Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004

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EXECUTIVE SUMMARY

Adopting new energy-efficient technologies and practices is key to reducing energy consumption and maintaining economic growth. As efficient technologies and practices (T&Ps) increase their market share and become conventional, new T&Ps worth promoting need to be found. Fortunately, innovators introduce new T&Ps more rapidly than the market can assimilate them. Some have greater potential than others, so periodic, systematic evaluations of emerging T&Ps serve to identify the best candidates for program development. Comparing findings over time gives additional insights into the efficiency industry's health. Our current analysis, the third in a decade, began by identifying 198 T&Ps, which were screened to select those that promise to (1) save at least 0.25% nationally when mature and accepted, (2) avoid large "lost opportunities" in new construction, or (3) capture important regional opportunities. There are still many promising technologies and practices that will save large amounts of energy. On the other hand, the number of "pure" technologies that emerged from the screening process was smaller than before. We compensated by increasing the number of "practices" that reflect new system views of older issues. Particularly attractive candidates include two distribution system improvements (leakproof ducts and duct sealing) and two practices (design of high-performance commercial buildings and retrocommissioning). Automated HVAC system diagnostics and 1 Watt standby power for home appliances complete the high priority list. We also identified 16–22 medium priority measures.

INTRODUCTION

In 1993 and 1998, ACEEE and collaborating organizations published studies of emerging technologies (Nadel et al. 1993; Nadel et al. 1998). Each profiled and analyzed 80–100 technologies that had been recently commercialized or were expected to be commercialized in the next five years. The studies examined technologies in the appliance, lighting, HVAC, water heating, drive power, office equipment, and miscellaneous end-uses. For each technology, likely costs, commercialization date, and potential energy savings were examined, leading to lists of technologies with the largest potential for cost-effective energy savings. These studies contributed to advancing energy efficiency. The first study contributed to such initiatives as the Consortium for Energy Efficiency's residential clothes washer and high-efficiency commercial air conditioner initiatives, the U.S. Department of Defense's incandescent replacement light bulb procurement, and the U.S. Environmental Protection Agency's involvement in Lawrence Berkeley National Laboratory's aerosol duct-sealant project. The second study highlighted HVAC, lighting, and integrated new building design. It also identified large opportunities for improved appliances, water heating, onsite power production, and the building shell.

However, the information in these studies is becoming dated. Some technologies have since been commercialized and others have faced difficulties, while new technologies continue to be developed. Some of the early "low-hanging fruit" among energy-efficient technologies have already been harvested. New gains will come from other fruit, less obvious orchards, and improved methods of achieving performance in the field (practices). This project updates and revises the earlier studies. We started with reconnaissance for new technologies and practices, but also revised our methods to include region-specific and new construction opportunities.

OBJECTIVES

Among the objectives of this new study are:

- to identify new research and demonstration projects that could help advance high-priority emerging technologies;
- to identify potential new technologies and practices for market transformation activities; and
- to gain new insights into the technology development and commercialization process by comparing 1998 expectations with 2004's reality

SCOPE

Our scope covered the residential and commercial sectors. We included both energy-saving technologies (e.g., a new air conditioner) and practices (e.g., improved air conditioner installation procedures). In this study, we defined "emerging technologies and practices" as those that either: (a) are not yet commercialized but we judge to be likely to be commercialized and cost effective to a significant proportion of end-users (on a life-cycle cost basis) by 2009; or (b) are commercialized, but currently have penetrated no more than 2% of the appropriate market.

METHODOLOGY

We identified 198 measures (technologies and practices) that might save substantial energy. Candidates were taken from lists of emerging technologies developed for the 1998 study; existing ACEEE, Davis Energy Group (DEG), Natural Resources Canada (NRCan), and Marbek Consultants databases and reports; recommendations from energy research organizations, major utility R&D departments, and state and provincial R&D institutions; recent conference proceedings; consultations with experts; and product and research announcements.

First, each measure was assigned to one of three preliminary categories: high, medium, and low potential. Low potential measures are those that are likely to have a cost of saved energy greater than current U.S. national average energy prices, or that can reduce U.S. and Canadian buildings energy use by less than 0.25%. High potential measures are likely to have a cost of saved energy less than 50% of current U.S. national average energy prices, and that can reduce U.S. or Canadian buildings energy use by 1% or more. Medium potential measures were neither "high" nor "low", or measures for which little is known, so further analysis is needed.

This study also includes several special cases, measures that would save less than 0.25% nationally, but still warrant consideration. Some are "lost opportunities," particularly for the new construction market. Because new construction is unlikely to account for more than 20% of the building stock by 2020, new construction measures otherwise could show no more than 20% of the effect of other measures. For many of these (e.g., glazing upgrades), the cost of later retrofitting is much higher. With similar justification, we include a few measures that have great potential regionally, but limited impact for the United States and Canada as a whole. Typically, these are climate-sensitive HVAC products; one example is air conditioners with evaporative condensers and high sensible heat ratios for the Southwest. The next step was further analysis of the poorly understood measures identified above, to place them more clearly in the high, medium, or low priority categories.

From this initial screen, we identified 76 candidates as likely medium and high priority emerging technologies. For each, we collected over 30 pieces of input data in a database. Each includes *market information,* a *base case,* and a *new measure* characterization for analysis. We also included the current status of the technology, the estimated year of commercialization, and the estimated measure life. Our cost data include purchase price and additional or avoided maintenance costs. Next, we developed qualitative measures of likelihood of success in the market (major market barriers, effect on customer utility, current promotional efforts, etc). These vary from 1 (difficult; multiple major barriers to overcome) through 5 (excellent chance of success; barriers clearly surmountable). *Feasible applications* is an estimate of the fraction of the appropriate building stock (such as new low rise residential) that could adopt the technology or practice.

Our outputs for individual measures are *savings,* including U.S. electricity (and peak demand), and gas *savings potential* in 2020 in GWh (million kWh) and TBtu (trillion Btu). We then computed the cost of saved energy (levelized cost) in both $/kWh and dollars per million Btu of primary energy ($/MMBtu). In some cases, the cost of saved energy is negative, meaning that the annualized capital and operating costs are less than those for the old, baseline measures. The cost of saved energy is rounded to the nearest cent, because of uncertainties in the analysis.

For this study, measures were divided into "high," "medium," "lower," "special," and "not a priority" categories, based on three factors: potential energy savings, cost of saved energy, and likelihood of success. Criteria and number of measures identified are given in Table ES-1.

Since many of the technologies and practices covered are still niche products, estimates of measure cost, savings, and commercialization date are imprecise. Due to these limitations, calculated costs of saved energy and savings potential ratings were rounded to one significant digit. Furthermore, the data reported should be viewed as the midpoint of a range, with endpoints 10–50% higher and lower than the midpoint. The size of the range varies with the quality of the data available for each measure.

Savings are not additive among measures. For example, the savings from adopting an advanced air conditioning method plus an improved shell measure will be less than the savings for each measure by itself. In this case, the improved shell would reduce the baseline energy use, thus giving smaller kWh savings.

Table ES-1. Priority Levels and Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of Success	Number of Measures
high	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5	3–6
medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5	16–21
low	NA	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	11–14
special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	12–22
not a priority		Fails to meet other thresholds			14–24
total					73

Notes:
To earn a "high" or "medium" priority, a measure must meet all the thresholds in the row. For example, high priority measures are those that show potential energy savings of at least 1% of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; *and* a likelihood of success rating of 3 or more. If a measure fails to meet one or more of these thresholds, it slips to the next lower priority.
The column for "Number of Measures" in this study reflects analytical uncertainty about costs (and applicability) by giving a range of measures that can be included in each category, such as 3–6 high priority measures. Typically, ranges are extended downward by a small amount (<10%) to include more measures and respond to the uncertainties in the analysis.

RESULTS

Seventy-two measures were studied in detail. Key results are summarized in Table ES-1, above.

The **high priority measures** are diverse. Two (leakproof ducts and duct sealing) are distribution system improvements and two are practices (design of high-performance commercial buildings and retrocommissioning.) Automated diagnostics complements retrocommissioning as a building operation improvement. The final measure, 1 Watt standby power for home appliances, is the only "pure" equipment measure in the high priority list. These measures are described more fully in the project report.

Seven of the 16–22 **medium priority measures** are lighting, primarily commercial measures (premium T8 lighting, one-lamp fluorescent fixtures, commercial LED lighting, and scotopic lighting). However, at least two lighting measures (airtight compact fluorescent downlights and CFL portable fixtures) are primarily residential. Twelve of the measures are primarily residential. Five of these deal with refrigeration-cycle equipment: improved refrigerators, air conditioners, and heat pump water heaters. Commercial measures include better management of networked computer energy use, and carbon dioxide-controlled ventilation to reduce fan power as well as chiller energy.

The common element among **low priority measures** is the low likelihood of success, frequently because they represent major changes from present methods and technologies. Low likelihood of success in the near term is exemplified by the very large savings associated with commercial "combined heat and power" (CHP) technologies incorporating microturbines and fuel cells, and even for residential CHP with Stirling engines.

"**Special" measures** have high value for specific regions or new construction, even though they may not have enough savings on a national basis to warrant national priority. About half of the special measures are feasible for new construction, but prohibitively expensive as retrofits. These measures include low energy designs and construction methods. Special also includes half a dozen measures specific to hot or hot and humid climates, typically advanced air conditioners such as the Cromer Cycle (combining desiccant and refrigerant systems in a single unit). The category also includes air conditioners optimized for hot-dry climates and two-speed pool pumps. Northern climates rate three special measures, including gas-fired absorption heat pumps, advanced condensing boilers for commercial applications, and roof-top year-round units with condensing furnace sections. Two further measures are applicable to guest rooms in the hospitality industry. These include "smart" door card keys that incorporate energy management and bathroom lighting that better matches use patterns. These may be indicative of opportunities that will arise when other industries are targeted for close examination.

Between 1993 and 1998, the number of measures attractive enough for analysis dropped by about 25%, but stabilized for this study (see Table ES-2). Similarly, the second study had only two-thirds as many high and medium priorities as the first. The current study is close to the 1998 level, but this study also includes special measures (see Table ES-1).

Table ES-2. Number of Measures by Priority—1993, 1998, and 2004 Studies

	1993	1998	2004
total measures analyzed	102	73	72
high priority	21	12	3–6
medium priority	32	21	16–22
high + medium	52	33	22–25

Note: Total for 2004 is lower than the sum of the two rows above because of overlaps: some measures are assigned H/M priority.

Twelve high-priority technologies and practices from 1998 carried over as high or medium priority in the present study. Three were dropped because they have estimated market shares above 2% (high efficiency washing machines, improved compact fluorescent lamps, and integrated commercial lighting systems). In the first two cases, large-scale market transformation programs supported market growth. In the case of washing machines, this success contributed to new 2004 and 2007 federal standards for washing machines and brought many new products to the high efficiency market. Ductwork integrity improvements and retrocommissioning have remained high priorities. Within the lighting technologies, two measures dropped lower for different reasons. General-service halogen IR reflecting lamps dropped in priority because they will not compete well with higher efficacy compact fluorescents that cost less. Thus, the market is being transformed by a competing technology, but to the same ends of greater efficiency and longevity.

Two 1998 high priority measures were dropped from this study. As far as we can find from our research, dual-fuel heat pumps have disappeared from the market. Similarly, electric integrated space- and water-heating systems are no longer available (except as ground-source heat pump components), and the gas- and oil-fired equivalents have had very low market penetration.

Discussion

Lessons Learned and Implications of the Study

Perhaps the most important finding of this study is that the well of emerging technologies and practices continues to yield many promising measures. Including special measures for new construction or regional applicability, we find more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 22–25 this time, but this study added 12–22 special measures that warrant serious consideration. Of course, the reservoir is changing. Some of the measures that would result in the largest savings would also require the greatest changes in the present mode of operations. Combined heat and power at commercial and residential scales, using emerging technologies such as fuel cells and Stirling engines, could save well beyond 1% of projected buildings energy in 2020, but would require substantial changes in how most utilities do business and see themselves, as well as substantial cost reductions. Measures to assure ductwork integrity are another example of the need to change the business model. Achieving real results will require that industry and consumers recognize the importance of energy distribution within the building (for comfort and air quality). Finally, retrocommissioning and advanced design practices have great importance and potential, as do training, incentives, and other “humanware” services.

Our consideration of special measures in this study illustrates another trend. While the earliest study (1993) could point to a relatively small number of technologies that each promised enormous savings, the present study, particularly in special cases, finds more broadly distributed savings that are smaller, on average. The 12 high priority measures in 1998 averaged about 824 TBtu per measure; the six highest priority measures in this study average about 533 TBtu per measure. The total estimated savings from all measures is only three-quarters as large as in 1998. We believe that the analyses were systematically more conservative this time, accounting for some of the difference.

However, there is another (pleasant) surprise in this study. Several measures that are assigned relatively high priority in this study were not available on the market for consideration in the 1998 study. These notably include "Super" T-8 lights and zone-level CO_2-based ventilation control, where critical research and development were nearly complete in 1998, but not yet announced. These have prospered in the market and no longer qualify as "emerging technologies."

Recommended Next Steps

Table ES-3 summarizes the next steps for the highest priority measures.

Table ES-3. Recommended Next Steps for the Highest Priority Measures

Measure	Name	Next Steps
PR3	commercial construction 30% > code	• dissemination of successful case studies • revised fee structures for mechanical designers • client education • better software
A1	1 Watt standby power	• ENERGY STAR® program for power supplies • possible manufacturer incentive for using better power supplies • mandatory standard for power supplies
PR1	advanced automated building diagnostics	• additional research • work on standard protocols for alarm and id transmission. • case studies on value based on real demonstrations
PR4	retrocommissioning	• better define approaches and appropriate applications for different approaches • benchmarking • MT with promotion, training, and incentives
H12	aerosol-based duct sealing	• raise consumer awareness of problems and savings • utility incentives • HVAC contractors taking on value-added service • training and certification • field tests in regions with basements and crawl spaces
H11	leakproof duct fittings	• raise consumer awareness of problems and savings • utility incentives • performance-based codes and standards • duct system integrity certification • field tests in regions with basements and crawl spaces

For most technologies and practices, the next steps can be generalized as follows:

Almost by definition, emerging technologies require unbiased, third-party demonstrations to convince customers that they will perform as advertised. Products of this work should include both marketing materials and detailed analytical case studies.

