace. The loggers were configured to record data as three-second averages of all values. The loggers have a stated typical accuracy of 0.5 percent for all values, including true wattage.

Static pressure measurements were made with Autotran Series 750 pressure transducers with a range of 0-1 inch of water column (IWC) (0.75% accuracy) using static pressure probe tips inserted into holes in the ductwork. The pressure transducers produced a 4-20mA signal that was sampled and recorded once a second by Onset Hobo® 4-channel data loggers (H08-006-04).

Temperature measurements were made with a single probe (TMC20-HA, 0.9F° accuracy) at each location sampled and recorded at one-second intervals by the Hobo® 4-channel loggers. Soda straws were used to hold the probes away from the ductwork metal and 4 to 6 inches into the air stream. The wet-bulb temperature measurement was made by sewing a cotton wick over the temperature sensor and saturating it with water.

The on/off status of the gas valve and air handler was recorded during testing using relays and Hobo® state loggers (H06-001-02) as described in more detail below in the Monitoring Approach section.

In the first round of testing, no changes were made to the blower speed settings. Data were recorded over a heating cycle that typically lasted at least 5 minutes, under continuous-fan operation, and in standby mode. Two-stage furnaces were tested in low- and high-fire modes.

These tests were repeated in the second round of tests, which also involved operating the furnace at the cooling speed. When weather permitted, this was done by actually initiating a call for cooling at the thermostat, and monitoring for a minimum of 15 minutes. When the weather was too cold to operate the air conditioning, the blower was simply set to the cooling speed and the furnace operation was monitored for a few minutes.

For the second round of testing, airflow was also measured using a Trueflow® airflow meter. This device replaces the filter with a flow plate with known pressure drop characteristics. Pressure drop across the flow plate was logged in the same way as the other static pressure measurements. Because the flow plate does not necessarily have the same pressure drop characteristics as the filter it replaces, a correction factor was employed based on the square root of the ratio of the supply duct pressure with the filter and the flow plate in place. Used in this way, the Trueflow® has a stated accuracy of ±10 percent. Flow measurements were generally made at the end of cycle, so as not to disturb other measurements. Flow measurements during actual cooling cycles were made after 15 minutes of operation.

Data (including airflow) were also collected at alternate air handler speed settings in the second round of testing. For non-ECM furnaces, this generally meant measuring at each of four speed tap settings. The ECM furnaces in the study had many possible speed settings; four to six settings across a range of available speeds were selected for testing.

Finally, firing rates for the furnaces were also established during the second round of testing. This was done by timing how long it took for the furnace to consume two to three cubic feet of gas according to the home's gas meter.

Testing — Data Reduction Protocol

Raw data from the testing were in the form of one-second snapshots (pressure and temperature) and three-second averages (power, amperage, power factor, and volts) over the entire testing period. The three-second power data were first converted to one-second level data (by replicated observations between actual data points) and then merged with the pressure and temperature data to produce a single, one-second interval stream of data for the testing. Status change information from the state loggers was also merged into this dataset.

The beginning and ending points of individual tests, such as a heating cycle or a period of continuous-fan operation were marked in the data based on field notes, and average values over a core period of steady-state operation was identified for each. The core period was generally defined by removing the first and last 30 seconds of data, then taking the mean of the remaining data. For heating cycles, steady-state operation was defined as the period between blower startup at the beginning of the heating cycle and gas valve shutoff at the end. The identified core periods were visually inspected to ensure that transient effects (such as a spike in blower motor wattage at the time of startup) were not inadvertently included. For airflow measurements, the process involved also identifying a core period of operation with the flow plate and the filter in place.

The analysis also relied on measurements of total electricity use over relatively fixed operations, such as the startup phase of a heating cycle. These were calculated by simply summing the watt-seconds of electricity use between relevant events. For example, the electricity consumption during heating cycle shutdowns was calculated by summing the watt-seconds of electricity used from the point the gas valve closed (denoting the termination of a call for heat) to the point the blower motor shut down.

Time constraints typically prevented operating the furnaces to the point of steady-state conditions in terms of temperature rise. The field data were extrapolated to steady-state conditions using methods described in Appendix B.

Monitoring Approach

The goal of the monitoring was to track the amount of burner and blower on-time and cycling behavior of the furnaces as a function of outdoor temperature. This was generally done by monitoring the status of the gas valve and the air handler.

Gas valve status was recorded by wiring a relay (RIBUC1) in parallel with the gas valve such that whenever the gas valve was energized the relay contacts also closed. The relay contacts were connected to a Hobo® state logger (H06-001-02), which recorded the date and time (to the nearest 0.5 seconds) each time the gas valve opened and closed. For two-stage furnaces, two relays and data loggers were used; one recorded the status of the first stage, and the other tracked the status of the second stage. The gas valve used in some lines of furnaces in the study (Sites 12, 18, 24 and 27) was not amenable to connecting a relay; for these sites, the status of the combustion inducer blower was tracked, and the data were adjusted based on measured time delays between the inducer and gas valve operation.

Blower status was similarly monitored by attaching a relay with a state logger to the electronic air clear (EAC) terminals on the furnace control boards. The EAC terminals are typically energized whenever the blower operates.

In addition to tracking gas valve and blower status, a 20-amp current transformer (Hobo® CTV-A) was attached to the furnace to measure total amperage draw by the furnace. This was sampled every 90 seconds and recorded by a 4-channel Hobo® data logger. The amperage data was mainly used as a cross-check against the status data.

Finally a temperature logger (Hobo® H8 series) was placed at the thermostat to sample and record the temperature every 15 minutes. Some sites also received an outdoor temperature logger (Hobo® H8 Pro series) to record outdoor temperature as well (most of the subsequent analysis relied on weather station data, however).

Special consideration was needed for the two fully modulating furnaces in the study (Sites 28 and 32). Simply tracking gas-valve on/off status was not adequate for these because their output can be modulated between 40 and 100 percent of full output. The approach used was to leave these sites as the last for testing and monitoring installation, and then leave the Dent power monitoring equipment behind to record actual average wattage over one-minute intervals for these furnaces, in addition to tracking gas valve and air handler on/off status. One additional channel of the Dent loggers was also dedicated to recording the control voltage to the gas valve; this voltage varies from 6 to 18 VAC in proportion to the degree of modulation. The Dent loggers had sufficient on-board storage for about a month's worth of one-minute furnace wattage and gas valve control voltage data.

The data loggers and sensor wires were color coded so that the homeowners could replace the loggers as they filled up. Approximately once a month, each homeowner was mailed a new set of data loggers, along with a return envelope for the current loggers and a postcard to record the date and time of the swap (indoor temperature loggers were swapped only once over the course of monitoring). A few loggers were incorrectly configured, or not plugged in correctly, but these amounted to no more than 40 out of more than 750 data files received over the course of monitoring the 31 sites. In addition, some data loggers filled up before they could be swapped out, particularly the state loggers, which can hold a fixed number (about 1,000) of on/off cycles rather than data over a fixed amount of time. These data were accurate but incomplete. Considerable effort was spent identifying gaps in the data and removing the small amount of erroneous data from incorrectly configured loggers.

The monitoring equipment was installed at the sites over the latter part of February 2002, and monitoring officially continued through the end of August to capture the cooling season. Because some data loggers were not yet filled up and equipment was not completely removed until later in the fall, some data were obtained for the fall of 2002. No summer data was obtained from Site 5, because the homeowners left for the summer in early June. Fortunately, despite the late start of the study in the 2001/02 heating season, the coldest weather of the year occurred in early March just after the completion of monitoring installation. The furnaces were thus monitored over about a 100F° temperature range, from about -5°F to +95°F.

Monitoring — Data Reduction Protocol

Raw data from the monitoring was in the form of a stream of date/time stamps of status changes for the gas valves and air handlers, 90-second interval data for furnace amperage, and 15-minute interval data for indoor temperature. The bulk of the analysis for this report was conducted using daily summaries of these data. Total daily burner and blower hours and cycles were calculated from the status data, as were minimum, maximum, and median daily cycle lengths. These were merged with daily average furnace amperage and indoor temperature data, as well as with daily average outdoor temperatures obtained from each of four nearby NOAA weather stations. Days with less than 90 percent data recovery were discarded. Appendix F provides basic scatterplots of some of these variables.

The resulting dataset of daily summary data formed the basis for the regression models of daily operating hours and cycles described in detail in Appendix C. Essentially, these models provided a means of estimating operating hours and cycles as a function of outdoor temperature. When combined with a distribution of outdoor temperature, the models provide estimates of total operating hours and cycles over the course of a year or season.

Results

Overview

Although furnaces involve a number of components, the air handler is by far the most important when it comes to electricity use.[2] As will be shown later, the air handler typically accounted for 75 percent or more of the electricity consumed by the furnace in the study. The test data collected on the furnaces in the study confirm two primary ways in which ECM furnaces save air handler energy: 1) an ECM is inherently more efficient than a typical PSC air handler motor; and, 2) ECM-based air handlers can be operated over a much wider usable range of speeds than can typical four-speed PSC air handlers.

Both of these advantages can be seen graphically in Figure 2, which shows the characteristic curve of blower power draw versus airflow for each site in the study. Though differences in variables such as duct and filter resistance make each curve unique—and strict comparison between sites difficult—the ECM-based air handlers generally draw less power at a given airflow than the PSC-based air handlers. This is consistent with the notion that ECM blowers are inherently more efficient (Byrne, 2000).

Moreover, Figure 2 dramatically illustrates the wider airflow range available from the ECM-based air handlers.[3] In practical terms, this means that these furnaces can operate at far lower wattage in situations where less airflow is needed, such as continuous fan-only operation and reduced-output heating for furnaces with multistage firing.

This report examines differences between ECM and non-ECM furnaces in four basic operating modes: heating, cooling, fan-only operation, and standby. These modes and key results are described below.

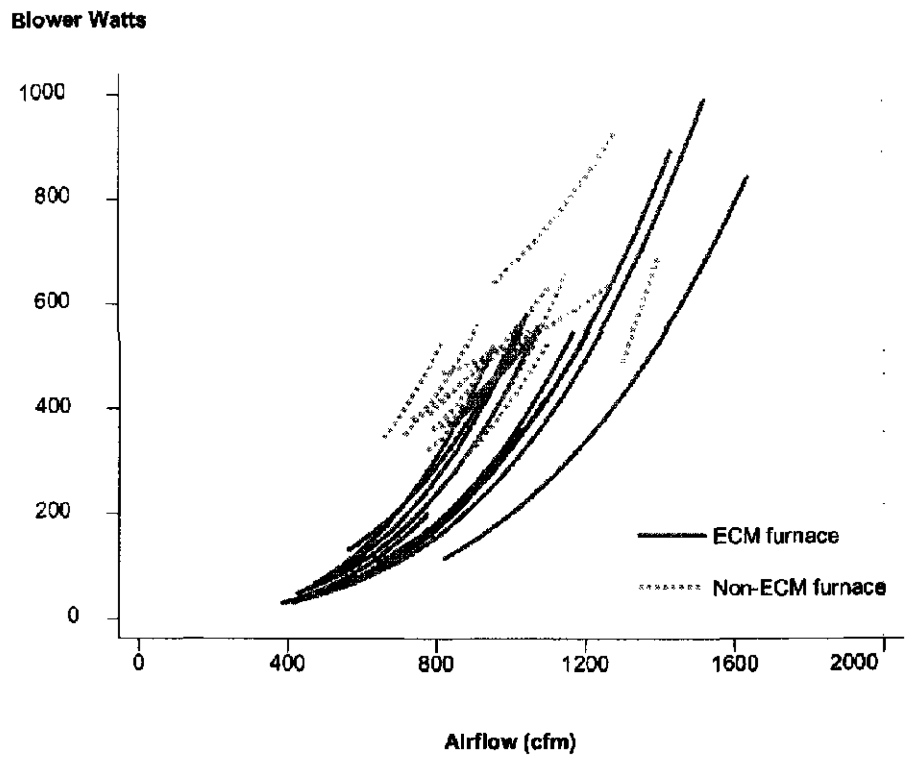
Heating Mode

The study suggests that a typical non-ECM condensing furnace in Wisconsin will fire for a total of about 1,000 hours over the course of an average heating season, and consume about 800 kWh of electricity—most of which will be used to power the air handler. A typical multi-stage ECM furnace will mainly operate in a reduced low-fire mode, with its full firing capability used primarily to recover from thermostat setback periods. Although the ECM furnace will operate more total hours in heating mode (since it is producing less heat per hour in low-fire mode), it will do so with far lower electrical power requirement for the air handler: the result is that the ECM furnace will use about half the electricity in heating mode (400 kWh) over the course of an average heating season.

[2] Throughout this report, the term "air handler" refers to the furnace blower motor and fan assembly used to circulate air through the furnace and deliver heated air to the house.

[3] Actually, many of the ECM furnaces are capable of higher airflows than shown. For the study, tests were conducted only up to the selected cooling speed based on the size of the central air conditioning system.

Figure 2: Blower power versus airflow curves for study furnaces.



Cooling Mode

In cooling operation, the furnace air handler provides airflow over the evaporator coil for the central air conditioning system to remove heat and circulate cooled air through the house. Airflow requirements in this mode are typically large, so the savings from ECM-based air handlers stem from their inherently higher operating efficiency. The study results suggest that a typical 2.5-ton air conditioner that is operated for 400 hours over an average Wisconsin cooling season will require 225 kWh of air handler energy from a non-ECM furnace and 155 kWh from an ECM furnace, for a difference of about 70 kWh. In addition, less air handler energy in the summer means less waste motor heat that must be removed by the air conditioner: this adds perhaps an additional 25 kWh to the cooling-mode savings for a typical ECM furnace.

Fan-Only Operation

Some homeowners choose to operate their furnace air handler continuously, regardless of the need for heating or cooling, to filter the air in the home or perhaps even out temperature variation around the home. Airflow requirements in these situations are low, but non-ECM furnaces are typically set up to deliver the heating-mode airflow when called upon for fan-only operation. The result is high air handler power requirement (typically about 500 Watts), and—over the more than 7,000 hours that would be typical for year-round continuous fan operation—more than 3,500 kWh of electricity consumption. As the study data show, however, a typical ECM furnace can operate at a very low airflow rate, and provide adequate air circulation for about 80 percent less air handler energy.

Standby Operation

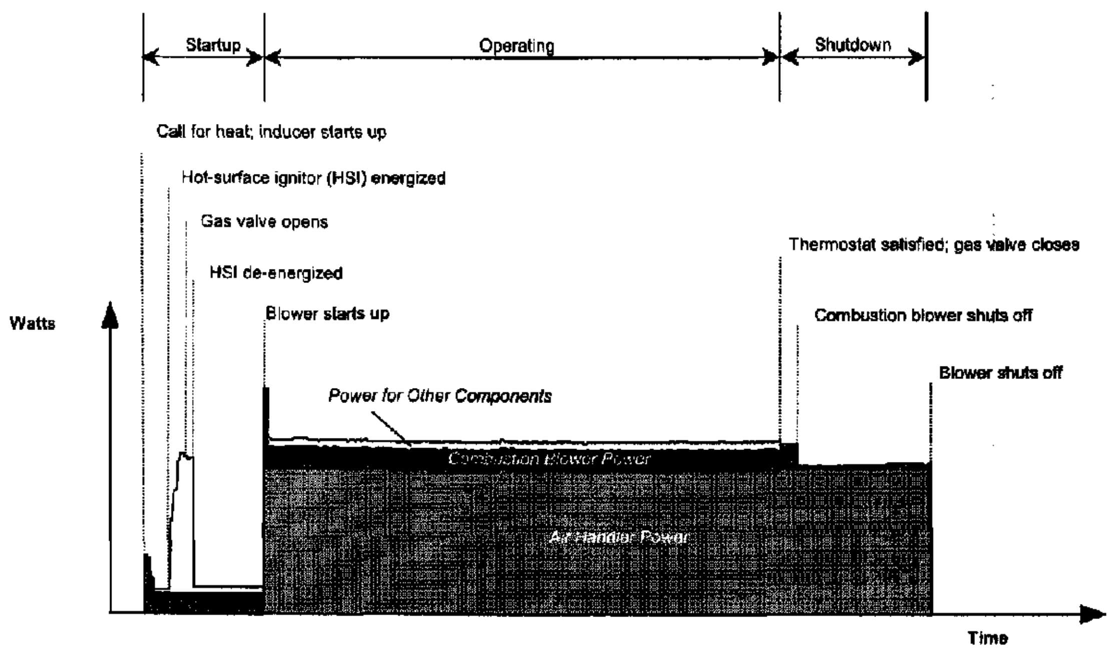
Standby is what furnaces do when they are not being called upon for heating, cooling airflow, or continuous fan-only circulation. Except for furnaces that are called upon to provide continuous air circulation, most furnaces spend the vast majority of their time (typically more than 7,000 hour per year) in this mode drawing a small amount of power that adds five to ten percent to the total annual electricity use for the furnace. The study results indicate that ECM furnaces use more electricity than non ECM furnaces in standby, which reduces the savings from these furnaces by about 30 kWh typically.

The sections that follow cover each of the above operating modes in more detail. Final sections examine the geographic variation in the results, the impact of filter pressure drop on power requirements, and power factor measurements.

Heating Mode

Heating is the most complicated mode of operation for furnaces, involving the most components of the furnace, as well as ignition and shutdown sequences. Figure 3 shows electrical consumption over a heating cycle for one of the furnaces in the study (similar plots for all of the furnaces can be found in Appendix B).

Figure 3: Electrical profile of a typical heating cycle.



Though they differ in timing and in some of the details, the furnaces in the study all follow same basic sequence of operation for heating:

1. Upon receiving a call for heat from the thermostat, the combustion blower starts up.
2. When the system is satisfied that combustion airflow is adequate, the hot-surface igniter (HSI) is energized and after a short warm-up period the gas valve is opened, igniting the burners.
3. After a warm-up interval, the air handler starts up. At this point the furnace begins to deliver warm air to the house.
4. When the thermostat terminates the call for heat, the gas valve immediately closes, extinguishing the burner; after a short purge period, the combustion blower also shuts down.

5. After a pre-programmed period of scavenging heat from the furnace, the air handler shuts off, completing the heating cycle.

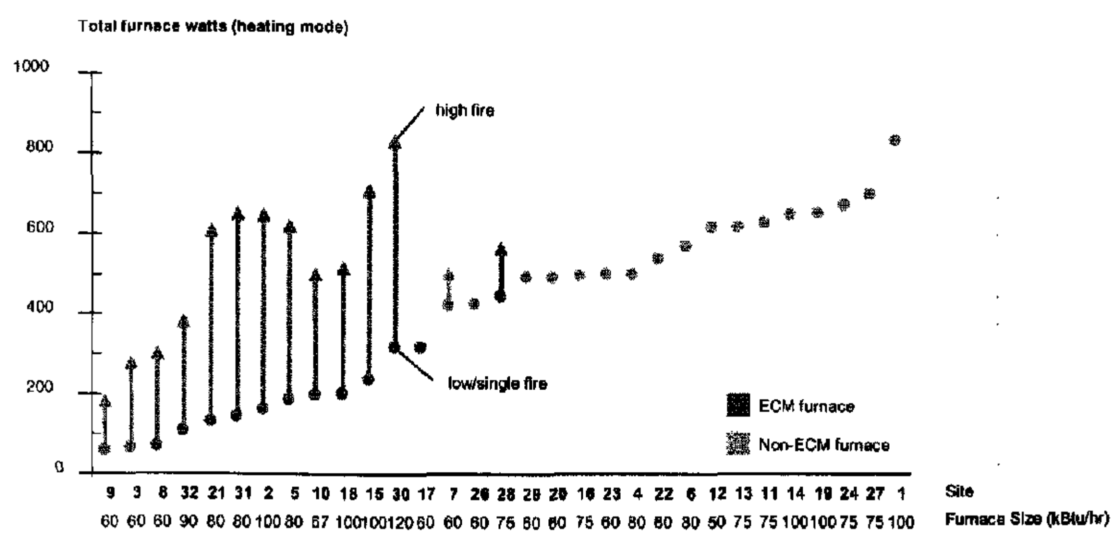
A heating cycle can be divided into three phases: startup, operating, and shutdown. The electricity consumed in the startup and shutdown phases is relatively constant from one heating cycle to the next, and hence is proportional to the number of heating cycles the furnace goes through. The total electricity consumed in the operating phase depends on how long the furnace is run. As the heating load on the home increases, both the number of cycles and the length of the heating cycle can be expected to increase. Analysis of the monitoring data collected on the furnaces in the study suggests that most of the increased run-time for furnaces comes from an increase in the number of cycles the furnace goes through rather than increases in the length of the cycle (see Appendices C and D).

Steady-State Power Draw

Figure 4 shows the overall power consumption of the furnaces in heating mode with both the burner and air handler in operation. It is readily apparent from this figure that the multi-stage ECM furnaces consume significantly less power in low-fire mode than do the single-stage non-ECM models. Some of this difference is no doubt due to the inherent efficiency advantage of the ECM blower, but much derives from the fact that the multi-stage ECM furnaces move considerably less air in low-fire mode. Since blower power is proportional to the cube of the airflow, even a modest reduction in airflow results in substantially lower blower power draw.

In high-fire mode, the multi-stage ECM furnaces in the study do not show as clear an advantage over the single-stage non-ECM furnaces in terms of power draw. The 60,000 Btu/hr models (Sites 3, 8 and 9) all show significantly lower power draw in high-fire mode compared to the non-ECM 60,000 Btu/hr sites (Sites 7, 26, 29, 20 and 23). When viewed in terms of blower wattage versus airflow, these furnaces are clearly set up to deliver less airflow at high-fire. But the 80- to 100-kBtu ECM furnaces draw about the same amount of power as the non-ECM furnaces in this size range.

Figure 4: Heating mode power draw.



Heating Speed Selection and Temperature Rise

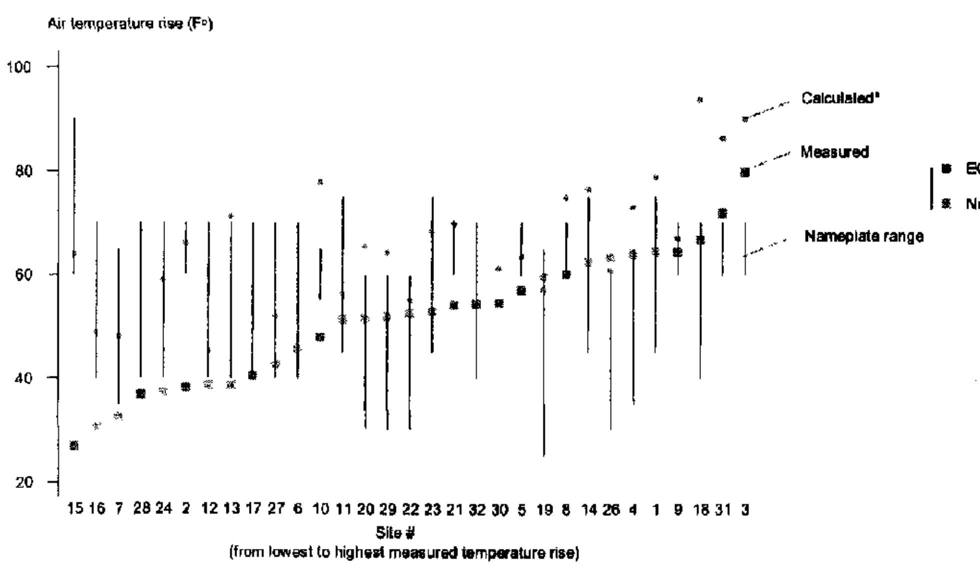
Because air handler energy is a large part of the total power draw, the field selection of the heating blower speed at the time of installation can affect the power consumption of the furnace. The non-ECM furnaces in the study generally have four speed taps to choose from: low, medium-low, medium-high, and high. These furnaces were all set to either medium-low or medium-high, and most appear to be set at the factory default value.

Among the ECM furnaces, it is noteworthy that some are not field adjustable in terms of the heating mode blower speed. These furnaces sense actual airflow and attempt to achieve a preset target airflow. The two fully modulating furnaces can be field set for either a 50 or 65 F° temperature rise. The lower figure would correspond to a higher airflow rate, and vice versa. Both of the furnaces in the study were set for the 50 F° rise; when we tested the higher setting (for Site 28), blower wattage was reduced by about 50 percent.

Each furnace has a nameplate range for temperature rise (i.e. the difference between the supply and return air temperatures in steady-state operation)—typically 40 to 70 F°. Furnaces operating below the nameplate temperature rise are probably moving excessive air—and using excessive electricity—while those operating above the range risk premature heat exchanger failure. Tests on the furnaces in the study showed that dropping one speed tap setting from the default reduced airflow and blower wattage by about 10 percent on average.

Steady-state temperature rise was calculated for each furnace based on test data (see Appendix B). The measurement data suggest that low temperature rises (indicating excessive airflow) are more common than the reverse—12 of the furnaces in the study were below the nameplate range, and only three were above the nameplate range (Figure 5).

Figure 5: Extrapolated temperature rise.



*Calculated based on measured airflow and rated heat output (adjusted for difference between rated and observed heat input)

However, the measurement data did not correspond well with the temperature rise calculated from the measured airflow and the estimated heat output of the furnaces. This second method generally predicted a higher temperature rise than was measured directly (Figure 5). It is possible that the single probes used to monitor air temperature on the supply side underestimated the average temperature of the overall air stream.

Heating Cycles and Hours of Operation

The monitoring data from the study allowed the development of models of daily hours of operation and number of heating cycles as a function of outdoor temperature. These models are needed to extrapolate the monitoring results to a full heating season and adjust the data to average weather conditions. (See Appendix C for more details on the modeling approach).

When modeled with Madison, Wisconsin weather data (which is close to the population-weighted average heating degree days for the state [WEB, 2002]), this exercise shows most furnaces in the study going through between 2,000 and 10,000 heating cycles per year with 500 to 1,500 burner-operating hours (Figure 6 and Figure 7).

The two furnaces with the lowest operating hours (Sites 30 and 14) are known to have substantial alternative heating sources in the home: the occupants at Site 30 rely mainly on a wood stove for space heat and use the furnace primarily as a means of distributing the wood heat throughout the house; the homeowner for Site 14 reported heavy use of a gas fireplace. Two other homes in the study had multiple heating systems, but showed operating hours that were not dissimilar to homes with a single heating system. Site 9 has in-floor hydronic heat in the basement. Site 8 has separate furnaces for each floor of the home (the monitored furnace served the first floor).

Hours of operation also depends on the relative sizing of the furnace in relation to the home's heating load, which in turn is a function of the size of the home, its thermal integrity, and the thermostat setpoint. Site 5 had by far the highest estimated operating hours; this site is also an older home with the highest measured average indoor temperature (see Appendix D). Indeed, three of the five older homes in the study occupy the top three slots in terms of estimated operating hours.

To get a better idea of the sizing of the furnaces in relation to the heating load of the homes, the modeled behavior of each furnace can be combined with knowledge of the gas consumption rate of the furnaces to estimate the percent of full furnace capacity at a given indoor/outdoor temperature difference. Figure 8 shows the results for an indoor/outdoor temperature difference of 90F°, which is within the 80-95 F° range specified (by region) by Wisconsin code (Comm 22.07). The results indicate that most of the furnaces in the study will run at only 40 to 60 percent of their full capacity under these conditions, and are thus about twice as big as needed to meet the daily heating load under these conditions. Since only one furnace in the study (Site 26) falls within the zone where 90 F° is the required design temperature differential, and the remainder fall in the zones where 80 to 85 F° design conditions are required, the results clearly demonstrate that furnaces are typically sized much larger than within 15% of design as required by Wisconsin code (Comm 22.12). Also, given that low-fire output for the two-stage furnaces in the study is typically about 65 percent of high-fire, it also means that these furnaces could meet the design heating load using just the low-fire mode of operation.

There is, however, another consideration in furnace sizing—setback recovery. Many of the homeowners in the study practiced temperature setbacks. As will be demonstrated later in this report, analysis of the time it takes to recover from the setback temperature (as a function of outdoor temperature) suggests that some furnaces would have quite long setback recovery periods under design conditions. From this standpoint, these furnaces are not over-sized.

Figure 6: Annual heating cycles.

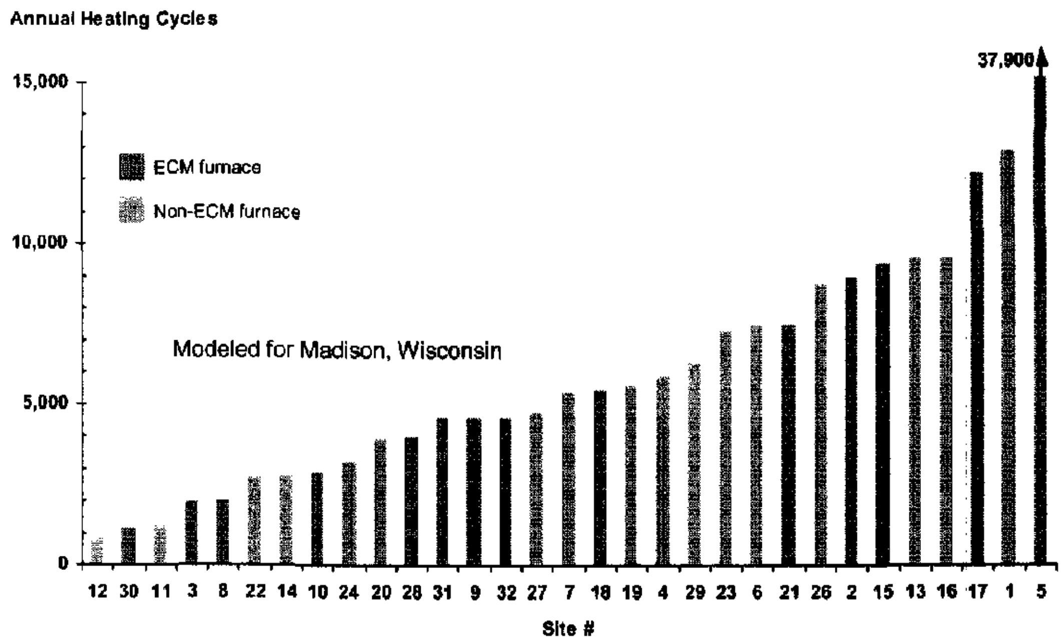


Figure 7: Annual operating hours.

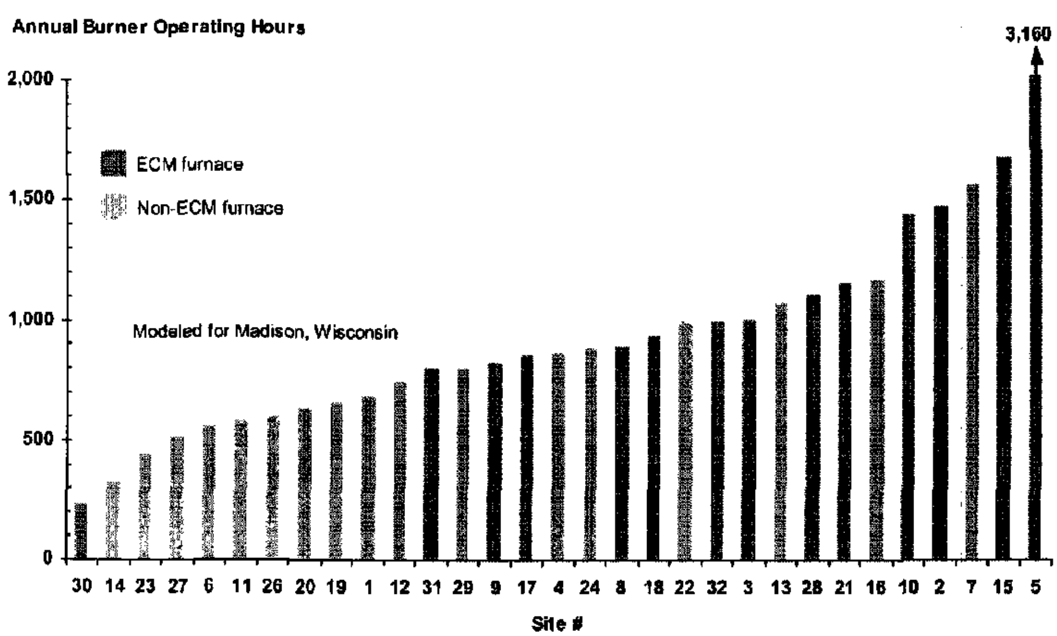
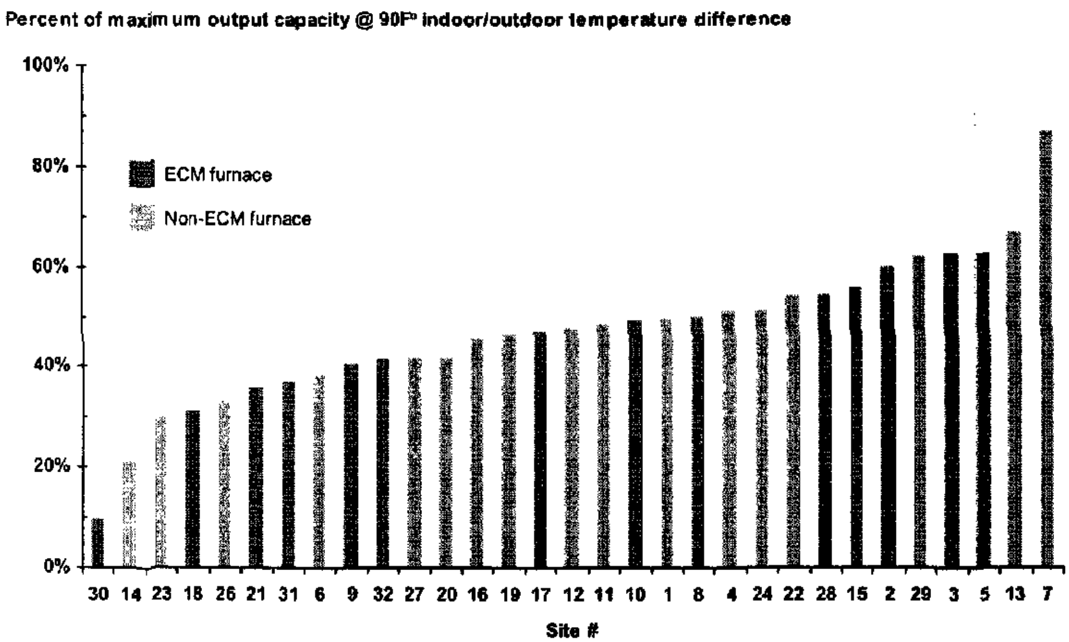


Figure 8: Percent of full capacity at design conditions.