For emerging practices, "infrastructure" development is even more important than demonstrations. The "inputs" include training design team members, and helping them develop better working methods. Software tools are increasingly a key infrastructure component. Frequently, infrastructure work will include support for building code revisions to accommodate new methods and technologies.

Finally, groups interested in market transformation should begin developing prototypes of appropriate programs for the measures they find most promising. This effort will both encourage the manufacturers and help identify missing pieces (such as performance certification) that are required for success. This is particularly important for programs dealing with practices (such as retrocommissioning and advanced, integrated designs), which have been less common in the past.

In combination, these recommended next steps can help pave the way for increased market adoption of these emerging technologies and practices. Finally, we recommend another assessment of emerging technologies and practices for energy efficiency for completion in about five years, in order to identify new opportunities.

CHAPTER 1: INTRODUCTION

BACKGROUND

In 1993 and 1998, ACEEE and collaborating organizations published studies of emerging technologies (Nadel et al. 1993; Nadel et al. 1998). Each profiled and analyzed approximately 100 technologies that had been recently commercialized or were expected to be commercialized over the next decade. The studies examined technologies in the appliance, lighting, HVAC, water heating, drive power, office equipment, and miscellaneous end-use fields. For each technology, likely costs, commercialization date, and potential energy savings were examined, leading to lists of 12 (1998) and 21 (1993) high priority technologies with the largest potential for cost-effective energy savings.

These studies brought many technologies to the attention of utilities, government agencies (e.g., DOE and EPA), and other energy efficiency professionals, and have contributed to the advancement of energy efficiency in a substantial way. The first study contributed to such initiatives as the Consortium for Energy Efficiency's residential clothes washer and high efficiency commercial air conditioner initiatives, the Department of Defense's incandescent replacement light bulb procurement, and EPA's involvement in Lawrence Berkeley National Laboratory’s aerosol duct-sealant project. The second (1998) study pointed particularly to HVAC, lighting, and integrated design for new buildings as measures with the highest priority. Since this study was published, substantial progress has been made on quite a few of these measures. High-efficiency vertical-axis clothes washers are now produced and marketed by several manufacturers. Commissioning of existing buildings and aerosol-based duct sealing are receiving increased attention from program operators, building owners, and HVAC companies. Integrated new home design is incorporated into both the ENERGY STAR®-qualified New Homes program and the Building America program, which together influence tens of thousands of homes built annually. Plus, many products featured in this study have entered the market, including reduced-cost CFLs, ceramic metal halide lamps, “low leak” home electronics, compact fluorescent floor and table lamps, heat reflecting roofing materials, heat pump water heaters, and new fuel cell and micro turbine products.

However, the information in these studies is now somewhat dated. Some technologies are competing in the mainstream market and are now no longer “emerging,” others have faced difficulties, and additional new technologies continue to be developed. We have also built on the second study’s exploration of energy-saving *practices* as well as technologies. This recognizes that some of the early “low-hanging fruit” among energy efficiency technologies have already been harvested. New gains will come from other fruit, less obvious orchards, and improved methods of achieving performance in the field (practices).

This Project

Recognizing the need to update and expand upon the earlier work, several of the original sponsors and some new ones agreed to fund a new emerging technologies study. As with the original studies, this follow-up brings together ACEEE and the Davis Energy Group. Thanks to funding from Natural Resources Canada (NRCan), we have also been joined in this work by Marbek Resource Consultants, Inc. This study completely revises the earlier studies, starting with fresh reconnaissance for new technologies and practices. In addition, even greater emphasis was placed on non-utility follow-up activities for each technology and practice (including both research and development, and commercialization/market transformation actions).

Among the objectives of this new study are:

- To identify new research and demonstration projects that could help advance high priority emerging technologies
- To identify potential new targets for market transformation activities
- To gain new insights into the technology development and commercialization process by comparing 1998’s expectations with 2004’s realities

This study differs in one other important area: for the first time in this series, we have estimated the demand savings (or increased demand) associated with each technology. Our ranking parameters do not include peak power (kW) considerations but the information is computed for each treated technology and practice, for reference by analysts and program managers.

Project Scope

The project scope covers the residential and commercial sectors, including measures that are used in and on buildings. Both energy-saving technologies (e.g., a new air conditioner) and practices (e.g., improved air conditioner installation procedures) are included. Only measures that save energy, including more efficient generation sources (e.g., fuel cells) and renewable energy sources appropriate for buildings are included. Load management measures that only shift energy use from one time period to another are excluded. Measures are included that save electricity, natural gas, oil, and propane. Measures that shift from one fuel source to another are included, provided they save energy on a primary basis (e.g., electricity is evaluated based on the heat rate of power production) and are cost effective to end-users on a life-cycle cost basis, assuming national average energy costs.

For purposes of this study, emerging technologies and practices are defined as those which either:

(a) Are not yet commercialized but are likely to be commercialized and cost effective to a significant proportion of end-users (on a life-cycle cost basis) by 2009

(b) Are commercialized, but currently have penetrated no more than 2% of the appropriate market

More specific evaluation criteria are treated in Chapter 2, "Methodology." In order to keep the project cope to a manageable level, we needed to exclude measures with only long-term potential as well as measures that have already shown significant acceptance in the market.

Uncertainties in the Analysis and Other Caveats

Since many of the technologies and practices covered, whether presently commercialized or not, are still just niche products, estimates of measure cost, savings, and commercialization date are generally imprecise.

Due to these limitations, in calculating cost of saved energy and savings potential ratings, figures were rounded to one significant digit; finer distinctions would be meaningless. Furthermore, the data reported should be viewed as the midpoint of a range, with endpoints 10–50% higher and lower than the midpoint. The size of the range varies with the quality of the data available for each measure. In some cases, data were obtained from several sources and there was general agreement between sources as to specific data values. Many of these cases included data obtained from independent analysts who do not have a vested interest in promoting a product. In cases that meet most of these criteria (designated by an "A" rating in the data quality field of the database), the range of likely values will generally be within 10–20% of the specific values listed. In other cases, data were based on only preliminary estimates obtained from only one source, often a source with a vested interest in promoting the product. In these cases (designated by a "D" rating in the data quality field of the database), the range of likely values may be as much as 50% higher and lower than the specific values listed. In still other cases, solid estimates were obtained from one source, or less precise estimates from several sources. In these cases (designated by a "B" or "C" rating in the data quality field of the database), the range of likely values is between the two extremes discussed above.

Data Quality	Meaning	Estimated Error
A	Data from independent analysts, typically multiple sources	10–20%
D	One source, typically vested interest	50%

Organization of this Report

This report includes several chapters as follows:

1. The current **Introduction** to the study.
2. **Methods** by which we worked includes step by step descriptions of the process and discussion of the different types of information and data collected on each measure.

3. **Results** of the overall study summarizes the results of the analysis and some of the trends that emerge from our research.
4. **Discussion** of the implications of the project includes a comparison with the results of the prior studies, and the lessons this comparison teaches.
5. **Recommendations and Next Steps** emphasizes ways to advance the highest priority technologies and practices.
6. **Measures** presents the analyses of the individual technologies and practices. It includes approximately one-page written summaries on each of the measures examined in detail in this study. These summaries describe the technology or practice; its current status; likely costs, savings, and commercialization date; and recommended next steps for advancing the measure. Finally, this chapter includes a summary table for each measure that summarizes the information in the database.

In addition, we provide an appendix—a compilation of lower priority emerging technologies that were screened out during the early stages of the project and for which more detailed research and analysis were not done.

The final report, both Web-based and printed, also includes an appendix on additional analyses specific to California.

A separate report is being prepared by Marbek Resource Consultants, Ltd. to apply the information from this study to the Canadian context.

CHAPTER 2: METHODOLOGY

This chapter presents the methods used in this project, methods designed to efficiently support production of three documents:

1. A report analogous to the 1998 report on emerging technologies and practices for the buildings sector in the United States
2. Appendix B of the above report, which contains California-specific revisions for climate-sensitive measures and a supplement on five additional technologies
3. A report on the same technologies and practices built on the same data but adapted to a Canadian context

In this project, we examined 75 emerging technologies for the buildings sector. By "emerging technology," we mean technologies and practices that are either commercialized but have less than a 2% market share in the relevant market, or that are not yet commercialized but are likely to be commercialized within five years.

DEVELOP INITIAL MEASURE LISTS

In order to develop a list of potential candidate measures meeting the project criteria, we used sources including:

- Lists of emerging technologies developed for the 1998 study
- Existing ACEEE, DEG, NRCan, and Marbek databases and reports
- Measure recommendations from energy research organizations including DOE and its national laboratories, EPA, EPRI, GRI, E Source, major utility R&D departments, and state and provincial R&D institutions
- Recent conference proceedings and journals
- Consultations with experts on particular end-uses including conversations with major equipment manufacturers and innovative smaller firms
- Product and research announcement information received at ACEEE, DEG, and Marbek

This information was gathered through a literature search and phone calls to program managers at the organizations listed above.

PRELIMINARY DIVISION INTO PRIORITY CATEGORIES

Our initial list totaled 198 measures. As a first step to narrow this list down to a more reasonable size, measures were assigned to one of three preliminary categories: high, medium, and low potential measures. Low potential measures are those that are likely to have a cost of saved energy greater than current U.S. national average energy prices or that can reduce U.S. and Canadian residential/commercial energy use by no more than 0.25%, even when they have fully saturated appropriate markets. High potential measures are those that are likely to have a cost of saved energy less than 50% of current U.S. national average energy prices and that can reduce U.S. or Canadian residential/commercial energy use by 0.50% or more when they have fully saturated appropriate markets. Medium potential measures are those that fit neither the high nor low potential categories or measures for which too little is known about them to quickly assign a category.

In addition, the current study includes several special cases, measures that would not save as much as 0.25%, but should be included for other reasons. The first of these is "lost opportunities," particularly measures that can have high impact in the new construction market. Because new construction is unlikely to account for more than 20% of the building stock over the project term, new construction measures otherwise could show no more than 20% of the effect of other measures. For many of these (e.g., glazing upgrades), the cost of later retrofitting is much higher. Thus, we have considered these measures on an ad hoc basis.

With similar justification, we include a few measures that have great potential regionally, but limited or no impact for the United States and Canada as a whole. Typically, these are climate-sensitive HVAC products. A "cold-climate" heat pump that requires no resistive back-up at much lower temperatures than today's common products would be of value in northern regions. In the West and Southwest, air conditioners with evaporative condensers and high sensible heat ratios would have value, while the Southeast needs high efficiency latent heat removal, particularly in residential and light commercial buildings.

For this categorization, U.S. energy use and price data for 2003 from the Energy Information Administration's *Annual Energy Outlook 2003* report are used (EIA 2003). Canadian energy use and prices are taken from *NRCan's 2002 End-Use Energy Data Handbook* and Statistics Canada energy price information (NRCan 2002). For the California report, we use *California Energy Demand 2003–2013*, published by the California Energy Commission (CEC 2003).

Measures were placed into categories based on previous studies including the 1993 and 1998 studies; several recent market transformation screening studies; other published work such as reports by DOE, EPA, EPRI, CRI, Platt's (formerly E Source), and national laboratories; and screening calculations by the project team. High potential measures were automatically included on the list of measures analyzed under this project. Low potential measures were not researched further; but brief write-ups on these measures are included in the reports for the United Sates and Canada.

Select Measures for Detailed Analysis

Based on the results of preliminary steps 2 and 3, the project team developed a draft list of 75 measures for detailed analysis. This list, together with the list of measures that were not recommended for detailed analysis, was provided to the advisory committee for review and comment. Based on this review process, California parties asked for (and funded) the additional work for Report 3.

Detailed Data Collection

For each of the measures selected for detailed analysis, over 30 pieces of data were collected and compiled in a database. Based on these values, as well as a review of published literature on each measure and telephone conversations with researchers and manufacturers working on the different measures, written descriptions on each measure and their status and prospects were prepared. The variables considered are grouped into information on *the Market, the Base Case, New Measure Information, Savings Information, Cost, Likelihood of Success, Recommended Next Steps,* and *Notes.* The specific database variables within categories are:

Market Information

1. Measure number (letter/number code shows end-use and sequential number for easy reference between report and database).
2. Measure name.
3. Measure description (brief). One to two lines that expand upon name, e.g., central air conditioners with SEER of 14 or more.
4. Market sector(s): RES, COM, R&C, C&I, ALL.
5. End-use(s): COOK = cooking; COOL = space cooling; DISH = dishwasher; ELEC = home electronics (but excluding office equipment); HC = space heating and cooling; HEAT = space heating; LAUND = laundry; LIGHT = lighting; MOTOR = motor; OFFEQ = office equipment; REF = refrigeration; VENT = ventilation; WH = water heating; WSH = water and space heating; and OTH = other.
6. Energy types: ELEC, GAS, OIL, G&O, SOLAR, and ALL.
7. Market segments: NEW = new construction; RET = retrofit; ROB = replace on burnout; and OEM = original equipment manufacturers.
    - **NEW** means new construction of a building, as a whole, and major renovation/major modernization projects.
    - **RET** covers activity in an existing building except those covered under ROB below. RET includes new practices in existing buildings as well as the replacement of functioning equipment with more efficient equipment.

- **ROB** covers replacement of equipment or systems as a result of failure or tenant change-out.
- **OEM** refers to equipment components (such as appliance motors and power supplies for consumer electronics) that are purchased by manufacturers rather than end-users.