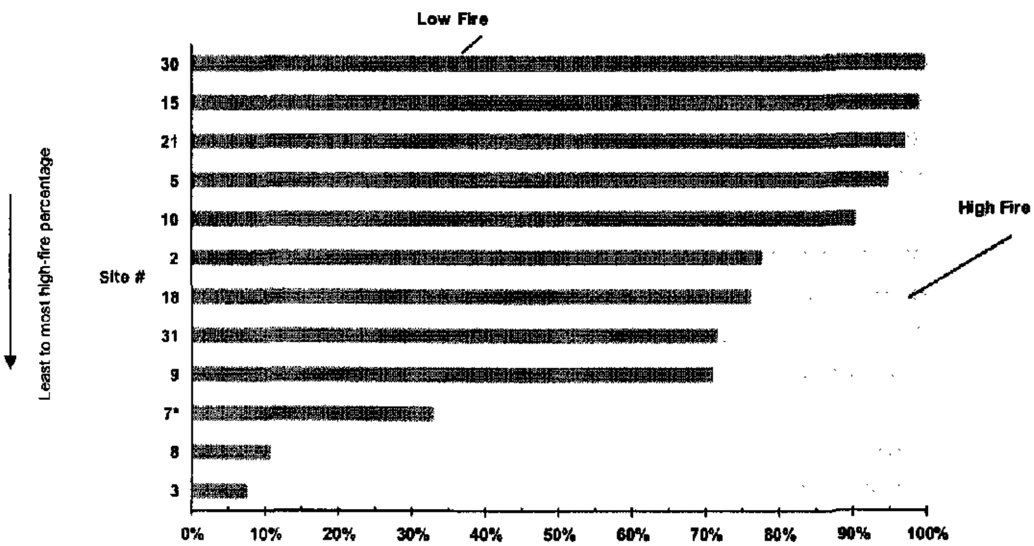


Low/High-Fire Ratio for Two-Stage Furnaces

The two-stage furnaces in the study can operate in one of two heating stages: high-fire (100 percent of rated output), or low-fire, which is generally about 65 percent of full output. The extrapolated low- and high-fire proportions for the two-stage furnaces in the study over the course of an average heating season are shown in Figure 9. Nine of the 11 ECM two-stage furnaces are estimated to operate in low-fire mode 70 percent or more of their firing time, a finding that is generally consistent with product literature claims.

Two ECM furnaces in the study (Sites 3 and 8), however, operated in high-fire mode nearly all the time during the monitoring period. Both of these sites exhibited very long heating cycles (for reasons that are only partially understood), and the high-fire operation appears to be the result of how the staging control was affected by this behavior (which was not seen for the six other sites with this type of staging control but more typical firing cycle lengths). Moreover, as will be shown shortly, the two sites in question still had lower electricity consumption than similar-sized non-ECM furnaces despite operating in high-fire mode the majority of the time.

Figure 9: Low/High-fire proportions for two-stage furnaces.



*Non-ECM furnace

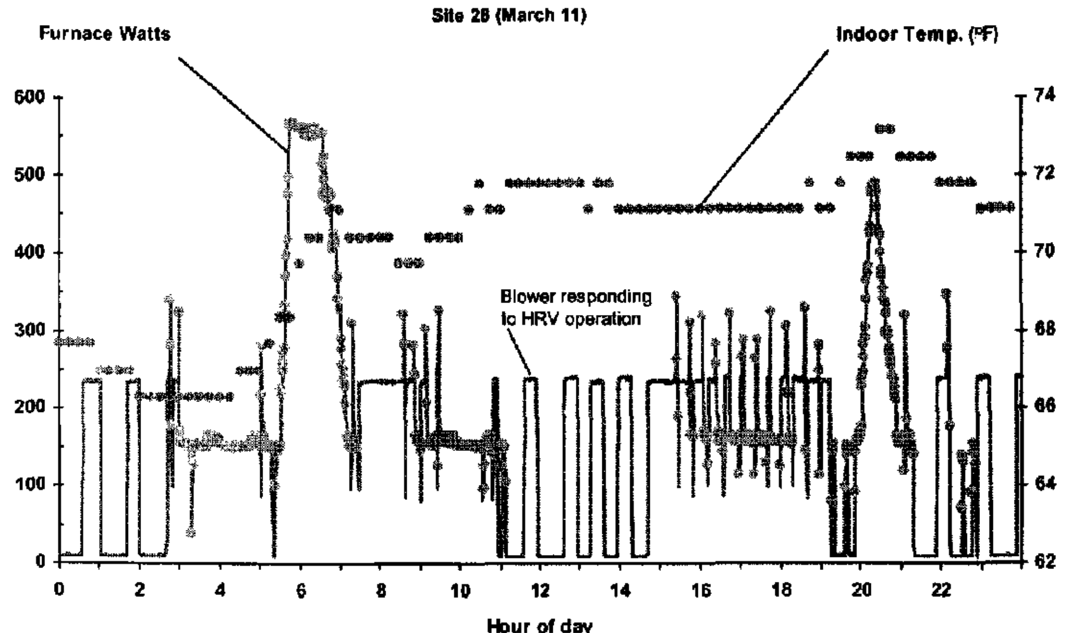
Modeled for Madison, Wisconsin

Operation of Fully Modulating Furnaces

The two fully modulating furnaces in the study (both of the same make, though different sizes) are capable of operating anywhere between 40 and 100 percent of full output. Modulation of these furnaces is controlled by a special thermostat designed for this furnace model. Figure 10 shows the operation of the furnace over a typical day for one of the sites. The furnace operated at low output (drawing about 150 Watts) except when the temperature was being boosted to a higher setpoint. During these periods, the furnace gradually ramped up to high output (about 550 Watts) over the course of about 15 minutes, then ramped back down to low fire when the room temperature began to approach the setpoint.

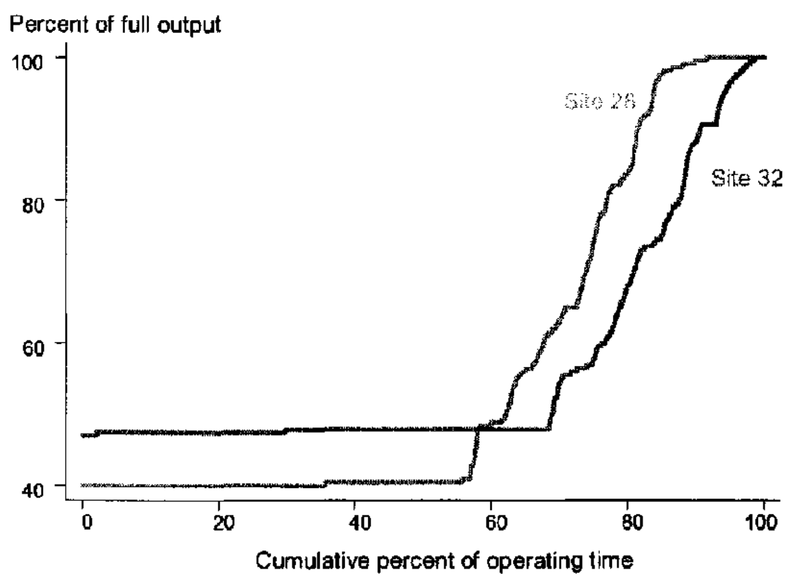
Analysis of about a month's worth of one-minute interval data on the control voltage to the gas valve (which is proportional to the firing rate) indicates that the furnaces at these sites operate at a fairly low firing rate half or more of the time (Figure 11).

Figure 10: Typical day of operation for a modulating furnace.



Furnace watts are one-minute averages
Indoor temperature data are 15-minute snapshots

Figure 11: Distribution of output for modulating furnaces.



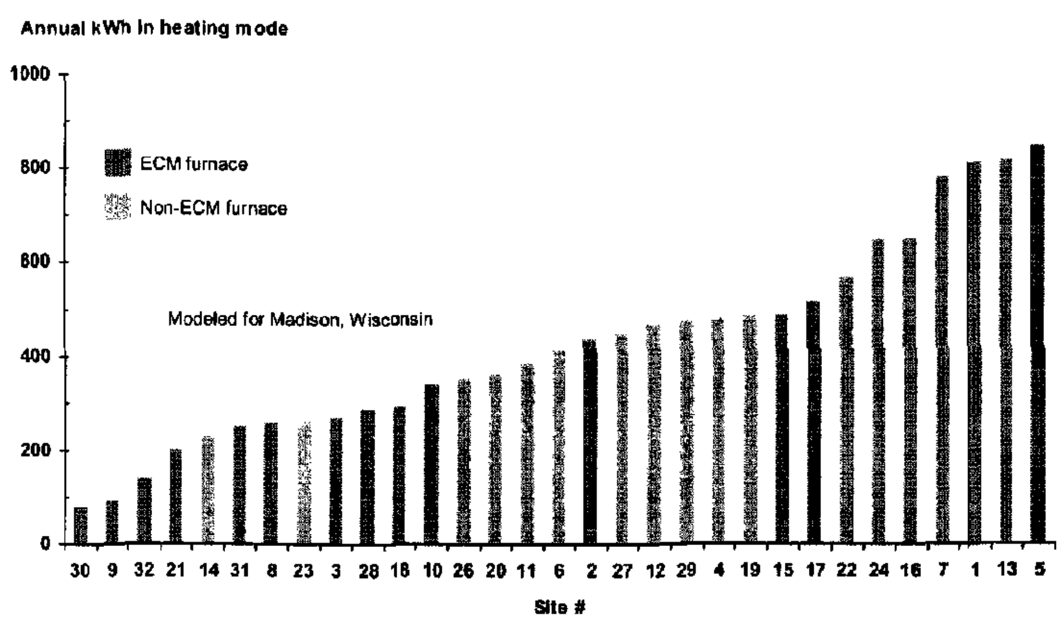
Annual Electricity Use in Heating Mode

As noted at the beginning of this section, furnaces use electricity during the startup, operating and shutdown phases of each heating cycle. When combined with the measurements of electricity consumption over the course of a heating cycle, the models of annual operating hours and cycles provide the basis for estimating annual electricity use by each furnace over a typical heating season. The data also allow this electricity use to be separated by furnace component and cycle phase.

Figure 12 shows estimates of the annual electricity consumption for each of the furnaces in the study. These estimates are obviously influenced by factors such as sizing, thermostat settings, and the use of auxiliary heat, all of which tend to cloud the comparison of ECM and non-ECM furnaces. For this reason, it is more instructive to look at the distribution of heating electricity use per therm of gas consumed (Figure 13). When viewed in this way, the two groups are clearly distinct, with the ECM furnaces mostly occupying the lower end of the distribution and the non-ECM furnaces at the upper end. The anomalous results for Site 17 appears to be due to misconfiguration of this three-zone system.[4]

The median ECM furnace in the study uses about 0.5 kWh per therm of gas in heating mode, which is about half that of the median non-ECM home. This suggests heating-mode savings of about 400 kWh per year for a typical older home with annual gas consumption of 800 therms.[5]

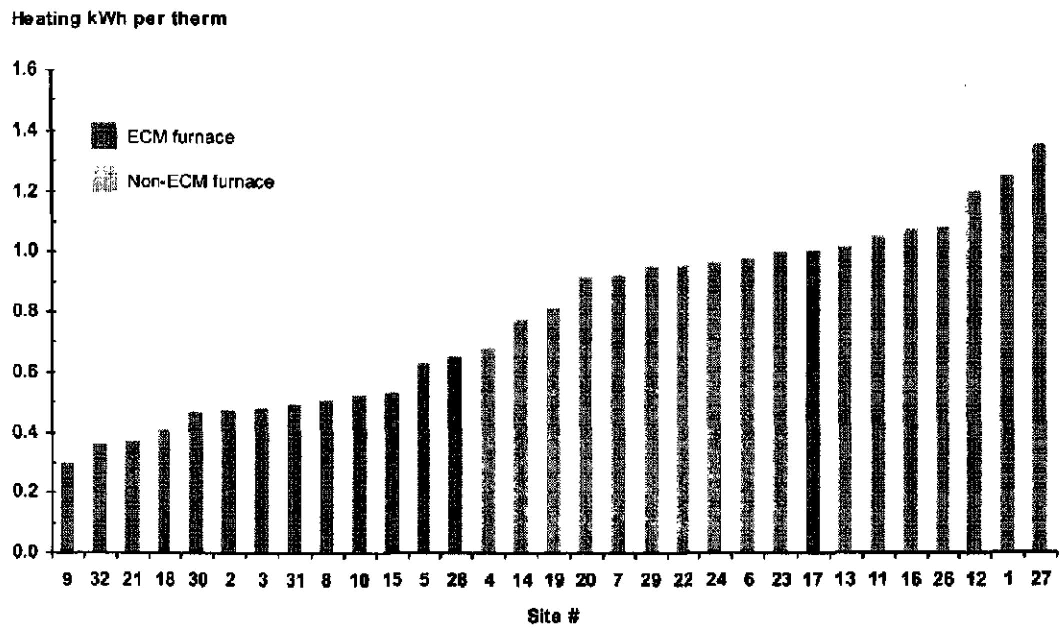
Figure 12: Annual electricity use in heating mode.



[4] Based on feedback from this study, the homeowner brought a heating contractor in to look at the system, which resulted in a number of changes to the setup of the system that should substantially reduce electricity use by the furnace.

[5] This level of gas usage is the average found from analysis of gas data for a sample of 97 Wisconsin homes built prior to 1994 with condensing furnaces in a recent characterization study of Wisconsin homes (Pigg and Nevius, 2000).

Figure 13: Annual electricity use per therm of gas consumed.



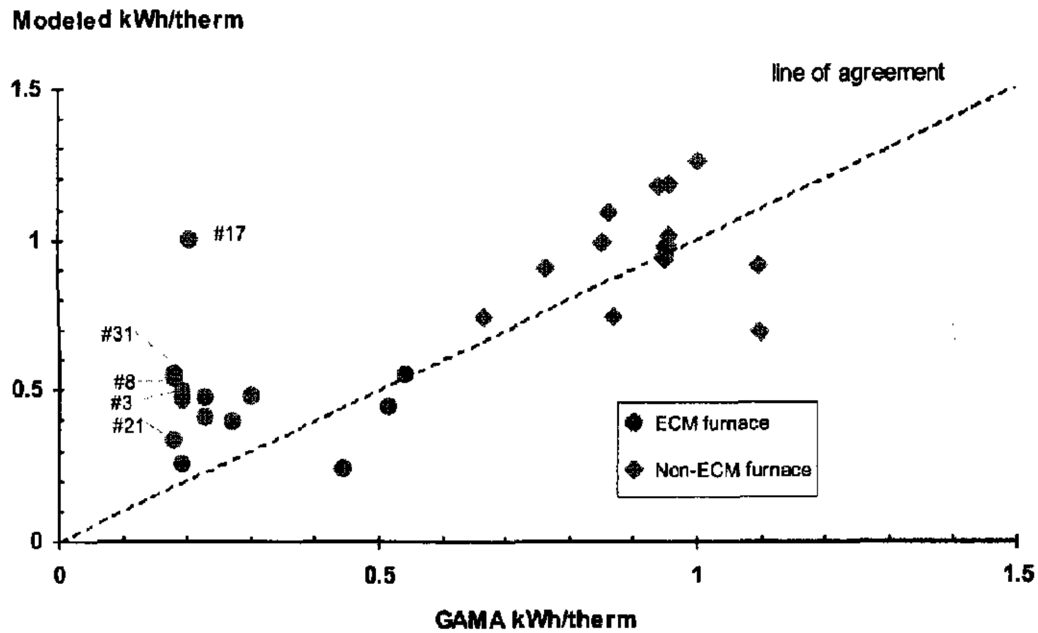
Heating Electricity Use — Field Results and GAMA Ratings

The estimates of annual electricity use per therm of gas consumption from the field results can be compared to rating data published by GAMA. The GAMA directory provides two published values for annual gas consumption and annual electricity consumption (Ef and Eae, respectively) under standard test conditions that can easily be combined to derive rating-based electricity use per therm.