Base Case Information

8. Base case description (typical unit size and characteristics of current practice to which new measure is being compared). Our units of analysis vary by measure, depending on the most appropriate way to analyze each measure. Sometimes the analysis is for a piece of equipment such as a refrigerator, other times it is for a system, such as lighting systems, and still other times is for a whole building. The unit of analysis for each measure is specified in the base case description. For new construction and equipment replacement measures, the base case corresponds to typical new construction and equipment replacement practices in 2002/2003. However, in cases where future improvements in equipment efficiency are known due to finalized or near-finalized building code and equipment efficiency standards, we will use the new standards to determine the base case.

8a. Units for above (e.g., horsepower)

9. Base case efficiency

9a. Units for above (e.g., EER)

10a. U.S. base case energy use. Energy use is calculated for typical operating conditions. For climate-sensitive measures, national average consumption was used if a measure is cost effective nationally (on a LCC basis at projected 2020 measure costs and energy prices). If a measure is not cost effective nationally (due to regional climate or energy price considerations), a subset of the country was explicitly defined and used uniquely for that measure. For measures that use both electricity and fossil fuels, separate numbers were listed for each energy source.

10b. Units for above (e.g., kWh, million Btu)

11. Peak energy use (based on 0.4% design temperatures in ASHRAE 2003, or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

[Note: for these and other variables, Canadian numbers will be used in the Canadian version of the report and California numbers in Appendix B.]

New Measure Information

12. New measure description (size and characteristics, for comparison to base case)

13. New measure efficiency

13a. Units for above (e.g., EER)

14. New measure U.S. annual energy use

14b. Units for above (e.g., kWh, million Btu)

15. Peak energy use (based on 0.4% design temperatures in ASHRAE [2003], or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

16. Current status of technology (COMM = commercialized; FLDTEST = field test; PROTO = prototype; RES = research)

17. Estimated date of commercialization (may be a range or an approximate figure, e.g., “2003–2005" or ”~1995")

18. Estimated measure life (years). These are average installed lives in the field, not engineering lives in a laboratory. Available data (e.g., ASHRAE 2003, Chapter A36: "Applications," Table 3) are of limited accuracy, but are often the best available.

Savings Information

19. U.S. electricity savings/year (of new technology relative to base case)
20. Peak demand savings (based on 0.4% design temperatures in ASHRAE 2003, or available load shapes)
    a. U.S. summer peak (2pm, very hot summer day in St. Louis)
    b. U.S. winter peak (6pm, very cold winter evening in St. Louis)

For many technologies, there are better energy savings than demand savings data. In some cases, we have used available empirical correlations, as noted for each affected T and P.

21. U.S. gas/fuel savings/year (of new technology relative to base case)

21a. Units for above (e.g., therms, gals., Btu)

22. Percent savings (of new technology relative to base case). Where a measure affects both electric and fossil fuel use, the percentage reduction in energy use is based on source energy savings using the projected national average heat rate for electricity generation in 2020. [Canadian version will be adjusted for Canadian heat rate.]
23. Feasible applications are the approximate percentage of end-use applications for which each technology is likely to be appropriate. This figure includes both technical and economic feasibility. "Feasible" means the fraction of technology and practice applications *nationally* that would be amenable to the improved T or P for the target market. For most measures, this is done on a national basis. However, for example, if the target market is new construction in the Southeast, percent feasible applies to that percent of new construction in the Southeast that is feasible. Any restrictions (e.g., new construction only, limited regional applicability) were made as a coefficient in the calculated 2020 savings potential, not in the "feasible applications" parameter. Feasibility does *not* take into account the likely commercialization date of the technology (Variable 17) nor the rate at which the equipment or building stock turns over (Variable 18). The Canadian report will go into greater depth and derive, where possible, the technology applicability rates by segment and end-use.
24. Annual U.S. savings potential in 2020: GWh

24a. Annual U.S. savings potential in 2020: trillion Btu (source energy)

For variable 24, potential energy savings were estimated for the United States using base case data by end-use from EIA (2003). For Canada, potential energy savings were estimated using the NRCan (2002). The general approach for estimating energy savings was to compute the product of projected energy use in 2020 for the specific end-use affected times the feasible applications times the proportion of the market that could be impacted by 2020. For retrofit measures, this latter figure was assumed to be 100%. For replacement measures (measures that are installed when existing equipment needs to be replaced), this proportion was calculated assuming that sales between 2005 and 2020 are affected. For these calculations, we assumed gradually rising sales, with a 10% penetration rate for applicable markets in 2005, 20% in 2006, etc., rising to 100% in 2014 and continuing at 100% for subsequent years.[1] For measures not yet commercialized, the savings potential only includes sales after the date of commercialization and thus for measures commercialized after 2005, the ramp-up begins in the year of commercialization. For new construction measures, the same approach was used as for replacement measures except that savings estimates include only buildings built in 2005 or thereafter. Thus, the energy savings estimates essentially are for the technical and economic savings potential. Such savings may be achievable for measures with a

[1] In the 1998 study we assumed 100% penetration in the first year of the analysis and thus savings in the 2004 study will generally be lower than savings estimated in the 1998 study.

likelihood of success rating of five (the maximum score) and for which full turnover of the stock will take place by 2020. For measures with a lower likelihood of success, penetration rates will probably be lower, but this difference is captured in the likelihood of success score and not the energy savings score. For measures that save one fuel but use more of another fuel (e.g., gas air conditioning that saves electricity but uses gas), energy savings are expressed in Btu, valuing electricity at 10,010 Btu/kWh. It should be noted that savings often overlap between measures and that savings across measures are frequently not additive. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, national savings estimates will be rounded to the nearest GWh or trillion Btu.

25. Industrial savings indicator: Yes/no variable to indicate if savings in industrial sector are likely to equal or exceed at least 25% of savings in residential and commercial sectors (from item above).

Cost Information

26. Retail (consumer) incremental cost (relative to base case) for typical unit once the technology is established (e.g., mature market costs). Costs are in 2003 U.S. and Canadian dollars for the respective reports. For commercial sector measures, costs are in quantities used in a medium-sized office/retail building; for residential sector measures, costs are in single-unit quantities.

27. Other direct costs/savings ($/year). Other important costs included in the analysis (e.g., additional or avoided maintenance costs and additional or avoided operating costs such as water, detergent, or use of a secondary energy source). Specifics are included in notes and write-up for technologies and practices affected. This includes demand charge savings where these are significant. For fuel switching measures, the cost of the new fuel is included as a cost and the cost of saved energy is calculated in terms of the fuel that is displaced. For periodic costs in the future (e.g., maintenance every five years), costs were annualized, assuming a 5% real discount rate.

28. U.S. cost of saved energy ($/kWh)

28a. U.S. cost of saved energy ($/million Btu)

Variable 28 reflects both equipment costs and other direct costs/savings. The *cost of saved energy* is the levelized cost of a measure over its lifetime per unit of energy saved. It is calculated by assuming each measure is financed with a loan, with a term equal to the measure life and an interest rate equal to the discount rate, and dividing the annual loan payments by the annual energy savings.[2] These calculations are based on future measure cost estimates and a 5% real discount rate, where 5% is a figure commonly used by electric utilities for energy-saving analyses.[3] For measures that save both electricity and natural gas, we allocated costs proportionately to the two fuels based on the primary energy savings achieved and calculated costs of saved energy separately for electricity and gas. For measures that have annual operating costs or savings besides energy (e.g., reduced or increased maintenance costs), changes in annual maintenance costs were included in the costs calculations. For example, for a measure that increases maintenance costs, costs included in the total were annualized capital costs and the incremental increase in maintenance costs. In some cases, savings in other costs are greater than annualized measure costs and the cost of saved energy is negative. For these measures, we inserted the word "negative" in the cost of saved energy field because once a cost of saved energy is negative, the exact value is immaterial and often misleading (for example, if costs are negative, the cost of saved energy *declines* as energy savings decline). For measures that save one fuel but use more of another fuel, cost of saved energy was calculated for the

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[2] The specific formula used for cost of saved energy is:

$$\frac{(\text{Measure Cost} \times \text{Capital Recovery Factor}) + \text{Annual Other Costs}/\text{Savings}}{\text{Annual kWh Savings}}$$

Capital Recovery Factor = ((1+D)L-1 × D) ÷ ((1+D)L - 1) where D is the discount rate and L the measure life.

[3] See, for example, PG&E 1995; 1996 and DOE 1997.

fuel being saved, but including the annual cost of the other fuel in the cost part of the calculations. For example, to calculate the cost of saved energy of gas air conditioning, costs include annual loan payments on capital costs, annual natural gas costs (valued at EIA projected values for 2020 but expressed in 2003 $), and incremental annual maintenance costs. As with the energy savings estimates, these figures depend on many assumptions and estimates and are highly approximate. Given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, cost of saved energy was rounded to the nearest cent.

29. Data Quality Assessment: (quality/accuracy of data on each measure, rated on a A-D scale, where A=very good, B=good, C=fair, and D=poor). For an A rating, data needed to be available from several sources, with general agreement among these independent sources on specific data values. Many of these cases include data obtained from independent analysts who do not have a vested interest in promoting a product. For a B rating, solid estimates from one source, or less precise estimates from several sources. For a C rating, preliminary estimates were available from only one source, often a source with a vested interest in promoting the product. For a D rating, data are essentially a "guesstimate" with no source willing to support a firm number.

Likelihood of Success

30. Major market barriers (brief list). Examples include third-party decision makers, high initial costs, and contractors unfamiliar with proper installation practices.
31. Effect of measure on customer utility (non-energy benefits and problems). Examples include cleans clothes better, increases worker productivity, or more difficult to maintain, etc.
32. Current activity promoting measure (a brief summary of who is doing what).
33. Likelihood of success rating (1–5 scale), where success is defined as penetrating at least 50% of feasible applications by 2020. Guidelines for these ratings are discussed further below.
34. Rationale for likelihood of success rating

    Values for variables 33 were determined qualitatively for each measure according to the likelihood with which market and technical barriers can be overcome, using the 5-point scale indicated below. Significant non-energy benefits can also offset some of the barriers and improve the likelihood of success, so where these exist, the likelihood of success is increased by 1 point on the 5-point scale.

    1 = Will be very difficult to succeed; there are multiple major barriers that will be difficult to overcome.

    2 = Will be hard to succeed; there are major barriers to overcome and while some progress can be made, substantial barriers will likely remain.

    3 = Moderate chance of success; there are substantial barriers to overcome, some major barriers can be overcome, but others will likely remain.

    4 = Good chance of success; the barriers appear surmountable but will take require extensive effort and time to overcome.

    5 = Excellent chance of success; barriers appear to be clearly surmountable.

    The project team prepared initial estimates of likelihood of success ratings and shared these preliminary values with the project Advisory Committee for review and comment. Based on these comments, some of the ratings were revised. In this way, the ratings reflect the consensus judgment of the people working on the project.

Recommended Next Steps

This is a brief note on the kinds of actions that might increase market penetration.

Sources

35. Using author/year format; multiple references are separated with semi-colons. If there is more than one source for a given author/year, a, b, etc. are used after the year (e.g., Suozzo 1997a, Suozzo 1997b).
36. Savings estimates
37. Peak demand estimates
38. Cost estimates
39. Feasible application estimates
40. Measure life estimates
41. Other key sources
42. Principal contacts (name, organization, phone number for people; sometimes includes organization Web page address).

Notes

43. This section of the data sheet includes important comments such as key assumptions made to calculate some of the above values; more extensive notes are included in the written report.

Selection of High Priority Measures

In ranking measures we recognize that measure scores are inexact and that small score differences are meaningless. We also recognize that no objective ranking process can capture the full range of issues that need to be balanced in order to fully assess potential initiatives. However, ranking measures helps separate high priority measures from low priority ones. Ranking also allows consideration of other issues to be focused on a limited number of measures that appear to be high priority.

For this study, measures were divided into "high," "medium," "lower," "not a priority" and "special" categories, based on three factors: potential energy savings, cost of saved energy, and likelihood of success. High priority measures are those that meet the following three criteria: potential energy savings of at least 1% of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; and a likelihood of success rating of 3 or more. Medium priority measures are those with potential energy savings of 0.25 to 1.0% of projected residential and commercial energy use in 2020; a cost of saved energy less than current retail energy prices; and a likelihood of success rating of 3 or more. Low priority measures are those with potential energy savings of less than 0.25% of projected U.S. residential and commercial energy consumption in 2020, a cost of saved energy less than current retail energy prices; and a likelihood of success rating of 2 or more. Special measures are those that will not save as much as 0.25%, but are included because they are particularly important for new construction or in specific regions (details on this category were provided earlier in this chapter). "Not a priority" measures are those with a cost of saved energy greater than current retail energy prices or a likelihood of success of 1. The differences among these priority categories are summarized in Table 2-1. In the Canadian report, Canadian energy use and energy prices will be used and in the California report we use California values.

Table 2-1. Priority Levels and Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of Success
high	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5
medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5
low	NA	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5
special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5
not a priority	Fails to meet other thresholds.			

Notes:
To earn a "high" or "medium" priority, a measure must meet all the thresholds in the row. For example, high priority measures are those that show potential energy savings of at least 1% of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; and a likelihood of success rating of 3 or more. If a measure fails to meet one or more of these thresholds, it slips to the next lower priority.

COMPARISON TO PRIOR EMERGING TECHNOLOGIES STUDIES

Many of the measures examined in the 1993 and 1998 reports were reexamined in this study. For these measures we compared our findings with our expectations from prior work in order to see which technologies fared as well as expected, which fared better, and which fared worse. In addition, for the 1998 high priority technologies that are not included in this study (which is the case if they now have more than a 2% market share or if their commercialization date is delayed beyond 2010), we looked at their current status in relation to our expectations. All of the 1998–2004 comparisons are summarized on a measure-by-measure basis. In addition, we examined these comparisons for trends across measures, particularly trends that teach useful lessons about the technology and practice development, commercialization, and diffusion process.

PREPARE REPORT AND DATABASE

The rest of this report summarizes our results. In particular, Chapters 1 through 5 summarize our findings and recommendations regarding high-priority measures, discuss recommended next steps for the high priority measures, and compare and contrast the results of the 1998 and 2004 studies. Chapter 6 (Analysis) includes approximately one-page descriptions of each of the measures examined in detail and one-page tables on each measure summarizing the information on each measure in our database. Additional information is provided in appendices dealing with California-specific and low-priority measures.