Figure 14 compares the modeled estimates of annual heating electricity use per therm from the field data to the GAMA rating data.[6] A number of observations can be made from this comparison. First, at a gross level there is a general correspondence between the two values; sites with low rated electricity use per therm (generally ECM models) tend to have low values from the field, and those with higher ratings have higher observed values. In fact, the data suggest that a simple discriminant of Eae/Ef = 6 (corresponding to 0.6 kWh per therm) can be used to distinguish ECM from non-ECM furnaces. (This discriminant may not be applicable to "southern" style furnaces that have proportionately larger blower motors to accommodate larger air conditioning systems.)

[6] For this comparison, the field data were adjusted to remove differences between the measured and nominal gas input rates for the furnaces. The adjustments were generally less than 15 percent (see Appendix B).

Figure 14. Modeled versus rated heating kWh per therm.



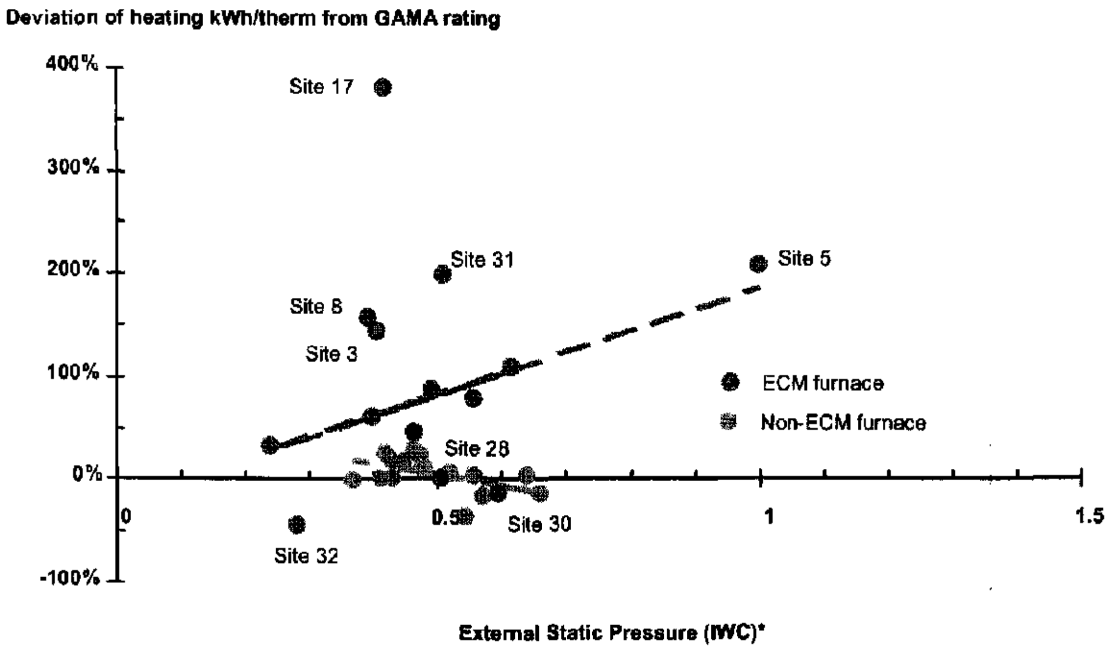
Second, the data suggest that the rating data tend to underestimate the actual electricity use of the furnaces on average—but more so for ECM furnaces on a percentage basis. In three-quarters of the cases, the field data show more electricity use per therm than the rating data would indicate, but this blends the fact that 86 percent of the ECM furnaces (12 of 14) exceeded the rating value compared to 65 percent of the non-ECM furnaces (6 of 17). Because the ECM furnaces generally occupy the low end of the kWh-per-therm scale, the difference between the two groups is fairly large in percentage terms: the median ECM furnace uses 82 percent more electricity per therm than the rating data would indicate, compared to just three percent for the median non-ECM site.

Clearly, there are site-specific configuration and behavioral factors that can strongly affect heating electricity use per therm. Site 17 uses much more electricity than its rating data would suggest; this furnace was found to be mis-configured for much higher airflow than needed. Similarly the two sites that operated in high-fire mode most of the time (Sites 3 and 8) are somewhat on the high side in kWh per therm compared to their ratings.

The data also reveal how behavioral factors can influence electricity use for the ECM furnaces. Sites 21 and 31 have identical furnaces that operate under comparable static pressures and have about the same total gas consumption. Yet Site 31 uses about 60 percent more electricity per therm than Site 21. The explanation for this difference is that the homeowners at Site 31 practice substantial day and night thermostat setbacks, while the homeowners at Site 21 keep their thermostat at a constant setting. The setback practice at Site 31 translates into about 30 percent high-fire operation compared to less than five percent high-fire at Site 21. Since high-fire operation has five to six times the overall power draw of low-fire for these sites but consumes only about 50 percent more gas, the upshot is higher electricity use per therm for Site 31.

The data also suggest that differences between static pressure levels in the field and those used in the ratings may underlie some of the observed differences. The ASHRAE standard on which the rating data are based stipulates a minimum external static pressure of 0.2 inches water column (IWC) at the highest firing rate for furnaces in the 55,000 to 80,000 Btu/hr size range, and 0.23 IWC for furnaces with firing rates of 80,000 to 100,000 Btu/hr. Both of these values are considerably lower than the observed external static pressure among the furnaces in the study, which ranged from 0.24 to 1.0 IWC and averaged about 0.5 IWC. (The field measurements were also made downstream of the central air conditioning evaporator coil, which means that true external static pressure across the furnace cabinet is even higher.) These high static pressures are consistent with other field data (e.g., Phillips, 1998 and Proctor and Parker, 2000)

Figure 15. Percent deviation of heating electricity use per therm from rating value.



*in high-fire heating operation

As Figure 15 shows, the data show some tendency for the discrepancy between measured and rated electricity use per therm to go in opposite directions for the two groups as static pressure increases: ECM furnaces use more as static pressure increases (though there is considerable scatter in the data) and non-ECM furnaces use less. This is consistent with the way these furnaces operate. Non-ECM furnaces operate at a fixed speed: as static pressure increases for these furnaces, airflow (and electricity use) declines. In contrast, the ECM furnaces in the study use a blower motor manufactured by General Electric that can sense airflow and adjust its speed accordingly. As static pressure increases on an ECM furnace, the blower motor compensates by running at a higher speed (and using more electricity) to continue to deliver the desired airflow.

If external static pressure under actual conditions is higher on average than those used in the rating procedures (as this and other studies suggest), the result would be to narrow somewhat the differences between ECM and non-ECM furnaces in electricity use per therm—though the ECM furnaces still clearly use considerably less electricity than the non-ECM models.

Electricity Use by Component and Operating Phase

Figure 16 shows how heating-mode electricity use is distributed between the inducer fan, the air handler and other components of each furnace. As could be expected, the air handler accounts for the bulk of the electricity use for all of the furnaces, typically accounting for about 80 percent of the total electricity use in non-ECM furnaces, and about 70 percent in ECM models. The ECM furnaces show a somewhat higher proportion of electricity use for "other" components: this is less a consequence of these components drawing more power than non-ECM furnaces than it is the result of much lower fan power, resulting in "other" representing a proportionally larger slice of the pie.

Similarly, Figure 17 breaks electricity into the three phases of operation for heating: startup (from the call for heat until the air handler starts), operating, and shutdown (from the end of the call for heat to air handler shutdown). Again, it is no surprise that the operating phase dominates, accounting for about 80 percent of the total on average. But the data suggest that there are conditions under which startup and shutdown electricity can exceed the operating electricity use. Less than half of the electricity for Site 1, for example, is used during steady-date operation. This site has the second shortest average firing cycle length in the study (about three minutes of firing per cycle), and it has a fairly long blower-off delay (two minutes). Thus, this furnace spends about a minute warming up, two minutes operating, and then two minutes shutting down. Site 17 also has a large proportion of its electricity use devoted to shutdown due to an unusually long blower-off delay (more than 7 minutes). Cycle lengths are discussed in the next section.

Figure 16: Heating-mode electricity use by component.

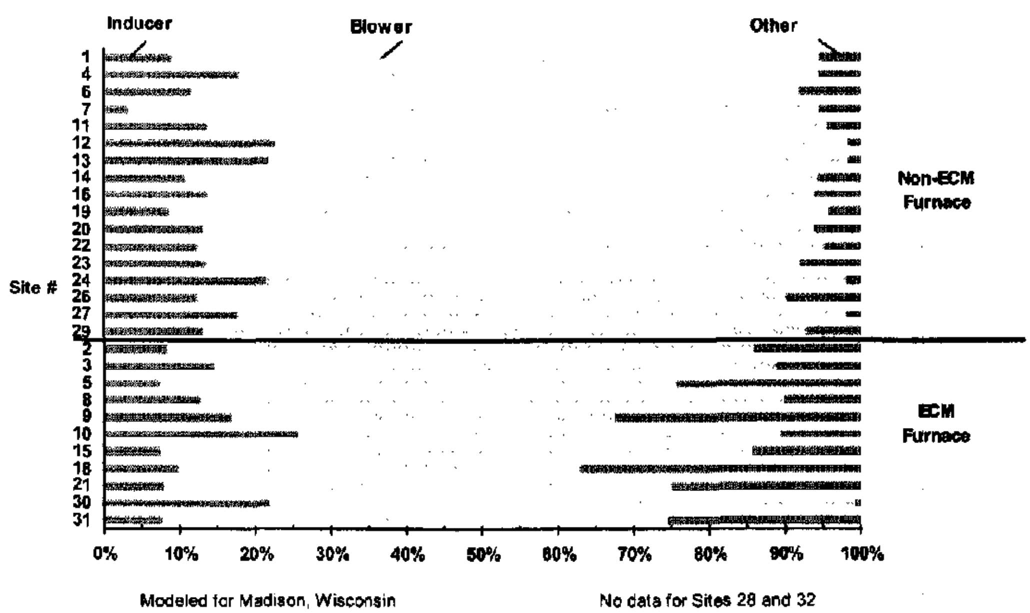
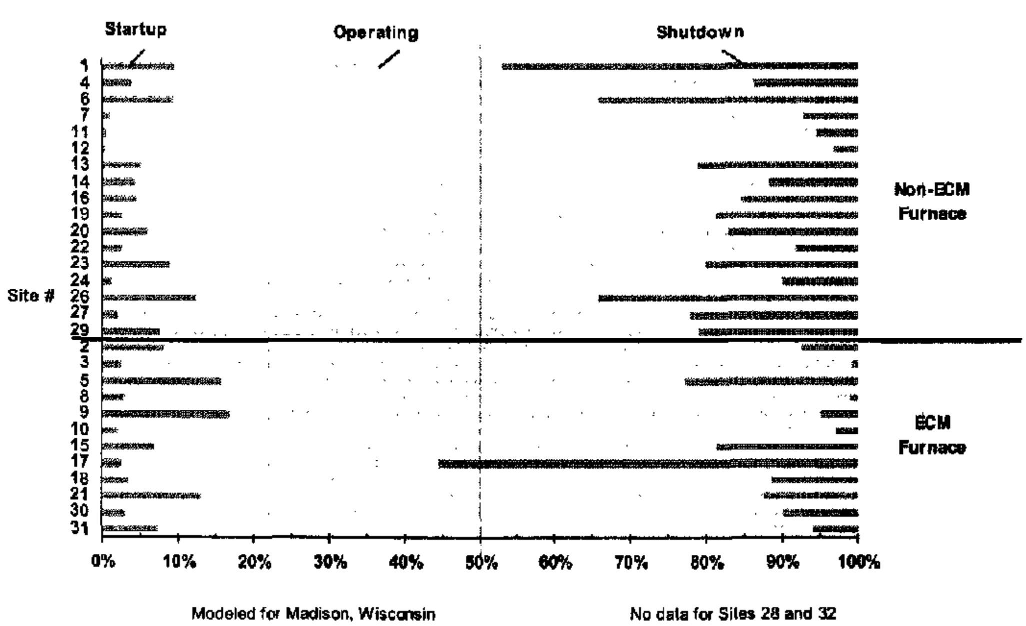


Figure 17: Heating-mode electricity use by cycle phase.



Cycling Behavior

As the preceding section shows, cycle length can affect electricity consumption. A certain amount of electricity is needed during the startup and shutdown phase of a heating cycle, so furnaces that cycle more frequently will use more electricity per therm of gas consumed.

Because of the way the data were collected, the study provides copious information on heating cycle length. We focus here on three summary statistics: the median and maximum daily firing time and the number of cycles per day. The median daily firing time is the middle value for firing length among all heating cycles in a given day and represents the length of a typical firing cycle for that day. The maximum daily firing time generally represents the setback recovery cycle for homes that practice thermostat setback. For many of the homes in the study, these values are a function of outdoor temperature; as outdoor temperature declines the median and maximum daily firing cycle length increases. For this reason, results shown below are normalized to a common outdoor temperature (see Appendix D).

Figure 18 shows the median firing cycle length for the study sites. Most furnaces in the study had typical firing cycle lengths between 5 and 15 minutes, but a few had relatively short cycles, and five sites had typical firing times that exceeded 20 minutes. As noted previously, the two, two-stage furnace sites with staging control issues are in this group. Thermostat deadband and placement as well as furnace sizing undoubtedly all play into the cycle length.

Figure 18: Median firing cycle length.

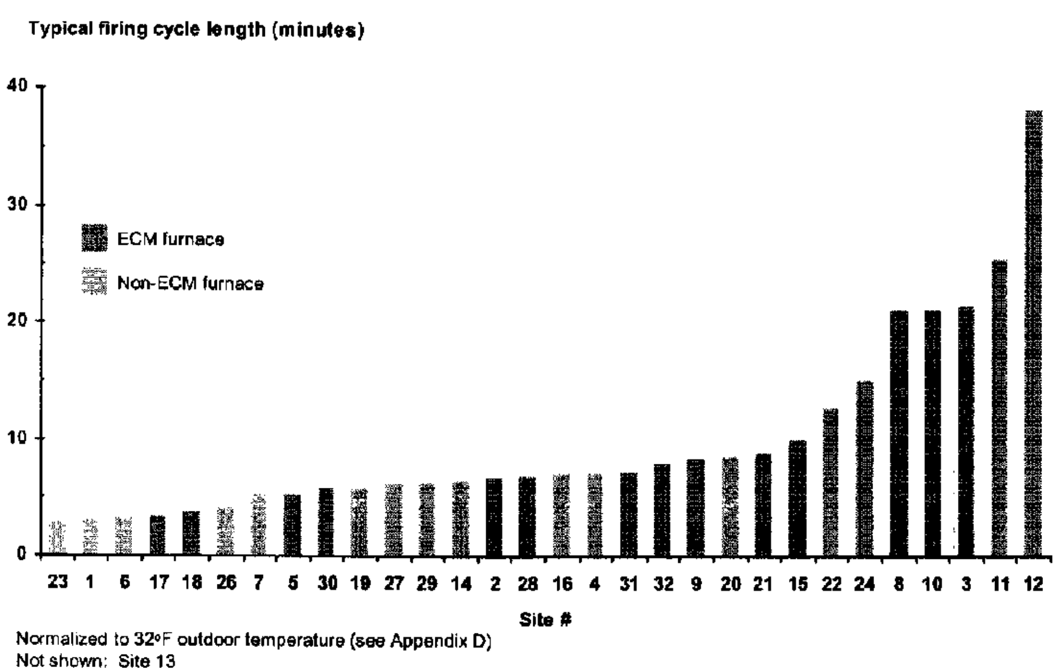
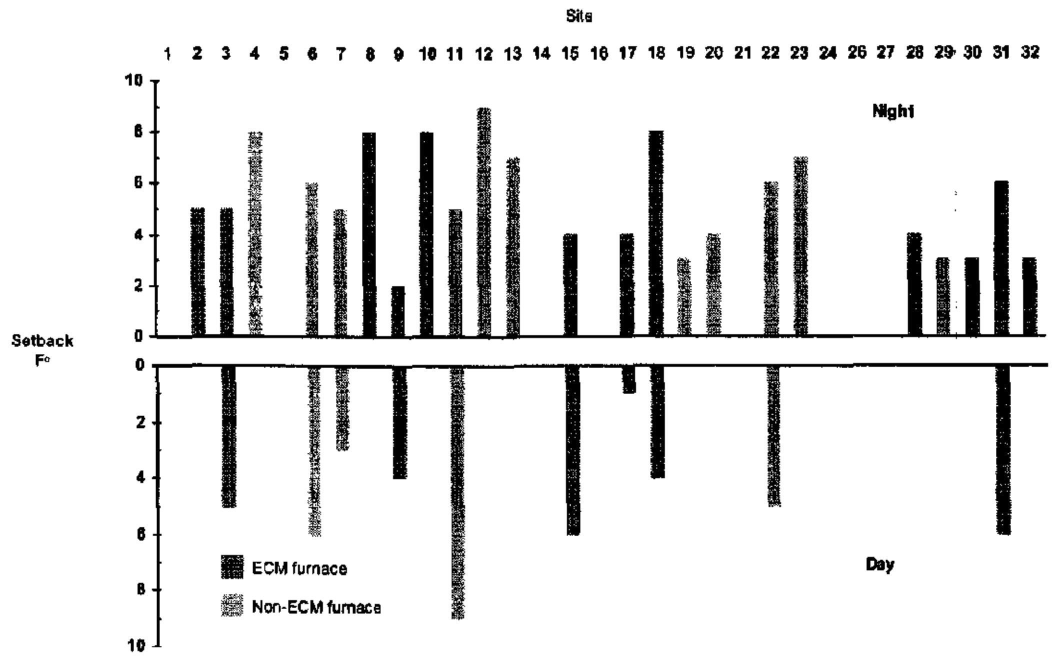


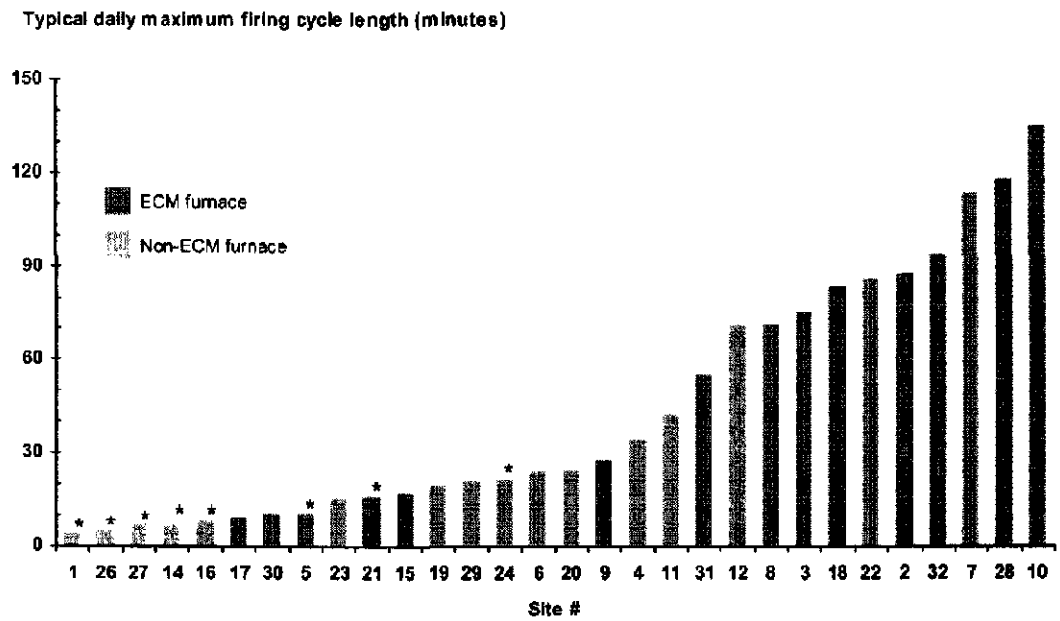
Figure 19: Typical daily thermostat setbacks.



Many of the homeowners in the study practiced thermostat setbacks, as Figure 19 shows (Appendix D contains more information about average indoor temperatures and time-of-day temperature profiles during the heating season). Analysis of the daily maximum heating cycle length—which normally represents the setback recovery period in homes where setback is practiced—shows a fairly wide range in setback recovery times under typical outdoor weather conditions (Figure 20). These recovery times are no doubt a function of both the depth of the setback and the sizing of the furnace in relation to the home's heating loads.

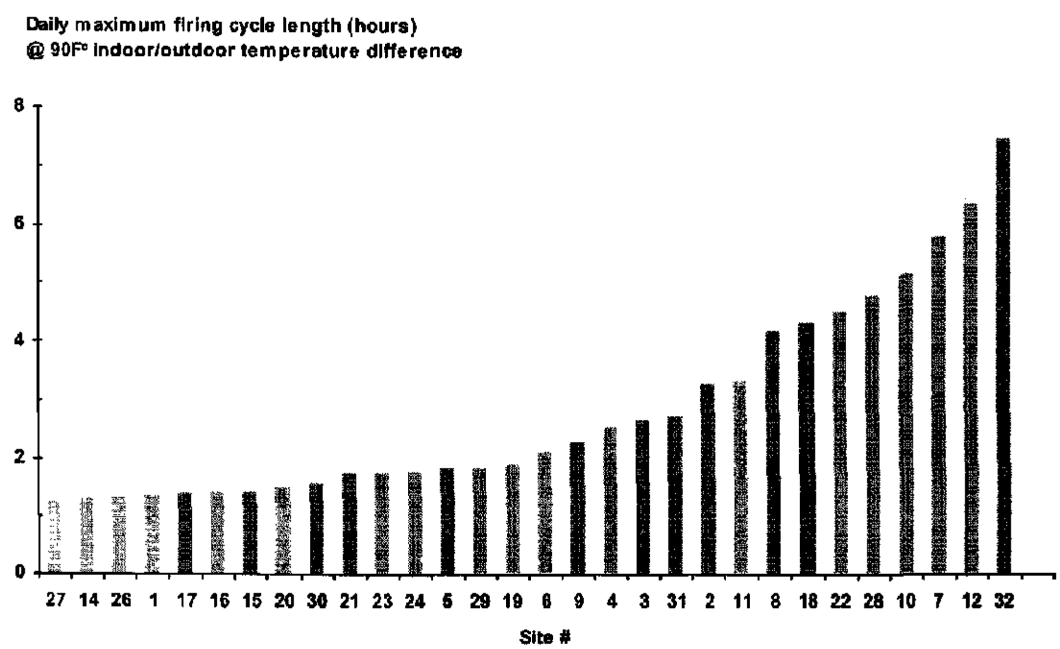
When the data on maximum daily firing cycle are extrapolated to design conditions (90 F° indoor/outdoor temperature difference), some sites appear to have very long setback recovery times (Figure 21). From this standpoint, these furnaces are not oversized. However, it can also be argued that if long setback recovery is an issue, homeowners should simply refrain from setting back the thermostat very much under extremely cold conditions.

Figure 20: Maximum daily firing cycle length under typical winter conditions.



*No setback practiced
Normalized to 32°F outdoor temperature (see Appendix D)
Not shown: Site 13

Figure 21: Maximum firing cycle length at design conditions.



The number of heating cycles that a furnace goes through in a day is strongly correlated with outdoor temperature for most of the sites (see Appendix C). Indeed it appears that, for the most part, it is more the increase in the number of heating cycles rather than the length of the heating cycle that contributes to the increase in total furnace run time as the outdoor temperature drops.

For most sites, the number of heating cycles in a day is fairly linear in outdoor temperature (scatter plots for all sites in the study are provided in Appendix C). However a few sites exhibit a relationship like the one shown in Figure 22, where there is an apparent limit in the number of heating cycles that the furnace can go through during a day. The exact cause of this behavior is unknown, but may be due to limits imposed by certain thermostats on the number of cycles per hour.

In any event, when normalized to typical winter conditions, there is a fairly wide variation in the number of daily heating cycles across the sites (Figure 23). As with heating cycle length, this variation probably reflects differences in thermostat deadbands, the relative sizing of the furnaces, and details about thermostat placement.

Figure 22: Daily heating cycles versus outdoor temperature for one site.

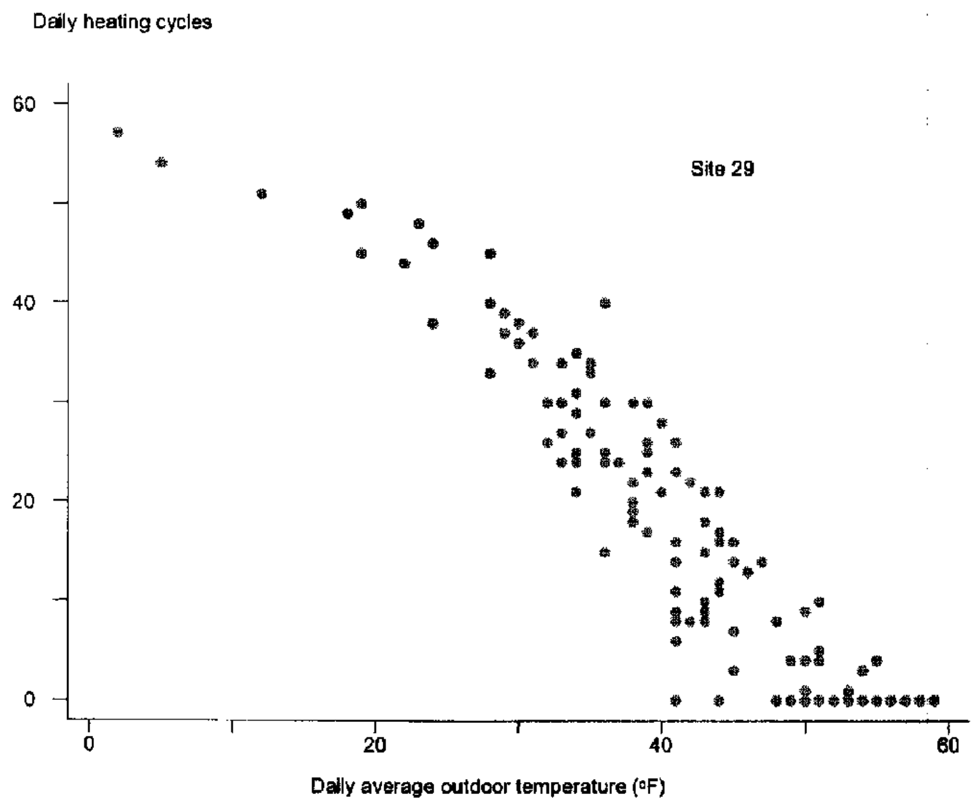
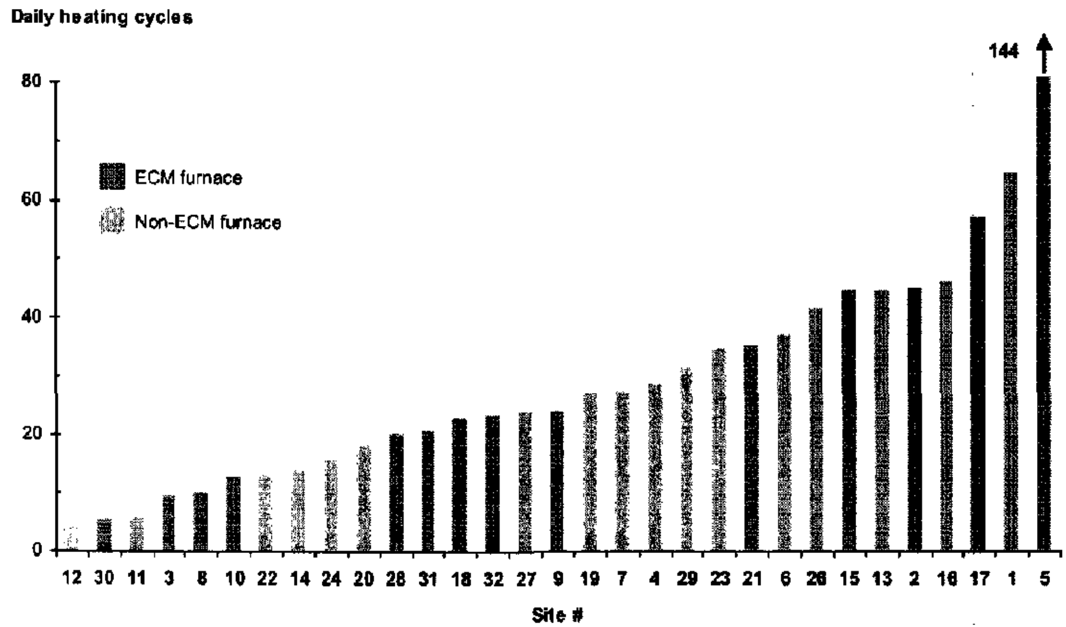


Figure 23: Typical daily number of heating cycles.



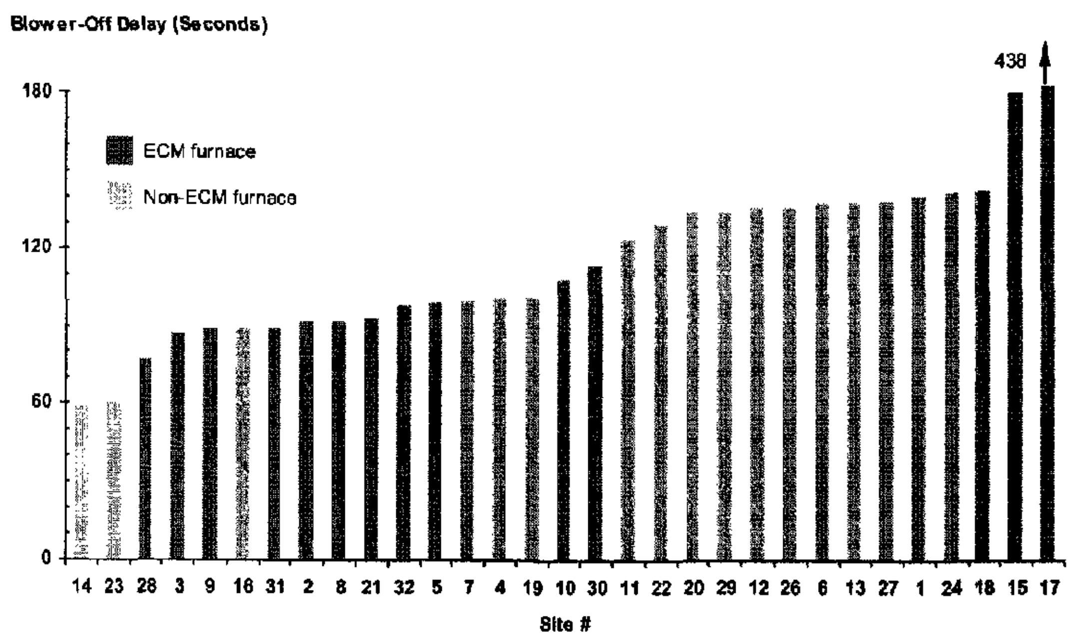
Normalized to 32°F outdoor temperature (see Appendix C)

Blower-Off Delay

The delay period between the time the call for heat ends and the air handler blower shuts down also affects electricity use. Longer blower-off delays translate into more electricity use per therm of gas consumed, though less so for the ECM models, as these furnaces typically drop to their lowest airflow during the blower-off delay. All of the furnaces in the study have blower-off delays that are field configurable via DIP switches on the control board.

Figure 24 shows the blower-off delays measured for the furnaces in the study during testing. Most are between 90 and 150 seconds. The very long blower-off delay for Site 17 is symptomatic of a number of configuration issues at this site.

Figure 24: Blower-off delay.

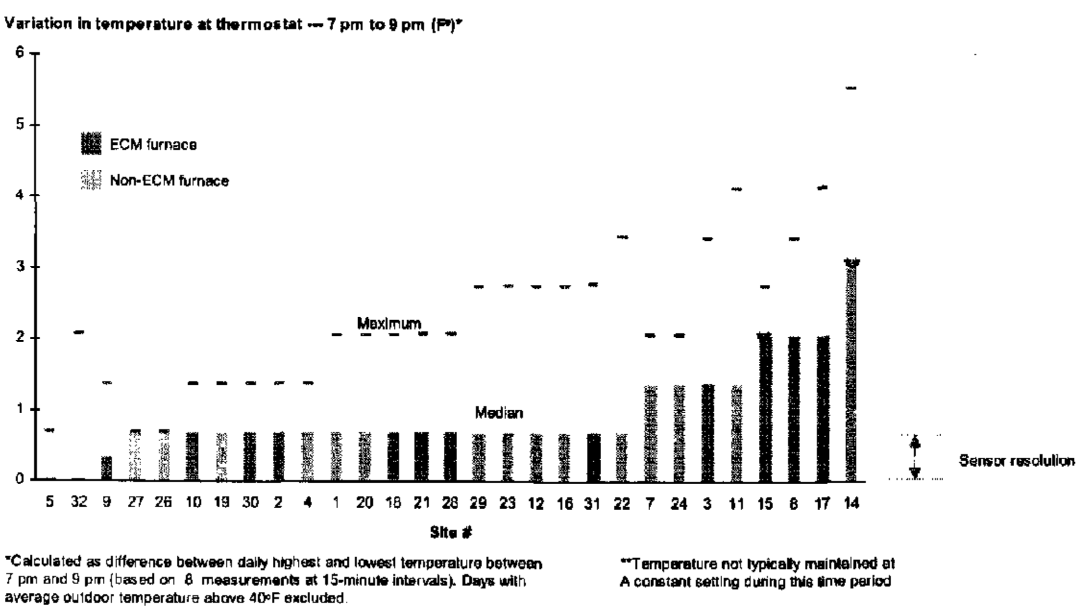


Heating Season Temperature Control

When it comes to maintaining tight control on indoor temperature, the data suggest that nearly all of the furnaces in the study do a good job. This observation comes from analysis of temperature data recorded by sensors placed at the thermostat as part of the study. The analysis focused on the daily period between 7 pm and 9 pm, which was the time the thermostat was most likely to be maintaining a constant setting (changes in indoor temperature at the beginning and end of setback periods could otherwise cloud the analysis). Analysis of the temperature range recorded during this time period shows that at most of the sites the indoor temperature typically varied by less than 1F° (the resolution of the sensors used was about 0.7F°), though a few sites showed a typical swing of 2 F° (Figure 25). These statistics may underestimate the actual swing if the heating cycle period is such that the 15-minute interval at which the temperatures are recorded tends to be at the same point in the heating cycle. Nonetheless, even the maximum recorded temperature swing over the course of monitoring during these hours indicates less than a 3F° variation for most of the sites.