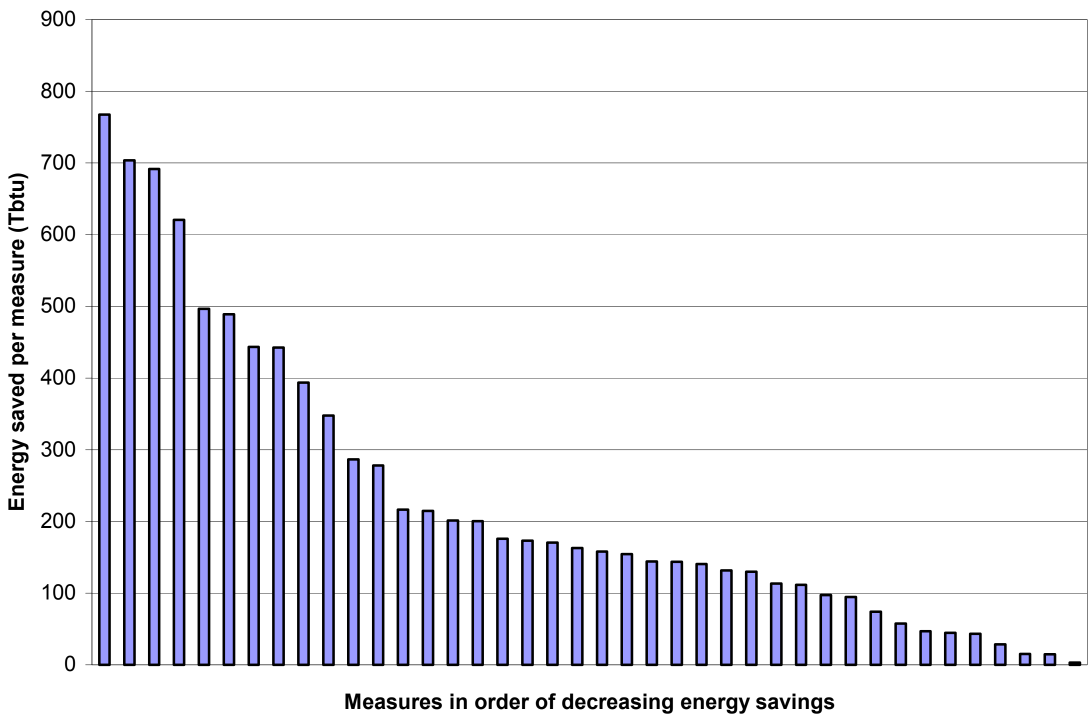
CHAPTER 3: RESULTS

VALUES OF DECISION PARAMETERS

Energy Savings

In this study, the first parameter used to establish priorities is the quantity of energy that the measure could save in 2020. As indicated in Chapter 2, high priority measures save at least 1.0% of total commercial and residential energy; medium priority more than 0.25% of the total, and low priority even smaller. Figure 3.1 shows energy savings by measure, from largest to smallest, exclusive of the "special" measures. "Special" measures should save at least 3% of energy use by new buildings or in specific regions.

Figure 3-1. Rank-Ordered Measures by Total Energy Savings Potential (Without "Special" Cases)



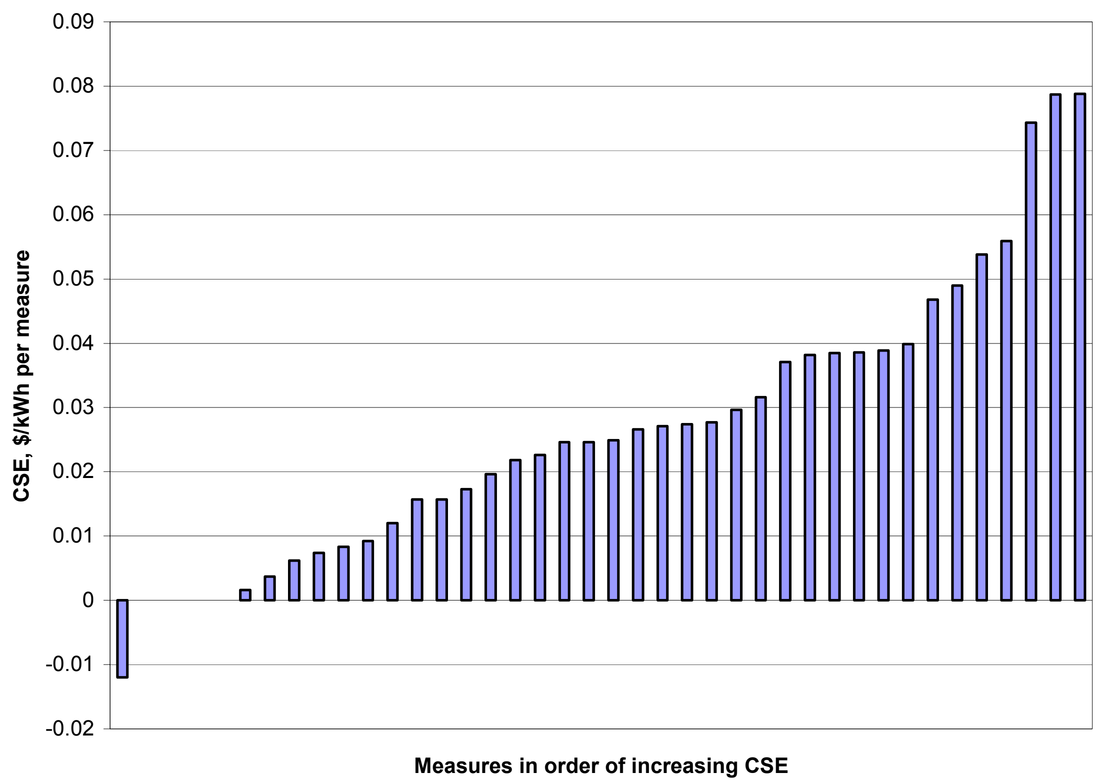
In terms of the study priorities, five or six measures are estimated to save at least 1% of commercial and residential buildings energy use in 2020 (given analytical uncertainties). These include automated building diagnostics, two HVAC measures (leakproof duct fittings and aerosol-based duct sealing), 1-Watt standby power for electronic devices, and two practices: integrated design practices (IDP) and LEED, with efficiency at least 30% better than Code.

Another 17 measures would save at least 0.25% but less than 1% of combined commercial and residential energy, as well as meeting all other criteria for medium priority. Seven low priority, two "special" and five "not a priority" measures also had savings in this range, but were judged to have too low a likelihood of success or too high a cost of saved energy to receive high or medium priority. The 1998 study identified 33 high and medium priority measures, compared with the 20–27 in this study (plus the 10–19 special measures this time). Thus, we have identified a comparable or larger number of large opportunities for savings.

Cost of Saved Energy

The cost of saved energy (CSE) is the second parameter used to prioritize measures. High priority measures have a CSE less than half the average of 2002 electricity tariffs nationally, \$0.041/kWh (this figure is the average of the national average for residential and commercial rates, by state, from EIA 2004). About 60% (40 of 69 measures with electricity use) have a CSE < \$0.41/kWh, the priority range (this number includes 11 special measures). For 16 others, \$0.41/kWh < CSE < \$0.081/kWh (medium priority range). In other words, over three-quarters of the electric measures studied have costs of saved energy less than the average electricity price in the United States today. The distribution is depicted in Figure 3-2.

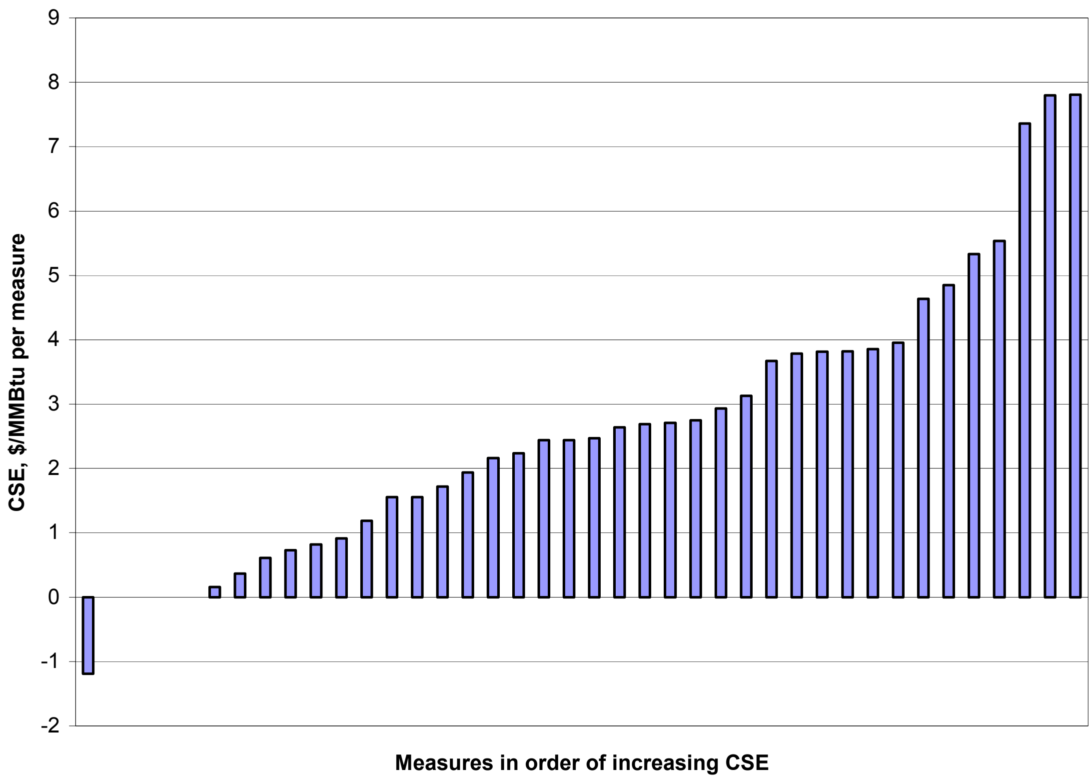
Figure 3-2. Rank-Ordered Measures by Cost of Saved Electricity



The CSE for source energy includes both direct use of natural gas on site, and the source equivalent energy of the fuel use at the power plant for electricity, using the projected 2020 national average heat rate, 10.10 kBtu/kWh. The distribution of the CSE for source energy is shown in Figure 3.3 (again, without the special measures). The cost of saved energy for 33 of 75 measures is less than half the average of the 2001 and 2002 retail prices for the commercial and residential sectors (which was \$8.13/MMBtu—EIA 2004).[4] Another 13 special measures had source energy costs this low, too.

[4] Because EIA's gas and electric divisions present their data in somewhat different formats, our electricity data is from 2002. Our gas values average 2001 (relatively high retail prices) with 2002 (lower retail prices).

Figure 3–3. Rank-Ordered Measures by Cost of Saved Source Energy



Likelihood of Success (Rating)

The third parameter we used to guide the decision on which measures would be grouped in high, medium, and low priority measures was the estimated likelihood of success (LOS) or *rating* of the measure. As noted in Chapter 2, LOS is based on analysts' judgment, combining considerations of major market barriers, non-energy benefits to purchasers, and current promotional activities. From these factors, we have estimated a LOS value (1 to 5, one being the least likely to succeed) and given a rationale (on the data sheets). Figure 3-4 shows the distribution of the likelihood of success parameter for this study and the 1998 precursor.

The average value for 2004 is 2.8, vs. 2.6 in 1998, a very modest change in the analysts' estimate of likelihood of success.[5] The largest change is the great reduction of measures rated with a 1 in this study, that is, those that are least likely to succeed. We attribute this change to more aggressive screening in initial stages of the project, based on the greater knowledge base from earlier work by this group and others. Table 3-1 summarizes definitions of likelihood of success ratings. In practice, no measure was recognized as belonging to Class 5 in either the 1998 or the 2004 study.

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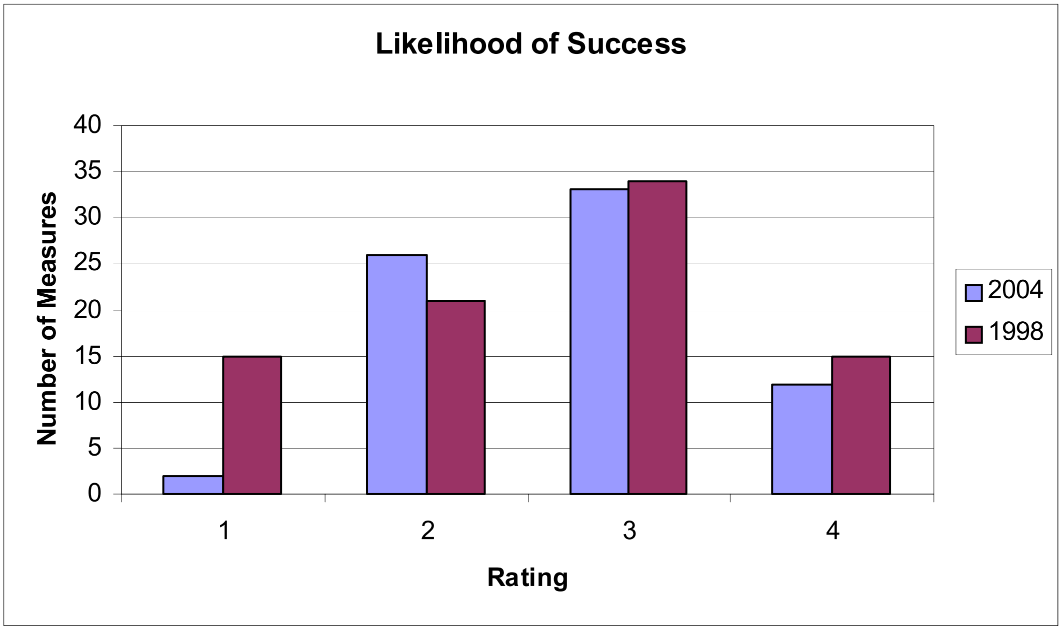
[5] Column heights are numbers of measures; averages are weighted (rating * number of measures). Since the distribution is categorical, not continuous, the term "average" is not to be taken in a strict parametric statistical sense. We quote it only to indicate the central tendency of the estimates of success.

Figure 3-4. Distribution of the Likelihood of Success Parameter for 2004 (Left Column in Each Pair) and 1998 (Right Column in each Pair)



Note: The X-axis is the rated likelihood of success and
the Y-axis is the number of measures with a given rating.

Table 3-1. Measures Rating Classes for Likelihood of Success

1—Difficult; multiple major barriers to overcome
2—Hard; major barriers to overcome
3—Moderate chance; substantial barriers
4—Good chance; barriers appear surmountable
5—Excellent chance; barriers clearly surmountable

Combined Effect

Table 3-2 summarizes the combined effects of the energy saved, cost of saved energy, and likelihood of success.

Table 3-2. Distribution of Measures by Classification Parameters

Priority	Threshold for Savings	CSE, $/kWh	CSE, $/MMBtu (source energy)	Likelihood of Success	Number of Measures
high	≥ 1.0%	≤ $0.0405/kWh	≤ $3.16/MMBtu	3–5	3–6
medium	≥ 0.25%	≤ $0.081/kWh	≤ $6.33/MMBtu	3–5	16–22
low		≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	11–14
special	>~0.05%	≤ $0.081/kWh	≤ $6.33/MMBtu	2–5	12–22
not a priority		Fails to meet other thresholds			14–24
total					72

Notes:
To earn a "high" or "medium" priority, a measure must meet all the thresholds in the row. For example, high priority measures are those that show potential energy savings of at least 1% of projected U.S. residential and commercial energy consumption in 2020; a cost of saved energy less than half of current U.S. retail energy prices; *and* a likelihood of success rating of 3 or more. If a measure fails to meet one or more of these thresholds, it slips to the next lower priority.
The column for "Number of Measures" in this study reflects analytical uncertainty about costs (and applicability) by giving a range of measures that can be included in each category, such as 3–6 high priority measures. Typically, ranges are extended downward by a small amount (<10%) to include more measures and respond to the uncertainties in the analysis.

This change in method also recognizes the increasing number of options that can have major regional impacts, or major impacts on new construction, but which have modest national impact because of their restricted spheres of influence.

Some Changes from 1998

For the present study, Table 3-3 shows the data that underlie our results.

Table 3-3. Measure Priorities Sorted by Cost of Saved Energy ($/kWh)

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
H11	leakproof duct fittings	489	1.03	0	0.40	4	H
PR3	int. design process (30% > code)	620	1.31	0.01	1.20	3	H
A1	1 Watt standby power for home appliances	497	1.05	0.02	1.90	4	H
H12	aerosol-based duct sealing	443	0.93	0.03	2.50	3	H/M
PR4	retrocommissioning	443	0.93	0.03	2.60	3	H/M
PR1	advanced automated building diagnostics	704	1.48	0.04	4.00	3	H/M
L16	airtight compact fluorescent downlights	393	0.83	-0.01	-1.20	4	M
R1	solid state refrigeration (Cool Chips™)	171	0.36	0	0	3	M
L15	scotopic lighting	154	0.33	0	0	3	M
L14	1-lamp fluorescent fixtures w/ high performance lamps	215	0.45	0.01	0.80	3	M
O1	EZConserve Surveyor software	286	0.6	0.02	1.70	3	M
W3	residential heat pump water heaters	158	0.33	0.02	2.20	3	M
L13	residential CFL portable (plug-in) fixtures	216	0.46	0.03	3.10	3	M
D2	advanced air-conditioning compressors	200	0.42	0.03	2.40	3	M
L11b	commercial LED lighting	176	0.37	0.03	2.90	3	M
H18	CO_2 ventilation control	163	0.34	0.03	2.70	4	M

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
S1	high performance windows (U<0.25)	144	0.3	0.03	2.70	3	M
L6	low wattage ceramic metal halide lamp	130	0.27	0.03	2.80	3	M
H7	"robust" a/c	278	0.59	0.04	3.80	3	M
S5	residential cool color roofing	144	0.3	0.04	3.70	3	M
A2	1 kWh/day refrigerator	140	0.3	0.04	3.90	4	M
H9	adv. cold-climate heat pump/frost-less heat pump	173	0.36	0.05	4.60	3	M
H15	"designs for low parasitics, low pressure drops"	94	0.2	0	0	4	M/L
D3	advanced HVAC blower motors	112	0.24	0.04	3.80	4	M/L
P2b	commercial micro-CHP using micro-turbines	692	1.46	0.05	5.30	2	M/L
H10a	ground-coupled heat pumps	15	0.03	0	0	2	L
D1	advanced appliance & pump motors; CW example	58	0.12	0	0.20	4	L
PR7	bulls-eye building commissioning	47	0.1	0.01	0.60	3	L
PR6	"better, easier to use, residential sizing methods"	113	0.24	0.01	0.70	2	L
R3	efficient fan options for commercial refrigeration	29	0.06	0.02	1.60	4	L
H13	microchannel heat exchangers	132	0.28	0.02	1.60	2	L

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
R2	modulating compressor for packaged refrigeration	45	0.09	0.02	2.20	4	L
L3	general service halogen IR lamp	74	0.16	0.03	2.40	2	L
L9	advanced HID lighting	97	0.21	0.05	4.90	2	L
P1b	residential micro-CHP using Stirling engines	201	0.42	0.06	5.50	2	L
P2a	commercial micro-CHP using fuel cells†	767	1.62	0.07	7.40	2	L
PR2	ultra low energy designs & zero energy buildings	199	0.42	0.01	0.60	2	S
H20	advanced condensing boilers (commercial)	23	0.05	0.01	0.60	3	S
S2b	"active window insulation, commercial"	93	0.2	0.02	1.80	2	S
L5	advanced daylighting controls	80	0.17	0.02	2.30	3	S
D4	hi-eff. pool and domestic water pump systems	19	0.04	0.03	3.40	3	S
W4	integrated home comfort systems	43	0.09	0.04	3.80	2	S
H1a	advanced roof-top packaged air conditioners	81	0.17	0.04	3.50	3	S
H1b	advanced roof-top packaged air conditioners	81	0.17	0.06	6.00	3	S
H8	residential gas absorption chiller heat pumps	41	0.09	0.07	6.60	2	S

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
S8	high quality envelope insulation	15	0.03	0.08	7.80	2	S
S3a	electrochromic glazing for residential windows	3	0.01	0.08	7.80	2	S
H16	high-efficiency gas-fired rooftop units	20	0.04	N/A	3.40	2	S
S9	engineered wall framing	12	0.03	0	0	3	S/X
H19	displacement ventilation	11	0.02	0	0	3	S/X
CR1	hotel key card system	15	0.03	0.01	1.30	2	S/X
H2a	Cromer Cycle air conditioner—residential	21	0.04	0.03	3.10	3	S/X
L7	hospitality bathroom lighting	28	0.06	0.04	4.00	3	S/X
H5	residential HVAC for hot-dry climates	11	0.02	0.04	4.40	4	S/X
S3b	electrochromic glazing for commercial windows	3	0.01	0.05	4.60	3	S/X
PR5	low energy use homes and zero energy houses	199	0.42	0.07	6.60	2	S/X
H2b	Cromer Cycle air conditioner—commercial	16	0.03	0.07	6.80	3	S/X
H17	transpired solar collectors for ventilation air	7	0.02	N/A	2.40	3	S/X
H4	CAC dehumidifiers/free-standing dehumidifiers	5	0.01	0.05	4.40	3	X

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
L8	universal light dimming control device	97	0.20	0.08	8.10	1	X
L11a	residential LED lighting	229	0.48	0.11	11.30	2	X
H10a	ground-coupled heat pumps (comm.).	43	0.09	0.13	12.60	2	X
H14	solid state refrigeration for heat pumps	106	0.22	0.16	15.60	2	X
S4	attic foil radiant barriers	27	0.06	0.16	16.20	2	X
P1a	residential micro-CHP using fuel cells	171	0.36	0.18	17.40	2	X
L10	hybrid solar lighting	270	0.57	0.27	26.30	2	X
H3	commercial HVAC heat pipes	8	0.02	0.28	27.30	2	X
L4	cost-effective load shed ballast & controller	1	0	0.43	42.90	3	X
H6	UV HVAC disinfection	19	0.04	0.57	56.50	2	X
S2a	active window insulation	41	0.09	0.73	72.20	1	X
W1	residential condensing water heaters	217	0.46	N/A	6.40	2	X
W2	instant. gas high-modulating water heaters	127	0.27	N/A	8.30	2	X

Notes: † Value of waste heat is critical

Two letters such as "M/L" in the "Priority" column suggest borderline situations, given analytic uncertainties. An "X" in that column indicates that the measure is not a national priority (<0.25% savings forecast, high CSE, low likelihood of success).

Of course, savings often overlap between measures and savings across measures are frequently not additive. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute. For this reason, national savings estimates are rounded to the nearest GWh or trillion Btu.

High Priority Measures

When we combine all three parameters (energy savings, cost of saved energy, and likelihood of success [rating]), only five or six measures meet all three thresholds (Table 3-4).

Table 3-4. High Priority Measures

PR1	advanced automated building diagnostics
PR3	integrated design practices (30%> code)
A1	1 Watt standby power for home appliances
PR4	retrocommissioning
H12	aerosol-based duct sealing
H11	leakproof duct fittings

Two of these measures are almost exclusively residential (A1 and H11), while two are commercial (PR1 and PR4). The other two (H12 and PR3) are applicable to both residential and commercial structures. A1 is unique in this set because it concerns equipment used in buildings (electronics, appliances), much of which has relatively short lifetimes. The others are most likely to enter the market in new construction and major retrofits/remodeling projects, and thus will penetrate somewhat more slowly. PR1 is complementary to PR4, retrocommissioning (medium priority), in that both intend to keep buildings working at the potential of the design intent.

Medium Priority Measures

In general, medium priority measures are those that could save at least 0.25% of projected 2020 buildings energy use, have a cost of saved energy ≤$0.081/kWh or ≤$0.633/therm, and have likelihood of success (rating) of at least 3. By these criteria, we identify about 20 measures in the current analysis. All qualify through their electricity savings. Table 3-5 lists the medium priority measures. Of these, about half are primarily residential vs. primarily commercial, and four have major opportunities in both sectors. By technology type, the residential list includes an appliance (advanced refrigerator) and several HVAC/water heating measures. Although the list includes a number of commercial lighting technologies, there are also two that are more relevant for residential applications: CFL portable lights and sealed CFL downlights. It is noteworthy that the CFL emphasis has shifted from the bulbs to measures that assure proper application and “lock in” savings by requiring CFLs instead of incandescents. Two measures are shell-related (advanced windows and cool roofs). Lighting dominates the medium priority commercial measures with five technologies, with the remainder including refrigeration, HVAC, and ventilation.

Table 3-5. Medium Priority Measures, in Order of Declining Energy Savings

L16	airtight compact fluorescent downlights
L1	high efficiency premium T8 lighting (100 lumens/w)
O1	EZConserve surveyor software
H7	"robust" a/c
L13	residential CFL portable (plug-in) fixtures
L14	one-lamp fluorescent fixtures w/high performance lamps
D2	advanced air-conditioning compressors
L11b	commercial led lighting
H9	advanced cold-climate heat pump/frost-less heat pump
R1	solid state refrigeration (Cool Chips™)
H18	CO_2 ventilation control
W3	residential heat pump water heaters
L15	scotopic lighting
S5	residential cool color roofing
S1	high performance windows (U<0.25)
A2	1 kWh/day refrigerator
L6	low wattage ceramic metal halide lamp
H15	designs for low parasitics, low pressure drops
D1	advanced appliance & pump motors; CW example
R3	efficient fan options for commercial refrigeration
D3	advanced HVAC blower motors
P2b	commercial micro-CHP using micro-turbines
W4	integrated home comfort systems

Note: Note that the three lowest measures are transitional medium/low.

Special Measures

As noted earlier,[6] this study includes several special measures, including lost opportunities in new construction, and measures of great regional importance but limited national savings. One new construction special case also saves enough energy to warrant high priority rating. This is integrated design, at levels 30% better than code (measure PR-5). If the costs are assigned to primary energy, it would not meet the combined criteria, but it qualifies readily as an electricity-saving measure. Table 3-6 summarizes the special measures. Roughly speaking, over 16 years of implementation between now and 2020, a new construction special measure could save 15–20% as much energy as a national high priority measure (1%), since the building stock increases by a bit more than 1% per year. An analogous approximate case could be made for regional measures.

This relationship gives us a tool for comparing the importance of special measures to national ones, within specific regions or for new construction: multiplying the national savings of Table 3-6 by about five will serve as a rough "rule of thumb." For example, it allows program operators in hot climates to consider the value of investing in modulating pool pump motors (D4) vs. a national measure that would save roughly 0.20% of 2020 national energy

[6] See "Preliminary Division into Priority Categories" and "Selection of High Priority Measures."

use. In this table, there is no clear break in estimated energy savings at levels below 0.09%, so local program considerations legitimately affect choices among measures of interest.