It is notable that there is no clear difference in temperature swing between the ECM and non-ECM furnaces. It is also noteworthy that three of the five sites with heating cycles that typically exceed 20 minutes in length (Sites 3, 8 and 11) are also in the group with wider temperature swings, suggesting that the thermostats for these systems have a wider deadband (although subsequent field checks for Sites 3 and 8 revealed that they were set for a nominal 1F° temperature swing).

Figure 25: Heating season indoor temperature swing.



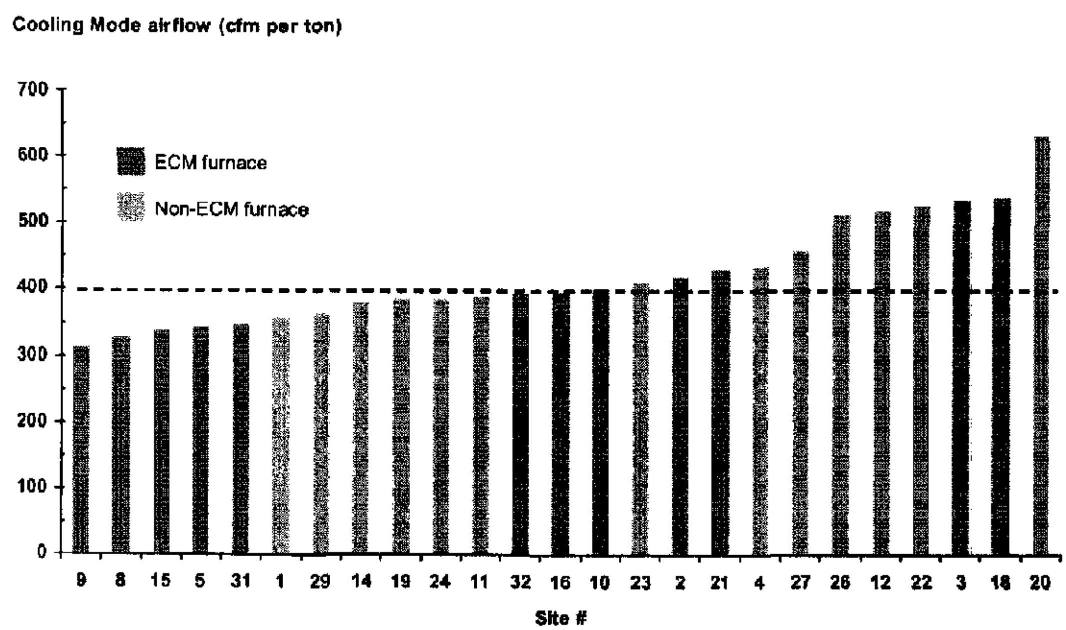
Cooling Mode

Airflow and Operating Watts

In cooling mode, the air handler operates at a pre-set cooling speed. The near-universal guideline is that the air handler should deliver 400 cfm per ton of air conditioning capacity. In practice, most non-ECM furnaces are simply set to the highest available airflow (only two of the 17 non-ECM furnaces in the study were set otherwise). ECM furnaces on the other hand typically have DIP switches that the installer sets to match the air conditioning tonnage, and provide 400 cfm per ton of airflow.

As Figure 26 shows, most of the furnaces actually delivered airflow somewhere in the range of 350 to 450 cfm per ton of air conditioning capacity when operating at the cooling speed. However, there is a group of mostly non-ECM furnaces with more than 500 cfm per ton of airflow. With the exception of Site 26—which was already set at the lowest possible cooling speed—these are sites with smaller central air conditioning systems for which the high speed setting on the air handler provides too much air flow. Air handler power requirements would be reduced by 20 to 25 percent (roughly 100 to 140 Watts) if the cooling speed setting was set to provide as close to 400 cfm per ton as possible.

Figure 26: Airflow per ton of air conditioning capacity at cooling speed.



Not shown: Sites 6, 7, 13, 17, 28 and 30

Figure 27: Cooling-mode wattage versus airflow.

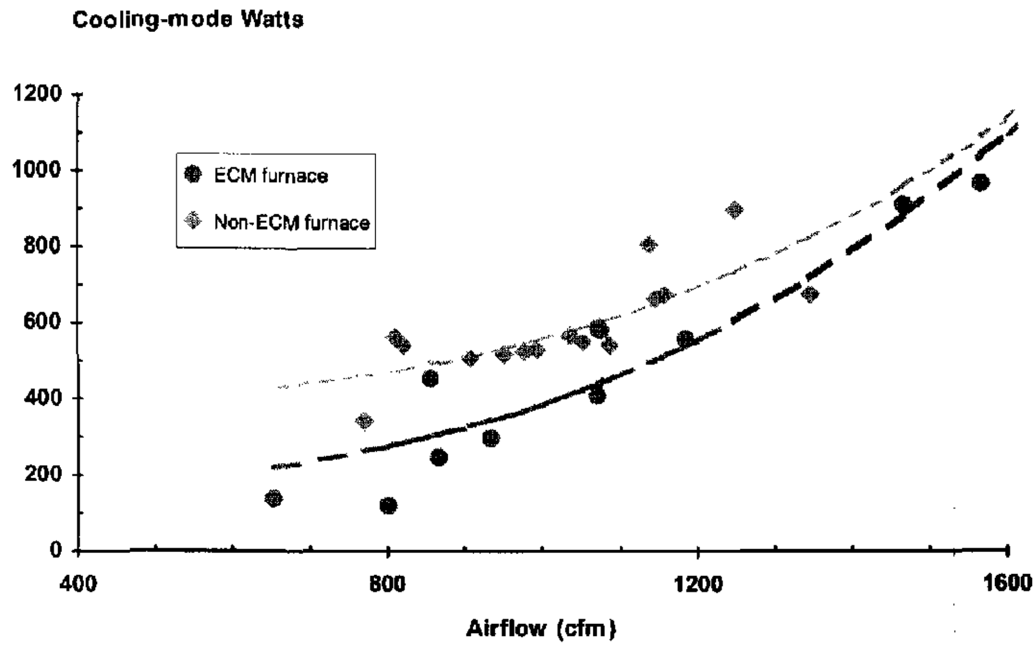


Figure 27 shows furnace wattage in cooling mode as a function of airflow. The data suggest that below about 4 tons of air conditioning (1600 cfm) ECM furnaces on average have lower power draw than non-ECM furnaces. Regression fits to the data suggest an average difference of about 175 Watts at 1000 cfm (2.5 tons) and 150 Watts at 1200 cfm (3 tons).

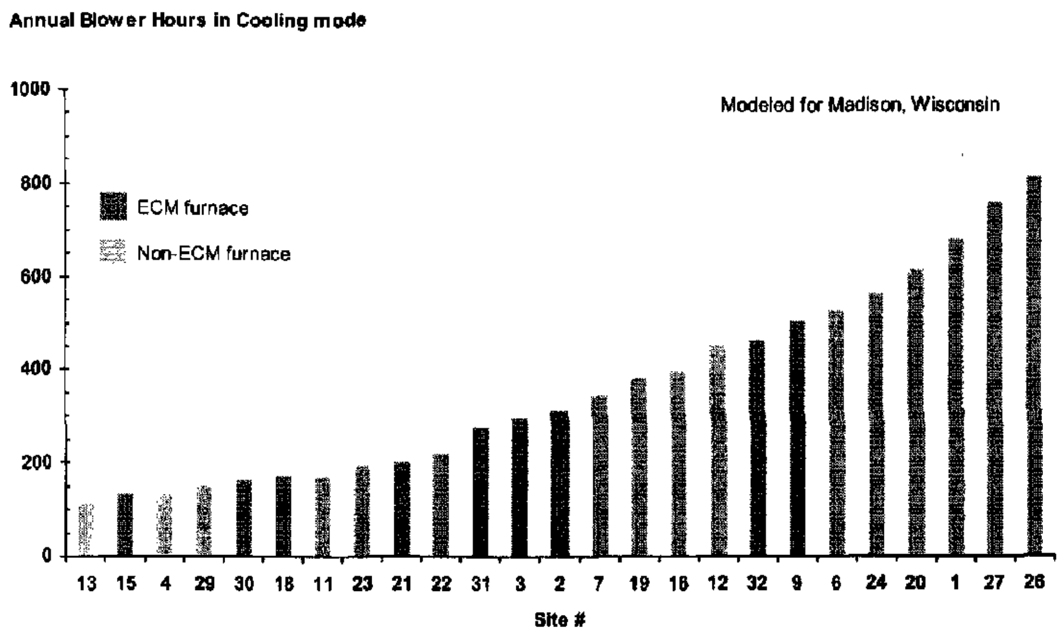
Operating Hours and Cooling-Mode Electricity Savings

Models of daily run-time as a function of outdoor temperature for each site (see Appendix C) show a wide range of predicted seasonal air-handler operating hours in cooling mode (Figure 28). This could be expected given the relatively discretionary nature of air conditioning use in Wisconsin.

However, if 400 hours is taken as a typical value for central air conditioning use, then ECM furnaces could be expected to yield 60 to 70 kWh of direct blower energy savings, based on the regression fits shown in Figure 27. Lower blower wattage also translates into less waste heat in the air stream to be removed by the air conditioning system. This additional electricity savings is estimated at about 20 to 25 kWh, bringing the overall estimate of ECM savings in cooling mode to 80 to 95 kWh per year for 2.5- and 3-ton air conditioning systems, respectively.[7]

[7] For example, for a 10 SEER system: 60 kWh of direct blower electricity savings * 3,413 Btu per kWh / (10 Btu per watt * 1000 watts per kW) = 20.5 kWh indirect cooling electricity savings.

Figure 28: Annual cooling-mode hours.



Not shown: Sites 5, 8, 10, 14, 17 and 28

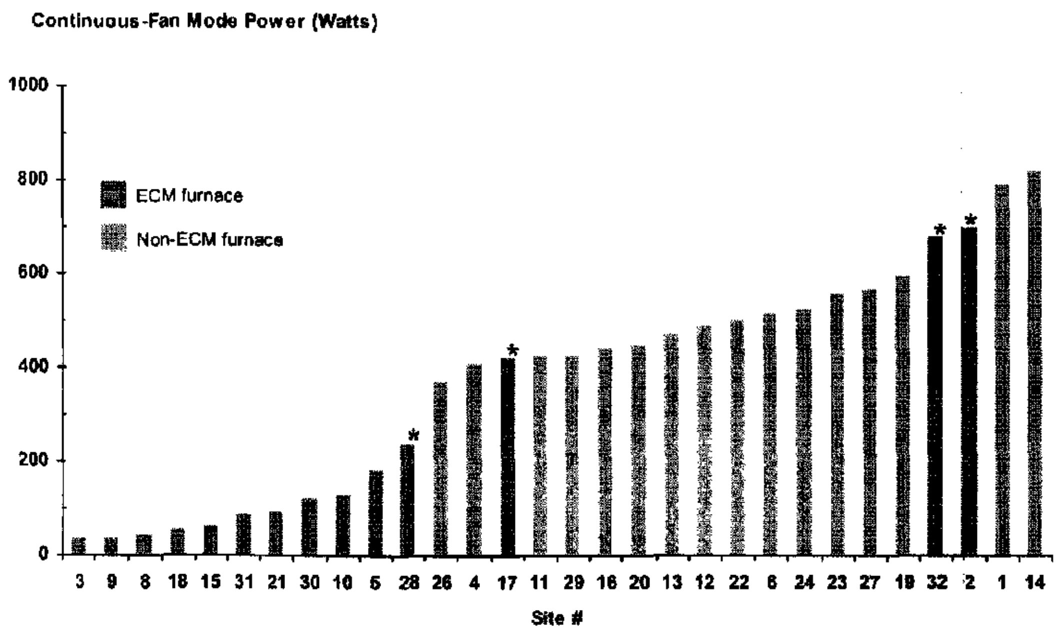
Continuous-Fan Mode

Continuous-fan mode corresponds to setting the fan switch on most thermostats to "on" (rather than "auto"). People choose to run the air handler continuously for a variety of reasons, but chief among these are filtering out house dust and reducing temperature differences in the home. A minority of participants in the study actually operate their furnace in continuous-fan mode part or all of the year (Table 1), but we tested all of the furnaces in this mode regardless of the actual practice of the homeowner, and were thus able to model continuous-fan electricity use.

Table 1: Continuous-fan use by study participants.

Continuous-fan use	Number of sites
Never	20 Sites
All year long	5 Sites (Sites 4, 10, 17, 18, 20)
Winter only	1 Sites (Sites 30)
Summer only	2 Sites (Sites 13, 21)
Ad hoc basis	3 Sites (Sites 8, 9, 14)

Figure 29: Continuous-fan mode power draw.



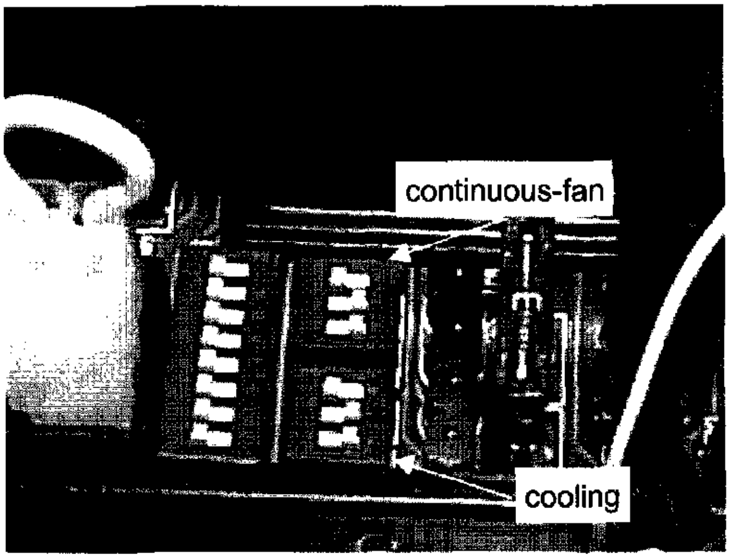
*configured for speed other than factory default

There is a clear difference in capability between the ECM and non-ECM furnaces in the study in power draw in continuous-fan mode. All of the ECM furnaces have a separate (and field adjustable) continuous-fan speed setting that is generally factory-set for a very low airflow delivery (typically 500-600 cfm). In contrast, all but two of the non-ECM furnaces in the study ran at the heating speed when called upon for continuous-fan operation.

As could be expected, this means that the ECM furnaces generally draw considerably less power in continuous-fan mode than the non-ECM sites (Figure 29). The ECM furnaces mostly draw less than 200 Watts of continuous-fan power, with 100 Watts as a reasonable average value. In contrast, the non-ECM furnaces drew between 400 and 800 Watts, with 500 being a typical value.

Four ECM furnaces were found to be configured to higher continuous-fan speeds than the factory default. Site 2 is the most interesting example of these. Continuous-fan airflow for the furnace at this site is determined by the settings of three DIP switches immediately to the right of an identical bank of DIP switches that set the cooling airflow. The settings at this site were found to be the same as the cooling airflow settings (Figure 30). This resulted in about twice the continuous-fan airflow than would have been the case at the factory default (1,400 measure cfm, versus 700 cfm) and nearly six times the blower power draw (750 Watts, versus 130 Watts).

Figure 30: Continuous-fan and cooling airflow DIP switches for Site 2.



Whether the contractor who installed the furnace was confused about how to set the DIP switches or simply felt that a furnace should deliver the cooling-mode airflow in continuous-fan mode is not known. However, it can be said that the homeowner was not consulted on this. When told about this, the homeowner—who did not normally use continuous-fan mode—said he had been under the impression that his new furnace was supposed to circulate air more quietly, but found it to be noisy when he tried running it in fan-on mode.

Both of the two modulating furnaces (Sites 28 and 32)—which were installed by the same heating contractor—were also found to be set to higher than default settings for continuous-fan mode. This furnace model has a DIP switch that allows one to choose between two airflow settings. When tested at the lower setting (500 cfm), the Site 28 furnace drew only 93 Watts, compared to 280 Watts at the higher setting (800 cfm).