Table 3-6. Special Measures, in Order of Declining Energy Savings Potential

PR2	ultra low energy designs & zero energy buildings	0.42
PR5	low energy use homes and zero energy houses	0.42
S2b	active window insulation, commercial	0.20
H1a	advanced roof-top packaged air conditioners	0.17
H1b	advanced roof-top packaged air conditioners	0.17
L5	advanced daylighting controls	0.17
H8	residential gas absorption chiller heat pumps	0.09
L7	hospitality bathroom lighting	0.06
H20	advanced condensing boilers (commercial)	0.05
H2a	Cromer Cycle air conditioner—residential	0.04
H16	high-efficiency gas-fired rooftop units	0.04
D4	hi-eff. pool and domestic water pump systems	0.04
H2b	Cromer Cycle air conditioner—commercial	0.03
CR1	hotel key card system	0.03
S9	engineered wall framing	0.03
H19	displacement ventilation	0.02
H5	residential HVAC for hot-dry climates	0.02
H17	transpired solar collectors for ventilation air	0.02
S3b	electrochromic glazing for commercial windows	0.01

Changes through Time

These data can also be used to compare measures in the 1998 and 2004 studies (Table 3-7). Note that Table 3-7 does not include extra attention to special measures (new construction and region-specific), since they were not included in the 1998 study, although integrated building design is included in the table.

Five measures, marked “MT,” were removed because they have become mainstream products in the market (advanced clothes washers and dish washers, improved CFLs, TP-1 distribution transformers, and commercial “cool roofs.” Indirect-direct evaporative coolers were not considered because no appropriate products are on the market today.

In addition, about 28 lower priority measures from 1998 were dropped from this study, largely because their market prospects have not grown as quickly as expected. Note also that in some cases the “mapping” from 1998 to 2004 measures is not exact, as we found it necessary to slightly modify the definition to capture current and expected future practices.

Table 3-7. Disposition of High and Medium Priority Measures

1998		2004		
#	Priority	Priority	#	Measure
A1	M	H	A1	"low leak" home electronics
A2	M	H	A2	one kWh/day refrigerator/freezers
A3	H	MT		high-efficiency vertical-axis clothes washers
A4	M	MT		high-efficiency dishwashers
A5a	M	M	D2	improved efficiency air conditioning compressors
A5b	M	L	R2	in 1998: improved efficiency refrigeration compressors
A6	M	L	D1	in 1998: advanced clothes washer and dishwasher controls
D5	M	L	D1	in 1998: switched reluctance drives
H14	M	drop		indirect-direct evaporative coolers
H18	M	M	H5	in 1998: evaporative condenser air conditioning
H2	H	M	H12	aerosol-based duct sealing
H3	M	M	H11	in 1998: commercial distribution system air sealing
H4	H	M	PR4	commissioning existing commercial buildings
H5	H	drop		dual source heat pumps
H8	H	M	H11	improved ducts and fittings
H9	H	L	H13	improved heat exchangers
I1	M	drop		advanced metering/billing systems
L11	M	M	L14	in 1998: one-lamp fixtures and task lighting
L14	M	M	L13	compact fluorescent floor and table lamps
L4	M	L	L8	improved fluorescent dimming ballasts
L7	H	MT		reduced-cost and/or higher efficiency CFLs
L8	H	L	L3	metal halide replacements for incandescents
P1	M	L	P1	fuel cells

1998		2004		Measure
#	Priority	Priority	#	
P2	M	L	P2	microturbines
P4	M	MT		dry-type distribution transformers
PR1	H	M?	PR2	integrated new home design
PR2	H	H	PR3	integrated commercial building design
S2	M	MT		(comm.) heat reflecting roof coatings
S3	M	L	S1	high R (>4) windows
W2	M	drop		integrated electric space conditioning/water heating systems
W3	H	L	W4	integrated gas- and oil-fired space/water heating systems
W4	M	M	W1	residential heat pump water heaters

Note: "H," "M" and "L" refer to priority levels. "MT" means "market transformed," i.e., that the technology or practice has a market share estimated as more than 2% today. "Drop" means that the 1998 measure was not included in this study. This may have occurred because products have been withdrawn from the market, or that our evaluation of the potential savings did not meet our threshold for consideration.

CHAPTER 4: DISCUSSION

In this chapter, we compare our results with the earlier ones in more depth, explore the implications of these findings, and recommend some early steps for high priority measures.

COMPARISON TO THE 1993 AND 1998 STUDIES

Between 1993 and 1998, the number of measures analyzed dropped by about 25%, but stabilized for this study (see Table 4-1). Similarly, the 1998 study had only two-thirds as many high and medium priorities as the first. However, the current study is close to the 1998 level. In addition, this study also adds 20 special measures for new construction or regional applications. Only three of these measures would save enough energy to qualify on the national scale as high or medium priorities.

Table 4-1. Number of Measures by Priority, 1993, 1998, and 2004 Studies

	1993	1998	2004
total measures analyzed	102	73	72
high priority	21	12	3–6
medium priority	32	21	16–22
high + medium	53	33	22–25[7]
special	N/A	N/A	12–22

Over the past decade and three reports on emerging technologies, there has been a reduction in the number of high and medium priority technologies identified, from 53 in the first study down to 22–25 in the present report. In retrospect, one interesting anomaly emerges. One reason for the drop in the number of high and medium priorities from 1993 to 1998 is that the cost of saved energy criteria changed, from $0.06/kWh to $0.041/kWh, and from $4/MMBtu to $3.16/MMBtu, so the screening was tighter. In this study, we also used a conservative assumption that emerging technologies and practices would gradually "ramp up" their market presence, rather than emerging at full potential, which reduced the savings proportionately. In addition, it is clear for the 2004 study that more conservative estimates of total energy savings had an effect on the number of measures considered high priority.

Still, it is instructive to compare the 1998 and 2004 results for high and medium priority measures (see Table 4-2).

[7] Total is lower than the sum of the two rows above because of overlaps: some measures could be considered either high or medium priority.

Table 4-2. Disposition of 51 High and Medium 1993 Measures in 1998 and 2004 Studies

Disposition	1998	2004 (relative to 1993)
moved into mainstream (> 2%)	8	16
remained high or medium priority	12	7
moved down to low priority	9	2
"special" (new category)		3
no longer included	22	24

It is heartening that 16 emerging technologies and practices (30%) have moved into the mainstream, with market shares > 2%, in a decade; these are listed in Table 4-3.

Table 4-3. Measures from 1993 That Have Become Mainstream Products

100 W equivalent screw-in fluorescent
advanced dishwasher & clothes washer controls
low energy & water use dishwasher
low temperature dishwashing detergent
low power color television
thermal bridging for fluorescent fixtures
high-R case doors
very low head pressure
supermarket refrigerator system integration
improved inkjet printers, etc.
improved cold-fusing printers, copiers, etc.
golden carrot refrigerator/freezer
horizontal axis clothes washer
high spin clothes washer

On the other hand, a number of measures that were considered quite promising in 1993 are not included in our study, largely because they have been discontinued as products or have not yet entered the market. These are listed in Table 4.4.

Table 4-4. Twenty-Four Measures from 1993 That Are Not Included in the Present Study

Outcome	Measure
mandated by law for 2010	zeotropic refrigerants
not yet achieved market penetration	200–300 kWh/yr refrigerator
not yet achieved market penetration	indirect/direct evaporative cooling
not yet achieved market penetration	advanced reflector design
not yet achieved market penetration	cool storage roof
not yet achieved market penetration	microwave clothes dryer
not yet achieved market penetration	coated filament lamp
not yet achieved market penetration	hafnium carbide filaments
not yet achieved market penetration	fluorescent surface wave lamp
not yet achieved market penetration	DC lighting system
not yet achieved market penetration	electrohydrodynamic HX enhancement
not yet achieved market penetration	cool ceiling displacement ventilation
not yet achieved market penetration	adsorption cooling
not yet achieved market penetration	combination refrigerator/water heater
not yet achieved market penetration	five phase motors
not yet achieved market penetration	heat pump clothes dryer
left the market	bubble-action clothes washer
left the market	Green Plug motor controller
now low priority	low-cost dimmable ballast
now low priority	general service halogen IR lamp
now low priority	ozonated commercial laundering
now low priority	advanced freezer
now low priority	dimmable CFL
now low priority	pilotless instantaneous DHW
now low priority	integrated fixtures and controls

Of these, at least two have been withdrawn from the market (bubble-action clothes washers and the Green Plug motor controller), and fifteen have not (yet) entered the market. With the benefit of hindsight, some of these are not surprising. Consider the combination refrigerator/water heater. Since refrigerators have become much more efficient, the value of the few hundred kWh/yr they dissipate as heat now is small compared with heating loads that often will be several thousand kWh/yr, so there is much less impetus for such products. DC lighting systems have another issue, the proverbial chicken-and-egg problem. They would primarily be useful for new construction but that market may be too small to be attractive. In addition, the bar has been raised by the emergence of newer and more efficient systems such as CFLs. Some other technologies have been out-competed by other emerging technologies. This probably explains the slow progress of general service and PAR halogen IR lamps, which are "in the shadow" of the rapid cost reductions and market share gains of compact fluorescents.

The pattern that emerges from review of the 1993 study is interesting. A decade later, more measures either largely failed by our criteria (25) or entered the mainstream marketplace (15) than remain as priorities for future work (11). Technologies are progressing but there are also failures. To some extent, we believe that this also reflects greater optimism by the earlier teams, compared to a more conservative approach by the present group. This is particularly true for estimates of energy savings. In addition, not all R&D efforts will succeed, almost by definition.

The 12 high priority measures in 1998 averaged about 843 TBtu per measure as potential national impact; the six highest priority measures in this study average about 533 TBtu per measure (see Table 4-5).

Table 4-5. Savings of Source Energy, 1998 and 2004

	1998		2004	
	# of measures	**average TBtu**	**# of measures**	**average TBtu**
high priority	12	843	6	533
hi, med, & low	68	1,239	36	245
hi, med, low, & special			48	198

In considering Table 4-5, it is important to note that savings often overlap between measures and that savings across measures are frequently not additive. Ignoring that fact and summing the savings for the sake of argument would reveal that a total estimated savings from all measures that is only half as large as in 1998. There are several reasons for this. As noted above, in 2004 we used more moderate measure penetration estimates than in 1998, which accounts for much of the difference. Second, in this study we chose to "ramp up" the market penetration of technologies and practices as they enter the market and increase their penetration, which further reduces the calculated savings. Third, the analyses were systematically more conservative this time, accounting for most of the remaining difference. Also, given the many assumptions made in the calculations, these estimates should be viewed as approximate and not absolute.

Comparison by Measures in Groups

Table 4-6 compares the number of measures studied (regardless of rating) in 2004 and 1998, by measures group.

Table 4-6. Changes in Number of Measures (Regardless of Rating) Within Groups Between 1998 and 2004 Studies

Measures Group	1998	2004
appliances	8	2
motors and drives	6	4
HVAC	19	23
lighting	15	14
power	5	4
practices	2	7
refrigeration	1	3
shell	5	10
water heating	7	4
laundry	3	0
miscellaneous, other	1	2

HVAC and lighting are the largest groups in both studies, with relatively small changes in numbers from study to study (although the measures within groups did change). The most striking change from 1998 to 2004 is the great reduction in the number of appliance measures considered, particularly in the context of the declines in the closely related water heating and laundry categories. Some measures are included in both studies (e.g., 1 kWh/day refrigerator, low-leak power supplies). Some, such as more efficient clothes washers, have been dropped because they succeeded in achieving more than 2% market share.

Appliances dropped from eight high and medium priority measures to two. Two measures entered the mainstream (high efficiency clothes washers and dish washers.) One moved up from medium to high priority (low "leak" home electronics.) One of the 1998 group, improved air conditioning compressors, was treated in the "drives" group this time but remained a medium priority. In addition, none of the advanced clothes washing technologies of 1998 remained on the 2004 list: ultrasonic clothes washers, micro filtration wastewater recovery, and ozonated commercial laundering. We did not find evidence of progress in the market for any of these.

Drives saw one category, advanced motors for appliances and HVAC, move from low to medium, in part because the current study "lumped" advanced technologies including switched reluctance and copper rotor into a single category of advanced appliance motors (D1.) This has two effects: Conceptually, it indicates that the study is indifferent about which specific motor technologies emerge as efficiency winners. Practically, it aggregates the savings from "motor improvements," so it is more visible as an opportunity in this study.

In *HVAC,* only one of about twenty 1998 measures moved into the mainstream (modulating gas furnaces). Six were dropped completely: cool storage roofs (but not reflective residential "cool roofs"), engine-driven vapor compression air conditioning, indirect-direct evaporative coolers, integrated chillers with heat recovery, dual source heat pumps, and ductless thermal distribution systems. None of these has enlarged its market visibility substantially. Indeed, residential engine-driven air conditioning, dual source heat pumps, and indirect-direct evaporative coolers are not now commercially available. Ductless distribution ("mini-splits") remains a niche solution for retrofits. Indeed, during this period there has been a slow expansion of capabilities offered in ducted systems, such as better filtration and integration with outdoor air for ventilation, which raises the competitive barriers for ductless systems. Condensing commercial boilers moved from low to medium priority, largely because of the current study's restricted focus on larger boilers for constrained applications. No other technologies moved up, and most of the remaining ones moved down from high or medium to medium or low.

Of the 15 *lighting/lighting system* measures in 1998, two (improved CFLs and integrated lighting systems) entered the mainstream through market transformation. No measures moved from lower to higher priority, but several moved downward. Five lighting measures were dropped in this study (indirect lighting, advanced light distribution systems, sulfur lighting, plastic downlight luminaires, and reduced-cost and/or higher efficiency CFLs). Indirect lighting seems to be part of the common palette of options today, driven by glare concerns in offices. In this study, we focused on a specific lighting distribution system, namely L10, Hybrid Solar Lighting, largely because high intensity sulfur lighting has not been a commercial success, and this was the "engine" that would have supported centralized lighting approaches. (Sulfur lighting, while highly efficient, has not been feasible in low wattage fixtures.) In California, dimmable CFLs are economically attractive, with a CSE of approximately $0.01/kWh, and they have better color rendition at reduced output than incandescents.

Power continued the same pattern: the time horizon of both fuel cells and microturbines was stretched out and their ratings reduced, and the two photovoltaic technologies were deemed unlikely to satisfy our threshold criteria in the near future. We believe that studies that fully incorporate the peak reduction benefits of photovoltaics are likely to find strong reasons to encourage their adoption in some sectors (commercial) and regions.