Hours of Operation and Savings

Continuous-fan mode hours are essentially all hours that the furnace is not operating in heating or cooling modes. The furnace models described in Appendix C predict thousands of hours of continuous-fan operation in this mode (Figure 31). Median run-time hours for the furnaces in the study were 7,400 for year-round operation, 3,500 for winter-only operation, and 2,000 for summer-only operation.

Using rounded median values for operating hours and wattage draws for ECM and non-ECM furnace in this mode, Table 2 shows estimates of electricity savings in continuous-fan mode.

Figure 31: Hours of operation in continuous-fan mode.

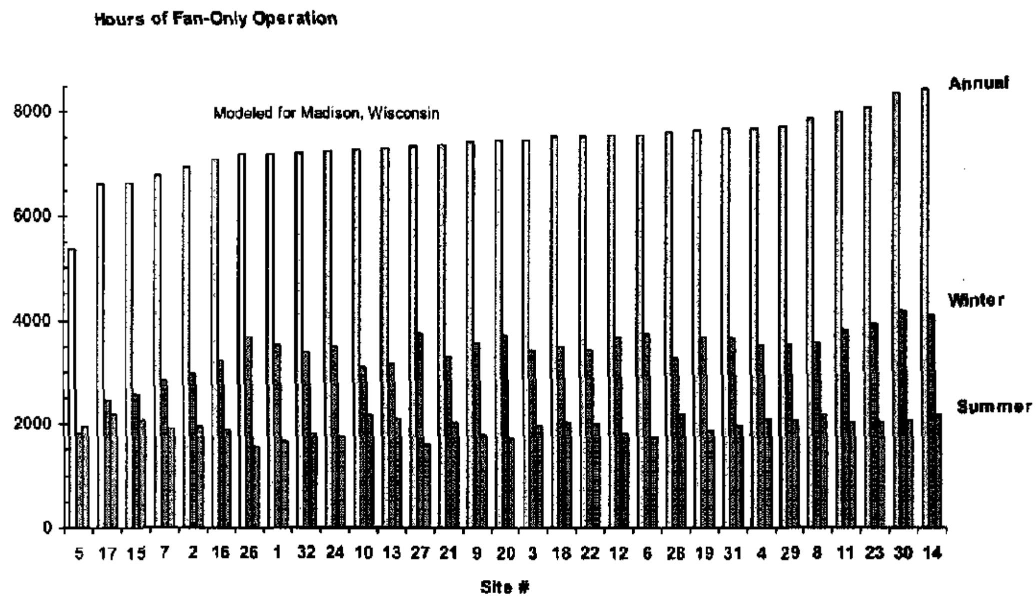


Table 2: Continuous-fan electricity use, by furnace type.

	Continuous-Fan Mode Electricity Use (kWh)		
Season of Use	**Non-ECM Furnace (median 500 Watts)**	**ECM Furnace (median 100 Watts)**	**Difference**
Year-Round (median 7,400 hours)	3,700	740	2,960
Winter Only (median 3,500 hours)	1,750	350	1,400
Summer Only (median 2,000 hours)	1,000	200	800

Central Ventilation and Furnace Air Handler Operation

Central ventilation systems such as heat recovery ventilators (HRVs) are sometimes wired with an air handler interlock, meaning that whenever the HRV operates, the furnace air handler also operates at the continuous-fan speed. Ten sites in the study had central ventilation systems, but only four of these were interlocked with the furnace air handler. (Sites 16, 26, 28 and 32—interlocked HRV operation (on a 20-minute on, 40-minute off schedule) can be seen for Site 28 in Figure 10 on page 19.)

Homes with an interlocked central ventilation system will thus have higher furnace electricity use if they do not already practice continuous-fan operation. Estimating this additional electricity use is difficult though, because homeowner use of the systems can vary substantially (Pigg, 2002b).

Standby Power Consumption

All of the furnaces in the study consumed a small amount of power in standby mode. Standby power ranged from 4 to 13 Watts, with a median of 8 Watts (Figure 32). The ECM furnaces dominate the higher end of the distribution, presumably due to large and more complicated control circuitry. On average, the ECM furnaces consumed 4 Watts of standby power above that consumed by the non-ECM furnaces in the study.

Modeling of the furnaces in the study suggests that furnaces not running in continuous-fan mode have an average of about 7,500 hours per year of standby operation (Figure 33). This translates into additional electricity consumption of about 30 kWh per year in this mode for ECM furnaces in the study.

Figure 32: Standby mode power consumption.

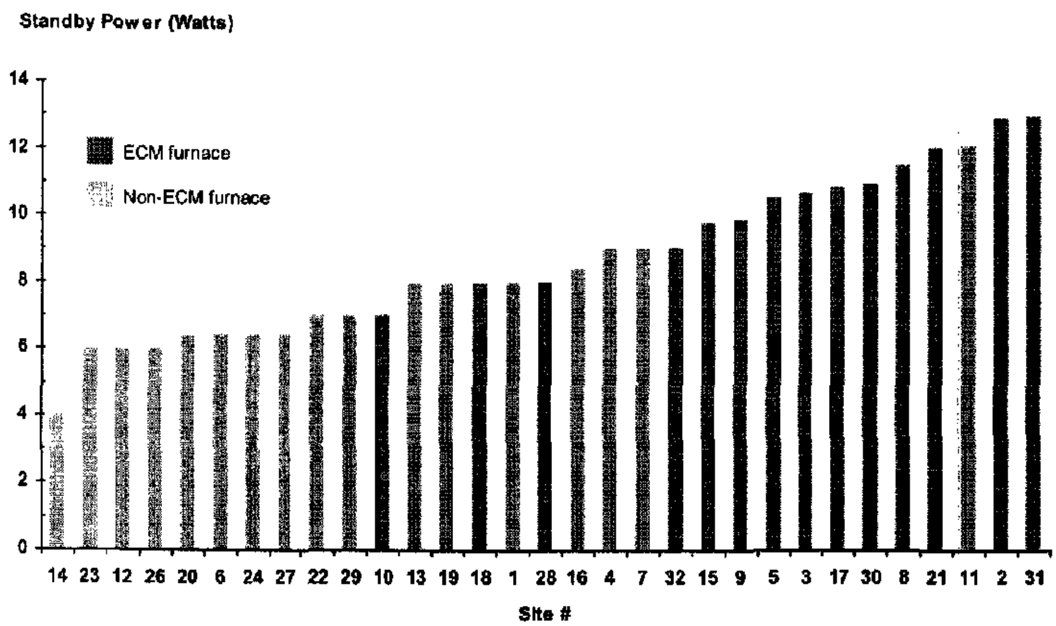
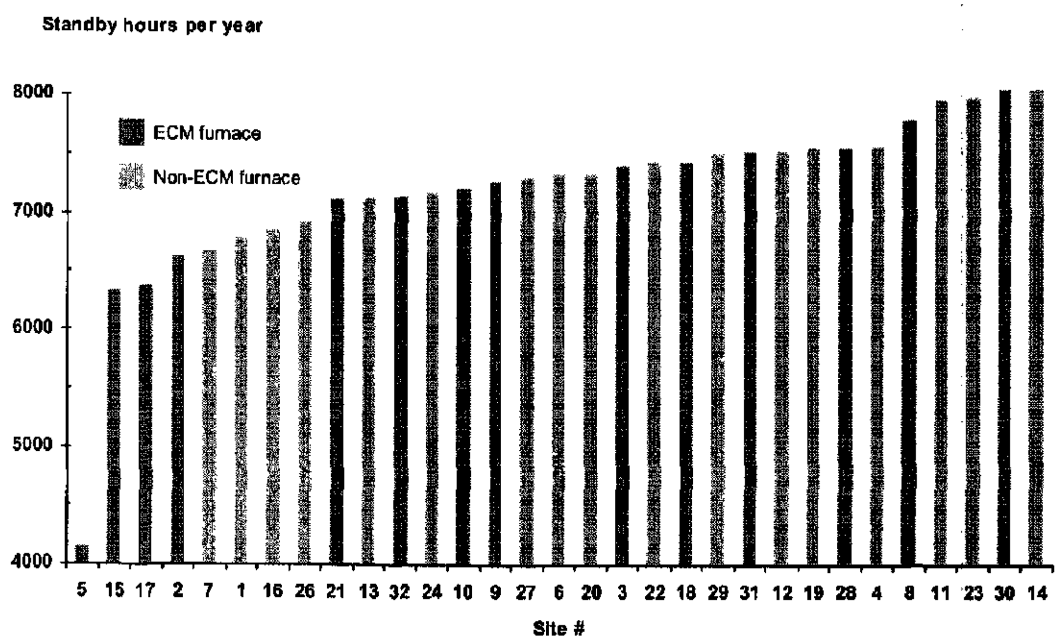


Figure 33: Annual hours of standby mode.



Modeled for Madison, Wisconsin
Assumes no continuous-fan operation

Summary of Electricity Use Results

Table 3 summarizes the preceding results based on typical values from the study. Two scenarios are shown: no continuous-fan use, and year-round continuous-fan operation. Both scenarios assume the presence of central air conditioning.

The results suggest that for the range of systems studied here, substituting an ECM furnace for a non-ECM furnace will save an average of about 465 kWh per year in homes that do not practice continuous-fan use, and about 3,455 kWh per year in homes that run the air handler continuously. At a current average electricity price of about 8 cents per kWh, this translates to $36 annual electricity savings in the former scenario, and about $270 annual savings in the latter.

Table 3: Summary of annual electricity use and ECM savings.

Mode of Operation	No continuous-fan use			Year-round continuous-fan use		
	Non-ECM	**ECM**	**Difference**	**Non-ECM**	**ECM**	**Difference**
Heating (kWh)[a]	800	400	400	800	400	400
Cooling (kWh)[b]	225	155	70	225	155	70
Continuous-Fan (kWh)	0	0	0	3,700	740	2,960
Standby (kWh)	60	90	-30	0	0	0
Total (kWh)	1,085	645	440	4,725	1,295	3,430
Indirect AC (kWh)[c]			25			25
Overall including indirect (kWh)			465			3,455

[a]For annual gas use of 800 therms.

[b] For a 2.5-ton air conditioner with airflow of 1000 cfm and 400 hours of operation per year.

[c]Represents additional air conditioning electricity difference from reduced need to remove air handler waste heat.

Geographic Variation

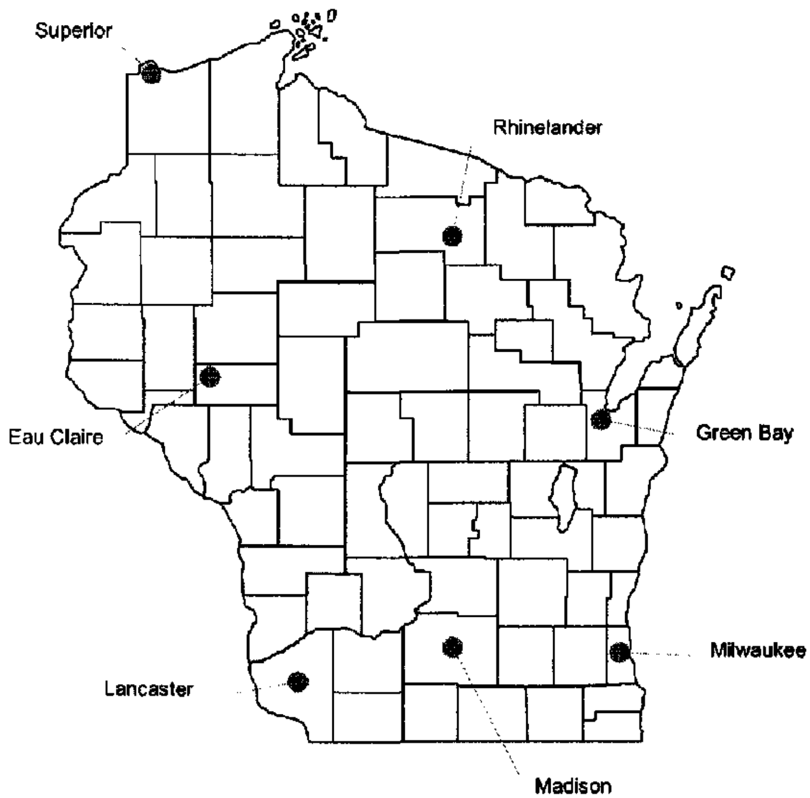
The results presented thus far are based on modeling the operation of the furnaces in the study with Madison, Wisconsin weather data. At about 7,600 heating degree days per year, Madison is close to the population-weighted average heating degree days for the state (7,800 heating degree days; WEB, 2002).

To provide a better sense of how the results vary over the state, Table 4 shows the median percentage difference in selected estimates when the furnaces are modeled with weather data in other parts of the state (Figure 34). While there are substantial differences in the modeled energy use for heating and cooling, heating electricity use per therm is relatively invariant to location. Similarly, modeled continuous-fan and standby hours are not strongly affected by location.

Table 4: Median change in selected modeled values for other locations, relative to Madison, Wisconsin.

	Green Bay	Milwaukee	Lancaster	Eau Claire	Superior	Rhinelander
Heating						
Therms	+7.5%	-7.3%	+1.8%	+17.8%	+28.4%	+26.5%
Cycles	+6.9%	-5.6%	+1.1%	+14.3%	+25.8%	+22.8%
burner hours	+7.8%	-7.9%	+2.0%	+18.9%	+29.2%	+27.8%
kWh	+7.7%	-7.6%	+1.9%	+18.4%	+28.8%	+27.3%
kWh/therm	0.0%	+0.1%	0.0%	-0.2%	-0.1%	-0.2%
Cooling						
Hours	-19.2%	+6.1%	+1.9%	-25.5%	-59.8%	-47.7%
kWh	-18.8%	+5.7%	+2.0%	-24.9%	-59.6%	-47.2%
Cont.-fan hours	-0.4%	+0.7%	-0.3%	-1.3%	-1.7%	-1.9%
Standby hours	-0.4%	+0.8%	-0.3%	-1.5%	-2.0%	-2.1%

Figure 34: Location of weather stations used for modeling.



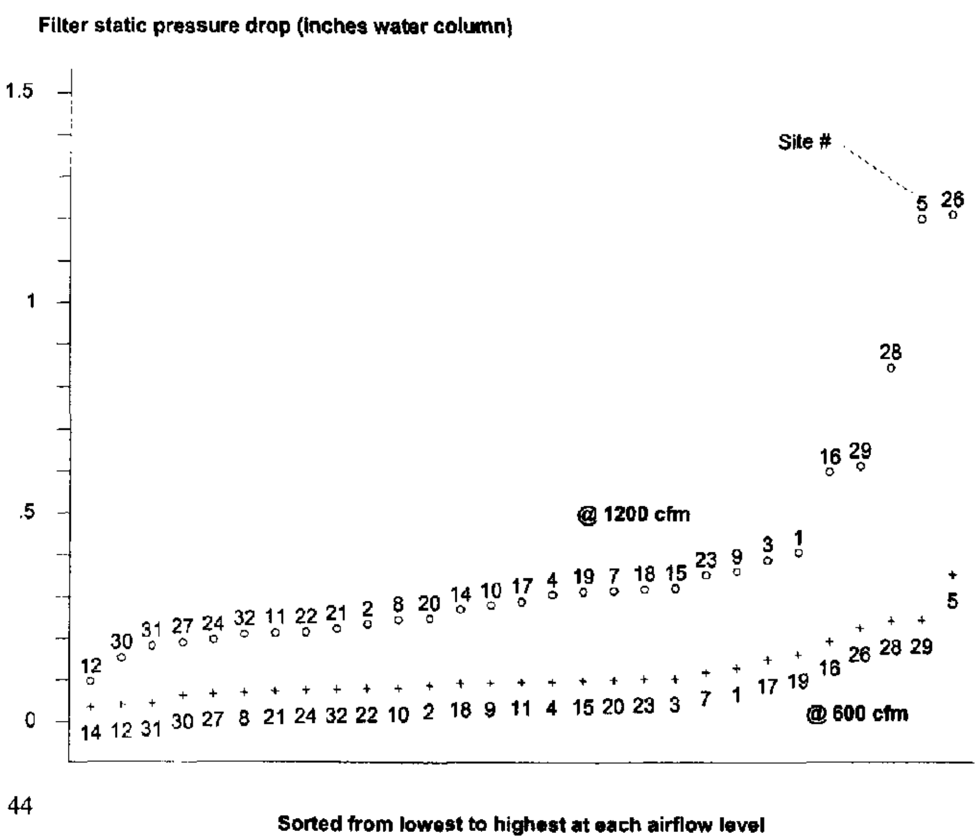
Filter Static Pressure Drop

As previously noted, the data from the study show higher electricity use with higher external static pressure for ECM furnaces. Moreover, the field measurements indicate that on average, about half of the total static pressure seen by the system is due to the pressure drop across the filter. This suggests that if filter static pressure can be reduced, the electricity use by ECM furnaces can be further reduced as well, since these furnaces compensate for high static pressure by increasing their speed and power.