Practices fared better; with the two from 1998 surviving and being joined by several others in this study, specifically retrocommissioning (M), and "bulls-eye" commissioning (L). We consider this to be an example of the generally greater importance of "people factors" as the early technology opportunities have been captured through standards and market transformation programs.

The 1998 study pointed out the potential of advances in *packaged refrigeration* for products such as beverage vendors and ice makers. Since then the Consortium for Energy Efficiency has established programs with common specifications for solid- and glass-door commercial reach-in refrigerators and freezers, glass door refrigerators, and ice makers (see http://www.cee1.org/com/com-main.php3). ENERGY STAR has a solid-door reach-in refrigerator program and one for beverage vendors. Thus, these products from the 1998 study have reached and gone beyond our 2% market share criterion and are no longer emerging technologies. Thus, the present study focuses on new opportunities in this sector, including solid state alternatives to vapor compression, modulating compressors, and advanced evaporator fan motors, as ways to further increase efficiency of commercial refrigeration products.

Two *shell* measures were dropped this time: low-e interior surfaces, and low-e spectrally selective retrofit window films. We find no evidence that these are important in the market today, or likely to become so. On the other hand, a number of new measures entered the system this time, such as active window insulation (M for commercial, L for residential) and residential "cool roofs." (Commercial "cool roofs" would have been included, but they are already beyond 2% of the market).

Finally, the water heating technologies are pruned in 2004 relative to 1998. Several measures that looked promising have shown limitations and/or slow market uptake. For example, the passive "GFX" gray-water heat exchanger will rarely be highly cost effective for retrofits, since it requires about a 4' vertical drop for the heat exchanger. This works for single- and two-story houses that have basements and sub-basement plumbing. However, it is problematic for single-story slab-on-grade and crawl space construction, unless plumbing is deep in the ground. It is unattractive for houses with basements, if the baths are on the first floor and the waste plumbing is near the basement ceiling. Although low-efficiency combination systems that use hot water heaters for domestic hot water and a heating coil for space heating have gained market share for apartments, more efficient devices have not been rapidly adopted in the new construction market. As retrofits, they are not very attractive unless both the furnace and the water heater are near the end of their service lives, in a planned upgrade. This is thought to be a rather limited fraction of the market, and dealers have reported concerns about call-backs. The heat pump water heater market has not grown, but remains poised for growth. Notably, DOE and others are beginning to pay attention to new approaches to water heating, including solar systems, but there seems little chance of large market penetration within 5 years, given today's market dynamics.

To the authors, one largely pleasant surprise in this study has been the results of the changing market for *residential clothes washers*. In advance of new federal standards in January 2004 and January 2005, horizontal axis and other technologies that are energy and water efficient have achieved significant market shares. In most cases, these premium products carry with them the advanced controls highlighted as opportunity A6 in the 1998 study. On the other hand, we find little evidence that the radically different laundry technologies studied in 1998 have seen widespread adoption (or emergence as commercial products) since that study. These include heat pump clothes dryers, ultrasonic clothes washers, and commercial ozonated laundry and micro filtration to recover wastewater and its heat.

The last important change from 1998 to 2004 is our greater awareness of *design and operating practices* as significant sources of energy savings. The 1998 study recognized two such measures, integrated new home design (PR1), and integrated commercial building design (PR2). In 2004, we examined seven practices, and six of them entered the analysis (see Table 4-7).

Table 4-7. Practices Evaluated in 2004 Study, Sorted by Priority

Measure	Name	Priority, First Round	In 1998?
PR3	IDP 30% > code	H	no
PR4	retrocommissioning	H/M	no
PR6	better, easier to use, residential sizing methods	L	no
PR7	bulls-eye building commissioning	L	no
PR2	ultra low energy designs & zero energy buildings	S	
PR5	low energy use homes and zero energy houses	S/X	

One high priority measure (advanced automated, building diagnostics) and one medium priority measure (retrocommissioning) identified in this study were not included in the 1998 project.[8] In addition, super T8 lamps and ballasts were introduced after the 1998 study, but have already emerged as mainstream products with 5% to 10% of the market (Sardinski and Benya 2003). Although we evaluated them in this study, they are not included in the results because they are no longer emerging.

Lessons Learned and Implications of the Study

Perhaps the most important finding of this study is that the well of emerging technologies and practices continues to yield many very promising measures. Including special measures for new construction or regional applicability, we find more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 20–25 this time, but this study added 12–22 special measures that warrant serious consideration.

Of course, the reservoir is changing. Some of the measures that would result in the largest savings would also require the greatest changes in the present mode of operations. Combined heat and power at commercial and residential scales, using emerging technologies such as fuel cells and Stirling engines, could each save well beyond 1% of projected buildings energy in 2020, but they will require substantial changes in how most utilities do business and see themselves, as well as substantial cost reductions. Others, such as measures to assure ductwork integrity, will require that industry and consumers change the value they assign to energy distribution services—or embrace new thermal and ventilation systems that are inherently less leak-prone. Finally, retrocommissioning and advanced design practices illustrate the greater importance and potential we find for training, incentives, and other “humanware” services. This includes both front-end (design) and continuing (operation) services, intervening at the points where the investment will make the most difference.

Including special measures in this study also illustrates another trend. While the earliest study (1993) could point to a relatively small number of technologies that each promised enormous savings, the present study, particularly in

[8] In addition, a low priority technology was removed, but the categories are not exactly the same, so we treat the 1998 Integrated Commercial (Residential) Designs as functionally equivalent to the Low Energy Designs and Zero Energy Buildings plus the IDP LEED level (30% > Code) of this study.

special cases, finds more broadly distributed savings that are, on average, smaller. We believe that the analyses were systematically more conservative this time, accounting for much of the difference. *As noted earlier, this table treats the savings from individual measures as additive, which they certainly are not. Therefore, it should only be used for estimating the difference between the potential savings found in the two studies.*

However, there is another (pleasant) surprise in this study. Several measures assigned relatively high priority in this study were not available on the market for consideration in the 1998 study. These notably include “super” T-8 lights and zone-level CO_2-based ventilation control, where critical research and development were nearly complete in industrial laboratories, but not yet announced.

CHAPTER 5: NEXT STEPS AND RECOMMENDATIONS

This chapter presents our recommendations for the next steps for emerging technologies and practices. Table 5-1 briefly summarizes recommended next steps for the high and medium priority measures, as well as the special measures applicable to new construction or specific regions.

Table 5-1. Next Steps for High and Medium Priority Measures, and for Special Measures Applicable to New Construction or Specific Regions

Measure	Name	Savings Potential (% of 2020 R&C Energy Use)	R&D	Demonstrations	Testing	Education	Training	Financing	Incentives	New standards	Other
High Priority											
PR3	IDP LEED level (30% > Code)	1.31	X	X	X	X					Revise fee structure for designers
A1	1-Watt standby power for home appliances	1.05				X			X	X	ENERGY STAR
High - Medium Priority											
PR1	Advanced Automated Building Diagnostics	1.48	X	X							
H11	Leakproof Duct Fittings	1.03		X	X	X	X		X	X	Tightness Standards
PR4	Retrocommissioning	0.93	X	X	X	X	X		X		
H12	Aerosol-based Duct Sealing	0.93	X		X	X	X		X		R&D for best target housing types, business model
Medium Priority											
P2b	Commercial micro-CHP using Micro-Turbines	1.46	X								Resolve interconnection issues
L16	Airtight Compact Fluorescent downlights	0.83							X	X	Code revisions
O1	EZConserve Surveyor Software	0.60		X	X	X					
H7	"Robust" A/C	0.59	X	X	X	X	X		X		Develop consensus specification
L13	Residential CFL portable (plug-in) fixtures	0.46		X		X	X				ENERGY STAR
L14	One-lamp flourescent fixtures w/ high performance lamps	0.45				X	X		X		Phase out incentives for lesser products
D2	Advanced Air-conditioning Compressors	0.42									Regional incentives appropriate
L11b	Commercial LED lighting	0.37	X			X			X	X	revise rating methods
H9	Advanced cold-climate heat pump/Frost-less Heat Pump	0.36		X	X				X	X	
R1	Solid state refrigeration (Cool Chips TM)	0.36	X								
H18	CO2 Ventilation Control	0.34		X		X					
W3	Residential heat pump water heaters	0.33		X		X	X		X		Good ENERGY STAR specification
L15	Scotopic lighting	0.33	X	X	X	X	X				
S5	Residential Cool Color Roofing	0.30		X		X			X	X	
S1	High Performance windows (U<0.25)	0.30	X			X			X		
A2	1 kWh/day refrigerator	0.30							X		Upgraded ENERGY STAR
L6	Low wattage ceramic metal halide lamps	0.27		X		X			X		
D3	Advanced HVAC blower motors	0.24	X			X			X	X	
H15	Designs for low parasitics, low pressure drops	0.20		X	X	X	X		X		Revising Design Fee structures
D1	Advanced Appliance & Pump Motors; CW example	0.12							X		Standards (DW, furnaces)
R3	Efficient Fan Options for Commercial Refrigeration	0.06				X				X	Revise ENERGY STAR
Special											
PR2	Ultra Low Energy Designs & Zero Energy Buildings	0.42		X	X	X		X	X		
PR5	Low Energy Use Homes and Zero Energy Houses	0.42	X	X	X	X	X	X	X		
S2b	Active Window Insulation, commercial	0.20	X								
H1a	Advanced Roof-top packaged air-conditioners	0.17		X	X			X	X	X	Consider economizers, etc.
H1b	Advanced Roof-top packaged air-conditioners	0.17		X	X			X	X	X	Consider economizers, etc.
L5	Advanced daylighting controls	0.17	X	X		X					Productivity impact R&D
H8	Residential Gas Absorption Chiller Heat Pumps	0.09	X	X	X				X		
L7	Hospitality Bathroom Lighting	0.06	X	X	X	X			X		
H20	Advanced Condensing Boilers (Commercial)	0.05				X	X				
H2a	Cromer Cycle Air-Conditioner - residential	0.04	X	X	X	X					More work on climate limits of applicability
H16	High-efficiency Gas-fired Rooftop Units	0.04		X	X	X			X		
D4	Hi-Eff. Pool and domestic water pump systems	0.04		X					X		Regional incentives appropriate
H2b	Cromer Cycle Air-Conditioner - commercial	0.03		X	X	X					More work on climate limits of applicability
CR1	Hotel Key Card System	0.03		X	X						
S9	High Quality Envelope Insulation	0.03				X			X	X	
H19	Displacement Ventilation	0.02			X	X	X				Codes revision
H5	Residential HVAC for Hot-Dry Climates	0.02	X	X	X					X	Revise standard
H17	Transpired Solar Collectors for Ventilation Air	0.02		X		X			X		
S3b	Electrochromic glazing for commercial windows	0.01	X								

Measure-by-measure recommendations for the high priority emerging technologies and practices are shown in Table 5-2.

Table 5-2. Next Steps Recommended for High Priority Measures

Measure	Name	Next Steps
PR1	advanced, automated building diagnostics	• continued R&D, particularly on open interfaces for seamless integration with BAS • field tests and monitoring for demonstrations
PR3	comm. construction 30%>code	• revised fee structures for mechanical designers • dissemination of successful case studies to design professionals • client education • better software
A1	1 Watt standby power	• ENERGY STAR program for power supplies • possible manufacturer incentive for using better power supplies • mandatory standard for power supplies
PR4	retrocommissioning	• better define approaches and appropriate applications for different approaches (e.g., for smaller buildings) • benchmarking • market transformation programs with promotion, training, and incentives
H12	aerosol-based duct sealing	• raise consumer awareness of problems and savings • utility incentives • HVAC contractors taking on value-added service • training and certification • field tests in regions with basements and crawl spaces
H11	leakproof duct fittings (transitional high-medium, retrofit analogue to H12)	• raise consumer awareness of problems and savings • utility incentives • performance-based codes and standards • duct system integrity certification • field tests in regions with basements and crawl spaces

Thus, we conclude that there are many opportunities for concerted action to accelerate the adoption of emerging technologies and practices in the near future. These new technologies and practices add to the available energy efficiency resource and help replace opportunities that have been implemented in recent years. However, to some extent, implementation efforts will need to be more targeted to get more of the potential from more diverse but smaller (on average) reservoirs. We recommend that this research be repeated in about five years in order to update information on the technologies and practices identified in this report, identify new emerging measures, and assess progress on the opportunities profiled in this report. Through these periodic reports we can continue to identify—and pursue—promising new opportunities.

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Chapter 6: Measures

A1 1-Watt Standby Power for Home Appliances

Description of Technology

Standby power is the electricity consumed by end-use electrical equipment that is switched off or not performing its main function. A wide variety of consumer electronics, small household appliances, and office equipment use standby power. Recent trends toward the incorporation of digital displays and other electronic components into white goods (i.e., major appliances), as well as the ongoing growth in the use of digital technology and devices, add to the list of products that consume standby power. The most common sources of standby power consumption include products with remote controls, low-voltage power supplies, rechargeable devices, and continuous digital displays. Although the amount of standby power consumed by an individual product is relatively small, typically ranging from 0.5 to 30 Watts, the cumulative total is significant given the large number of products involved: an estimated 50 to 70 Watts per U.S. house, or 5% of average residential electricity consumption (EIA 2003b; Meier 2002).

Current Status of Measure

Currently available technologies, including more efficient power supplies and improved product designs, have allowed a number of existing products to consume 1.0 Watt or less of standby power with no loss of functionality or user amenity. To date, these improvements have been adopted most readily for higher value products such as TVs, VCRs, mobile phones, and other portable technologies. The shift to high-efficiency components has been much slower for lower cost products. Digital cable boxes and satellite receivers are among the biggest consumers of standby power. Design improvements have led to reductions in standby power, but the1.0 Watt standby target is not routine yet.