Figure 35 shows the range of measured filter pressure drop normalized to two airflow levels that roughly correspond to low- and high-fire (and cooling) operation for a typical 80,000 Btu/hr furnace. There are five sites with noticeably higher pressure drops, but these do not appear to share common characteristics. Two of the sites use conventional ½ inch or 1 inch furnace filters, one (Site 28) uses a pleated media filter, one (Site 26) uses a washable filter, and one (Site 5) uses an electrostatic filter with a wire mesh pre-filter that was found to be extremely loaded.

If 0.05 IWC and 0.1 IWC are taken as the lowest easily achievable static pressure drop at these two airflows, then pressure drop across the median filter in the study could be reduced by about 0.05 IWC and 0.2 IWC, at 600 and 1200 cfm, respectively. Based on published performance data for one ECM furnace line, this could be expected to reduce air handler power requirements by about 10 Watts at the lower airflow rate, and by about 70 Watts at the higher rate for an ECM furnace, corresponding to perhaps a 10 percent reduction in total power requirements at both airflows.

Figure 35. Filter static pressure drop.



The above figures relate to the *median* furnace in the study. For a furnace with a high static pressure drop, such as Site 5, the savings from reducing the filter resistance (in this case by simply cleaning the mesh pre-filter) would be considerably higher. Based on the measurement data for Site 5 and the published performance data for the furnace, it appears that air handler power could be reduced by 40 to 60 percent by reducing the filter static pressure drop to a level comparable to the filters on the low end of the distribution.

Impact of ECM Furnaces on Gas Consumption

In theory, reducing blower electricity use will result in an increase in gas consumption during the heating season, because ECM furnaces have less waste blower heat, which would ordinarily somewhat offset the need for additional gas heat from the furnace. At least one field study (Gusdorf et al., 2003) has demonstrated as much when the furnace fan operates continuously throughout the heating season.

Gas consumption was not monitored for this study, so it is not possible to bring direct empirical data to bear on this question. The estimated typical 400 kWh electricity savings from ECMs in heating mode would translate into perhaps 15 therms of additional gas consumption at a typical gas efficiency for a condensing furnace. With continuous fan operation during the winter, this might rise to 65 therms.

However, the above figures assume that ECM and non-ECM furnaces have the same gas heating efficiency, which does not appear to be the case typically. The published heating efficiency (AFUE) for the 14 ECM furnaces in the study ranged from 92.5% to 95.0%, with a median of 94.1%. The 17 non-ECM furnaces had AFUE's that ranged from 92.0% to 92.5%, with a median of 92.2%. The difference between the median AFUE's for the two groups translates into about 16 therms less gas consumption for an ECM furnace with an annual heating load of 750 therms—enough to offset the calculated increase in gas consumption due to less waste electrical heat from an ECM furnace operating in heating mode. It is likely that a furnace operating in continuous-fan mode would still have a net increase in gas use, but the dollar savings to the consumer from reduced electricity use still overshadow any additional gas charges.

A Note on Power Factor

Although not a particular concern to consumers, power factor is of interest to utilities, which must size distribution systems to handle reactive as well as active power. Power factor measurements on the furnaces in the study showed that the ECM furnaces had somewhat lower power factors compared to non-ECM furnaces, except in standby mode. A more detailed compilation of power factor data can be found in Appendix B.

Table 5: Median measured power factor, by operating mode.

Operating Mode	ECM Furnaces	Non-ECM Furnaces
Heating	0.72 (low-fire) 0.68 (high-fire)	0.88
Cooling	0.63	0.81
Continuous Fan	0.69	0.87
Standby	0.62	0.40

Discussion

Results from this study are relevant from a variety of perspectives. The discussion that follows is organized around the following points of view:

- Wisconsin Focus on Energy program efforts
- National energy efficiency standards and program efforts
- Consumers
- Furnace contractors and distributors

Implications for Wisconsin Focus on Energy Program Efforts

First and foremost, the results from the study provide basic confirmation that multi-stage ECM furnaces do provide substantial electricity savings over conventional condensing furnaces. The savings are most dramatic in continuous-fan and heating modes, but are also apparent in cooling mode. Based on the small (and not necessarily representative) sample of homes covered by this study, the savings for a home in Madison, Wisconsin with typical gas consumption and air conditioning use appears to be about 450 kWh per year without continuous-fan operation, and more than 3,000 kWh per year with year-round continuous fan use. Peak demand savings are more difficult to discern from this study, but the results suggest that there are summer peak savings. Winter peak electricity demand is the most difficult to assess; many of the two-stage ECM furnaces will be operating in high-fire on a cold winter morning, and the data were most variable in this mode.

The above figures are meant to reflect the study results in a typical Wisconsin home. These may not be applicable to the population of participants in Focus programs that promote ECM furnaces if, for example, these participants use more or less gas, or have furnaces that are sized differently for their heating load.

Probably a larger source of uncertainty in estimates of savings due to program efforts to promote ECMs, however, lies on the behavioral side, which this study did not address. In particular, the average savings from a population of ECM furnaces is sensitive to the proportion of households that operate the furnace in continuous fan mode. Since the difference in savings between homes without continuous-fan use and those with year-round operation is so large, the average savings from blending these two is very sensitive to assumptions about the proportion of homes with continuous-fan use. If one assumes that 10 percent of homes practice year-round continuous-fan operation, then the overall average savings would be about 700 kWh per year (with half of the savings arising from homes with continuous-fan operation). Change this proportion to 20 percent, however, and the figure becomes 1,000 kWh per year, and continuous-fan homes represent two-thirds of the total.

In reality, the situation is more complicated than portrayed above. As the actual practices of the homeowners in this study demonstrate, some people practice year-round continuous-fan operation, but others do so only seasonally—or even on an ad hoc basis. Furthermore, some homeowners in new developments may practice continuous-fan operation temporarily to deal with ambient construction dust. Finally, other literature has alluded to a possible "take-back" effect; some people may purchase an ECM furnace precisely in order to operate their air handler continuously—in the absence of such a choice, they would not do so. All of these factors play into the average impacts from programs to promote ECM furnaces; unfortunately, these were mostly outside the scope of this technical look at these furnaces. Additional research is needed to quantify these practices in the Wisconsin population. Such research could be undertaken in conjunction with the biennial Appliance Sales Tracking telephone survey conducted by the Energy Center of Wisconsin.

The study also provides insights for efforts to affect how furnaces are installed and configured, such as the Wisconsin Efficient Heating and Cooling Initiative. Although these are discussed in more detail below under "Contractors and Distributors," it is worth noting here that the study offers evidence that high static pressure reduces the savings from ECMs, since these furnaces compensate by increasing the blower power input. This suggests that efforts to influence furnace filter selection and maintenance as well as duct design (for new construction) in order to minimize the static pressure experienced by an ECM furnace could bear fruit in additional electricity savings. This suggests a need to better understand the pressure drop characteristics of different types and brands of furnace filters, as well as how static pressure changes over time as the filters become loaded.

Further, the study suggests a need to promote the practice of always setting continuous-fan speed to the lowest possible option. Doing so requires no testing or equipment, and in most cases involves no action on the part of the installer, since most furnaces are already configured in this way. However, that four out of fourteen ECM furnaces in the study were configured for higher continuous-fan operation suggests that some contractors wrongly believe that more is better when it comes to continuous-fan airflow. Also, installers failed to take advantage of a separate low-speed tap for continuous-fan operation for some models of non-ECM furnaces.

Implications for National Energy Efficiency Standards and Program Efforts

This study provides some insights of national relevance. First, this study confirms previous research demonstrating that in actual practice static pressures are considerably higher than those stipulated in standard rating procedures. The furnaces in this study averaged 0.44 IWC of static pressure drop across the furnace and evaporator coil at high fire, which is more than twice the 0.2 inches generally used in the standard test procedure for rating furnace efficiency (which does not include pressure drop across the AC coil). In cooling mode, the study furnaces averaged an even higher 0.50 inches of static pressure drop. This difference is the most likely explanation for the finding that actual furnace electricity use in heating mode for ECM furnaces is on average higher than rating data would suggest.

Second, the study suggests that 0.6 kWh of heating electricity use per therm of gas consumption (or 6 kWh per million BTU of gas input) represents a useful demarcation line between electrically efficient furnaces (i.e., ECM model) and less electrically efficient models. This dividing point neatly separates the ECM and non-ECM furnaces in the study both in terms of their rating based electricity use per therm of gas consumption and in terms of the field results.

Third, the study indicates there would be some value in incorporating standby electricity use in national standards and program efforts. At a current 8 to 14 Watts, standby electricity use by furnaces exceeds that of many consumer electronic appliances, which typically have digital clocks and must sense inputs from infrared remotes. There is undoubtedly room for reduction in furnace standby electricity use with better control board design.

Finally, the study suggests that some fairly simple changes at the manufacturing level could have energy savings benefits even for non-ECM furnaces. For example, four non-ECM furnaces in the study had a separate speed tap lug for continuous-fan operation. This allows the air handler to run at the lowest speed setting in this mode independently of the speed selection for heating and cooling modes. Based on our test data, this could be expected to reduce continuous-fan electricity use by about 8 percent. However, none of the four study furnaces were field configured to make use of this feature, and the one heating contractor we spoke with who installs these furnaces stated he did not really understand its function. If the manufacturer were to simply plug the low speed tap wire into this lug at the factory, electricity use could be reduced by perhaps one percent on average across the units shipped by this manufacturer.

Implications for Consumers

This study clearly demonstrates that an ECM furnace is a "no brainer" for people who intend to operate their air handler continuously. With electricity savings on the order of $275 or more per year, the additional cost of these furnaces can be recovered within a few short years.[8] The extra cost of these furnaces is more difficult to justify solely on the basis of electricity savings for consumers who do not practice continuous-fan operation, but—with annual electricity savings of perhaps $30 to $40—the electricity savings are still worth considering.

Moreover, as a premium product, multi-stage ECM furnaces appear to offer comfort and noise advantages that may outweigh the electricity savings in the minds of many consumers. Though sound levels were not formally evaluated by this study, the ECM furnaces in the study were noticeably quieter in low-fire heating mode, which—as the study demonstrates—is the operating mode the majority of the time during the heating season.

Comfort was also not formally evaluated as a part of this study, but the data do document much lower airflow in low-fire heating mode for ECM furnaces, which could reasonably be expected to translate into fewer drafts from air handler operation. Though many ECM furnaces (indeed many new furnaces in general) are marketed as providing tighter control on temperature swings, the study did not reveal any clear difference in indoor temperature variation between ECM and non-ECM furnaces—though there are some limitations in our ability to measure such differences. The tightness with which indoor temperature is maintained is probably as much (or more) a function of the thermostat and its configuration as it is the type and model of furnace. Nonetheless, nearly all of the furnaces in the study showed a good ability to reduce temperature swings.

Implications for Heating Contractors and Furnace Distributors

Several field configuration lessons emerge from the data gathered for this study. First, the fact that some contractors are field configuring furnaces to operate at higher continuous-fan speeds than the factory default is troubling. Continuous-fan operation does not need high airflow; indeed higher airflow rates are more likely to create uncomfortable drafts in the home. And, from an energy efficiency perspective, higher airflow in continuous-fan mode wastes electricity. Even if the purchaser of a furnace does not intend to use continuous-fan operation, future occupants might do so, and it is unlikely that the initial configuration would be revisited. For all of these reasons, the

[8] Anecdotal reports put the cost increment for a typical two-stage ECM furnace over a conventional condensing furnace at $400 to $600.

general rule should be to use the lowest possible speed setting for continuous-fan mode, as most ECM furnaces are factory configured to do.

It is not possible to know from this study why the furnaces in the study were set up for higher airflow in this mode, nor is it possible to measure the prevalence of the practice. Two of the four such ECM furnaces were installed by the same heating contractor, one may have been a case of misunderstanding of DIP switch settings, and in one case, the high continuous-fan airflow setting was part of a larger array of configuration issues with a complicated zoning control system. Nonetheless the incidence is high enough to suggest the need for contractor training and education in this regard.

Second, installers should be cognizant of the relationships between furnace sizing, temperature swing, and staging control for two-stage furnaces. Long heating cycle lengths due to undersizing or other factors may interfere with staging control algorithms and result in excessive high-fire operation and undesirable variation in indoor temperature.

Third, when it comes to the perennial issue of furnace sizing, the study indicates that although most are considerably oversized in terms of meeting design heating loads—even under conservative assumptions for design conditions—the study does lend credence to the argument that some over-sizing is needed for setback recovery. The majority of homeowners in the study practiced thermostat setbacks during the heating season—as do the majority of Wisconsin homeowners in general—and recovery periods even under average winter conditions were fairly long for some of the homes. In this vein, the multi-stage ECM furnaces appear to offer the best of both worlds: reduced cycling, airflow and electricity use to meet the basic heating load of the home, combined with the ability to produce higher output to boost the indoor temperature after a setback.

Limitations

As with any effort, there are limitations to this study. The more important of these are enumerated below:

1. **Sample size.** As with any detailed field study, budget constraints prevented studying a larger sample of homes. With small samples the probability increases of obtaining a sample that—purely by chance—deviates substantially from the population from which it was drawn. This so-called sampling uncertainty can be quantified. For example, the 90 percent confidence interval for the average difference between ECM and non-ECM furnaces in heating mode electricity use per therm of gas for the study sample is ± 0.1 kWh/therm. With the study finding that ECM furnaces use about 0.5 kWh/therm less than non-ECM furnaces, one can be 90 percent confident from a sampling error standpoint that the average difference in the population is somewhere between 0.4 and 0.6 kWh/therm. However, non-random sampling errors probably dominate in this case (see next item); hence the report eschews reporting confidence intervals like the one above.

2. **Sample representativeness.** There are a number of ways in which the study sample might differ from the population at large in ways that would not be mitigated by a larger sample. Most notably, a variety of furnaces were deliberately selected for study; the market share for particular brands may therefore be under- over over-represented. Also, the study is dominated by new homes, many of which participated in the Wisconsin Energy Star Homes program—though about half the Wisconsin furnace market is thought to be made up of replacement furnaces for older homes. Finally, homeowners willing to participate in the study might be different than those who are not willing to participate—for example, they might be more inclined to operate in continuous-fan mode.

3. **Modeling uncertainty.** The study relies on models of heating and cooling energy use as a function of outdoor temperature to translate variable weather conditions over part of a season to long-term seasonal averages. There is uncertainty in this process, arising in the choice of the models used, in the fitting process for the model coefficients, and in the application of long-term averages in the context of climate change. In terms of the functional form of the models, the data suggest that, for most of the sites in the study, the majority of the variation in heating and cooling-mode hours and cycles is explained by outdoor temperature. However, other factors such as humidity during the cooling season that were not included in the models might change the estimates somewhat. Finally, there is also uncertainty in average values such as power draw measured during testing. These values can change over time, for example as filters load. Comparison of results across the two rounds of testing suggests that most values were stable to within about 10 percent.

References

ASHRAE. 1993. "Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers," ANSI/ASHRAE Standard 103-1993. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta, Georgia.

Byrne, Jeanne. 2000. "Motors Matter," Home Energy Magazine, July/August 2000.

Gusdorf, J, M Swinton, E Entchev, C Simpson, and B Castellan. 2003. "The Impact of ECM furnace motors on natural gas use and overall energy use during the heating season of CCHT research facility." Institute for Research in Construction , NRCC-38443, www.nrc.ca/irc/ircpubs, January, 2003.

Palmiter, Larry and Paul Francisco, "A New Device for Field Measurement of Air Handler Flows," Proceedings of the 2000 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings, ACEEE, Washington, D.C.

Phillips, Bert. 1998. "Impact of Blower Performance on Residential Forced-Air Heating System Performance." ASHRAE Transactions, V. 104, Pt.1, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc, Atlanta, Georgia.

Pigg, Scott and Monica Nevius. 2000. Energy and Housing in Wisconsin: A Study of Single-Family Owner-Occupied Homes. Energy Center of Wisconsin Research Report 199-1. Energy Center of Wisconsin, Madison, Wisconsin.

Pigg, Scott. 2002a. "Energy Savings from the Wisconsin Energy Star Homes Program," Energy Center of Wisconsin Research Report 211-1, Energy Center of Wisconsin, Madison, Wisconsin.

Pigg, Scott. 2002b. "Field Study of Ventilation in New Wisconsin Homes," Energy Center of Wisconsin Research Report 216-1, Energy Center of Wisconsin, Madison, Wisconsin.

Proctor, John, and Danny Parker. 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand," Proceedings of the 2000 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings, ACEEE, Washington, D.C.

Sachs, Harvey, Toru Kubo, Sandy Smith and Kalon Scott. 2002. "Residential HVAC Fans and Motors are Bigger than Refrigerators," Proceedings of the 2002 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings, ACEEE, Washington, D.C.

Wisconsin Energy Bureau (WEB). 2002. Preliminary Wisconsin Energy Statistics — 2002. Wisconsin Department of Administration, Madison, Wisconsin (www.doa.state.wi.us).