Energy Savings and Costs

Annual energy savings from reduced standby power consumption vary widely depending on the product. At the household level, standby power consumption currently accounts for approximately 600 kWh per year, which could be reduced to less than 200 kWh (or more than 65%) if existing sources were replaced with products consuming 1.0 Watt or less (Ross and Meier 2000). Efficient, low-loss external power supplies often cost manufacturers less than $1.00; the cost for internal power supplies in some products may be higher (Calwell and Reeder 2002). In some product categories (e.g., TVs and VCRs), there is no premium for products that consume less than 1.0 Watt at standby.

Key Assumptions Used in Analysis

For this analysis, we assume electricity savings for a typical household in which most of the sources of standby power (15 products accounting for approximately 50 Watts) are replaced with products meeting a 1.0 Watt threshold for standby power—a savings of 265 kWh per year. Total incremental costs for end-user products is assumed at $2 per product—some larger or higher-value products will have a higher increment while others will have little or no incremental cost—for a total of $30.

Recommended Next Steps

EPA has developed ENERGY STAR labeling programs for many of the consumer electronics products with standby power. TVs, VCRs, telephony products, DVDs, and home audio equipment currently set maximum standby power at one Watt or will move to a one Watt level by January 2005. For white goods, DOE has committed to incorporating standby power into all test procedures. Minimum efficiency standards for power supplies are also under consideration at the federal and state levels. Internationally, the International Energy Agency is working to develop a coordinated response in cooperation with industry. Chief among the remaining barriers to wider availability of products meeting a 1 Watt standby threshold are product diversity (including many low-value products) and the existing OEM supply-chain for commodity power supplies and other components. Continued efforts to promote product labeling, standards for power supplies, and international coordination on products with global markets are promising vehicles for increasing the acceptance of products with low standby power consumption.

A1 1-Watt Standby Power for Home Appliances

Description	Consumer electronics and other small home appliances with standby power use of 1W or less		
Market Information:			
Market sector	RES		
End-use(s)	OFFEQ, OTH		
Energy types	ELEC		
Market segment	OEM, NEW, ROB		
Basecase Information:			
Description	Typical home with 17-20 devices that consume standby power		
Efficiency	50		
Electric use	440	kWh/year	assumes constant standby losses at 8760 hours/year
Summer peak demand	0.050	kW	
Winter peak demand	0.050	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	Home replacing 15 devices with models consuming 1-watt or less of standby power		
Efficiency	20		
Electric use	175	kWh/year	assumes constant standby losses at 8760 hours/year
Summer peak demand	0.020	kW	
Winter peak demand	0.020	kW	
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	1996		
Life	7	years	
Savings Information:			
Electricity	265	kWh/year	
Summer peak demand	0.030	kW	
Winter peak demand	0.030	kW	0.030000012
Gas/Fuel	N/A	MMBTU/year	
Percent savings	60%		
Feasible applications	21%		Reflects % of total end-use products using standby power
2020 Savings potential	49,187	GWh	Savings equal to 3.0% of household electricity consumption
2020 Savings potential	497	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$30	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.02	$/kWh	
Cost of saved energy	$1.94	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Large number/variety of products; many low-value products; commodity power supplies/components		
Effect on utility	Improved consumer utility from lighter and more compact power supplies		
Current promotion activity	ENERGY STAR, int'l efforts, uniform test procedures, possible power supply standards		
Rating	4	(1-5)	
Rationale	Technology available and proven for most products, promotional activity underway		
Priority / Next Steps			
Priority	High		
Recommended next steps	Broader product labeling, power supply standards, international coordination		
Sources:			
Savings	Ross and Meier 2000; Meier 2002		
Peak demand	kWh/8760 hours/year		
Cost	Calwell and Reeder 2002		
Feasible applications	Meier 2002		
Measure life	Kubo, Sachs and Nadel 2001		
Other key sources			
Principal contacts	Chris Calwell, Ecos Consulting, 970-259-6801		
Notes	Alan Meier, International Energy Agency/OECD, +33 1 4057 6685		
	Standby power consumption accounts for varying fraction of each end-use.		

A2 ONE KWH/DAY REFRIGERATOR

Description of Technology

Under current U.S. appliance efficiency standards, the maximum annual energy use of 20 ft^3 U.S. refrigerators is 496 kWh/yr, or 1.36 kWh/day, with energy use scaled by formula for larger and smaller units. In 2004, ENERGY STAR will require 15% better performance, about 422 kWh/yr (1.16 kWh/day). Reaching the metaphoric "magic mile" of 1 kWh/day (365 kWh/yr) means improving the baseline efficiency by 26%. Two pathways for achieving the goal are continued incremental design changes (e.g., thicker walls) or very large changes in key components. This might mean vacuum panel instead of foam insulation, or modulating linear compressors.

Current Status of Measure

Oak Ridge National Laboratory employed an incremental approach involving doubling door insulation thickness, substituting efficient DC motors for AC, improving compressor efficiency, and changing from (timed) automatic defrost to adaptive defrost, and achieved 1.16 kWh/day, with further improvement to 0.93 kWh/day by using vacuum panel insulation around the freezer compartment, although the latter showed payback longer than the expected life of the refrigerator (Vineyard and Sand 1997). Large changes are exemplified by the LG implementation of SunPower-developed free-piston linear compressors, which are inherently modulating output devices. The LG side-by-side unit, now being sold outside the United States, saves 30% relative to the U.S. minimum efficiency standard and will be marketed in the United States beginning in January 2004 (Hollingsworth 2003). Because of the small number of moving parts, there is little reason to expect shorter life than conventional compressors.

Energy Savings and Costs

In LG design work, direct substitution of the linear compressor for a reciprocating unit reduced energy use by 24% in a 24 ft^3 side-by-side refrigerator/freezer. Optimizing the design for the modulating linear compressor with HFC-134a led to a 47% reduction in energy use. This efficiency level is likely to require using separate evaporators for the freezer and refrigerator, which will directly improve efficiency and also reduce frost control issues in the freezer section. The expected reduction for a smaller unit would be less, but a 40% reduction would still yield 300 kWh/yr, or 0.82 kWh/day. SunPower asserts that the technology will have rather consistent efficiency in sizes from 10W to 5 kW. Vineyard and Sand (1997) estimated manufacturers' cost of $53 to achieve 1.16 kWh/day, but much more ($134) to include vacuum panel insulation. Unger (1999) suggested that the linear compressor (when mature) may be less expensive than the components it replaces. LG reports that its 2004 models that introduce the linear compressor to the U.S. market will reduce energy consumption 30% without split evaporators and show no significant price increase relative to its reciprocating compressor models.

Key Assumptions Used in Analysis

For the package, we assume an incremental manufacturer cost of $2, based on information from LG. This translates to $4 incremental cost to the consumer, using Vineyard and Sand's 2:1 cost multiplier. Adding split evaporators would increase consumer costs further, by $50–60 (EPA 1993).

Recommended Next Steps

In the trade press, LG has expressed willingness to license the linear compressor technology to competitors. As a competitive market emerges, market transformation programs are likely to be highly cost effective, based on the low cost of saved energy in this highly competitive market. Tax credits pending in the 2003 federal energy bill would provide incentives for models 15% and 20% better than the current standard; a utility or public benefits program incentive for at least 30% better performance would encourage production of models with both linear (or other modulating) compressors and dual evaporators. In turn, these will prepare the ground for efficiency standards requiring consumption less than 1 kWh/day.

A2 1 kWh/day Refrigerator

Description	20 cubic foot top-freezer refrigerator using no more than 1 kWh/day		
Market Information:			
Market sector	RES		
End-use(s)	REF		
Energy types	ELEC		
Market segment	RET, NEW, ROB		
Basecase Information:			
Description	Unit meeting 2001 federal stds		
Efficiency	1.36	kWh/day	
Electric use	496	kWh/year	
Summer peak demand	0.062	kW	
Winter peak demand	0.059	kW	
Gas/fuel use	0		
New Measure Information:			
Description			Full-size, full-feature, unit using < 1.0 kWh/day
Efficiency	0.95	kWh/day	
Electric use	347	kWh/year	
Summer peak demand	0.043	kW	
Winter peak demand	0.042	kW	
Gas/Fuel use	0		
Current status	COMM		Entering US mkt Spring, 2004
Date of commercialization	2001		in Korea
Life	19	years	DOE
Savings Information:			
Electricity	149	kWh/year	
Summer peak demand	0.019	kW	
Winter peak demand	0.018	kW	
Gas/Fuel		MMBTU/year	
Percent savings	30%		
Feasible applications	90%		Assumed too costly for some niche products
2020 Savings potential	13,907	GWh	NEW + ROB
2020 Savings potential	140	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$70	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.039	$/kWh	
Cost of saved energy	$3.85	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	possible patent issues, reluctance by manufacturers to adopt new technologies		
Effect on utility	facilitates split evaporators, for better food preservation and additional efficiency		
Current promotion activity	Manufacturer and retailer		
Rating	4	(1-5)	
Rationale	Greater amenity, energy savings, and probably reduced cost/greater profitability, Stds. Eventually		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Promotion, Tighter Energy Star specification.		
Sources:			
Savings	Sunpower 2003; LGE 2003		
Peak demand	Massachusetts Joint Utility End Use Monitoring Project 1989		
Cost	ACEEE estimate based on Unger 1999 and Vineyard and Sand 1997		
Feasible applications	ACEEE estimate based on expected cost savings as well as energy savings		
Measure life	DOE Technical Support Document		
Other key sources			
Principal contacts	Crawford 2003; Hollingsworth 2003		
Notes			

CR1 Hotel Key Card System

Description of Technology

To reduce hotel/motel lighting and HVAC energy use, several products are coming to market that minimize usage during unoccupied periods through the use of the key card. The key card systems achieve this goal through different methods. One approach controls energy consumption through the door key card and additional sensors that determine guest occupancy. The second is a stand-alone unit that determines occupancy through a dedicated key card system; if the guest is present, the card is in the reader and if not the guest has the card and energy consumption is minimized.

Current Status of Measure

Key card systems have become universal in the hospitality industry due to the benefits of increased room security through reprogrammable key cards. Energy management features that control room HVAC and lighting operation represent the next logical step in key card evolution. Messerschmitt produces a system by which a central computer determines occupancy status and adjusts energy consumption accordingly. It keeps the temperature of the room constant at a minimal comfort level until a guest requests a more comfortable temperature. It will also hand over control of lighting when the guest is in the room and turn off lights when guests are not present (see http://www.messerschmitt.com/en/ftp/INCOS_e.pdf). Reth Ireland manufactures one of the stand-alone systems. When a guest enters a room he or she must insert the key card to control lighting and HVAC. The card is also used as the key card for the door, so as the guest leaves, the card is removed and room lighting and HVAC are switched to setback mode (Chen 2003).

Energy Savings and Costs

Key card products have the potential to considerably reduce room HVAC and lighting energy use. However, this is primarily a new construction measure since it is expensive to retrofit systems with the hardware and wiring to a central office computer. The incremental cost of adding the energy management features to the key card system is about $25 per room (Chen 2003). Additional wiring requirements to interface the key card system with the HVAC and lighting circuits is estimated at an additional $75 per room.

Key Assumptions Used in Analysis

Monitored motel room HVAC and lighting energy consumption with conventional packaged terminal heat pump equipment was found to be roughly 9.5 kWh per ft^2 per year at one site (DEG 2000). Based on detailed lighting fixture monitoring at ten hotel rooms (Page and Siminovitch 2000), we estimate roughly 60% of lighting energy usage occurs during the 9 AM to 4 PM period when rooms are generally not occupied. Based on key card control, we project a 33% reduction in lighting energy use. HVAC energy use is more difficult to quantify due to the unpredictable nature of how room units are controlled (DEG 2000). Estimating a 20% HVAC savings potential, overall room savings of 25% are projected. Installation costs are estimated at $100 per room above the cost of the key card door lock system.

Recommended Next Steps

Due to the fact that most of the key card systems are currently manufactured overseas, market penetration in North America may be slow. Education of large hotel/motel organizations is critical in improving their understanding of where energy use is occurring within their establishment. A case study with a side-by-side comparison of motels, with the key card system and without, would be useful in quantifying the savings potential of the system.

CR1 Hotel Key Card System

Description	Key card system to control room HVAC and lighting during non-occupied periods		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT,HC		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	300		sqft motel room conditioned by PTHP
Efficiency	6.8 HSPF, 10 SEER		
Electric use	2,850	kWh/year	assume 9.5 kWh/ft2-year
Summer peak demand	1.5	kW	
Winter peak demand	1.5	kW	
Gas/fuel use	0		
New Measure Information:			
Description	Motel room with key card system		
Efficiency	25% savings		
Electric use	2,138	kWh/year	
Summer peak demand	1.35	kW	10% average on peak
Winter peak demand	NA	kW	
Gas/Fuel use	0		
Current status	COMM		
Date of commercialization	2003		
Life	15	years	
Savings Information:			
Electricity	713	kWh/year	
Summer peak demand	0.2	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	25%		
Feasible applications	90%		of new construction
2020 Savings potential	1,449	GWh	lodging only
2020 Savings potential	15	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$100	2003 $	per room
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.014	$/kWh	
Cost of saved energy	$1.34	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Limited availability, unfamiliar, no case studies, occupant response?		
Effect on utility	Reduced occupant control capabilty as key card takes over during non-occupancy		
Current promotion activity	Little		
Rating	2	(1-5)	
Rationale	European technology which hasn't gained a foothold yet		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Education, documented savings, case studies		
Sources:			
Savings	LBNL		
Peak demand	DEG Estimate		
Cost	Chen 2003		
Feasible applications	DEG Estimate		
Measure life	DEG Estimate		
Other key sources			
Principal contacts	Chen 2003		
Notes			

W1 RESIDENTIAL CONDENSING WATER HEATERS

Description of Technology

Conventional storage water heaters have energy factors in the range of 0.6, meaning they waste 40% of the input energy. Condensing boilers can capture over 90% of the input energy. Condensing units capture almost all of the heat value of condensing flue gas water vapor to liquid (about 10% for natural gas). More importantly, their forced draft burners eliminate off-cycle heat transfer to the flue. As expected from the additional and improved components, condensing boilers have a substantial first cost premium.

Current Status of Measure

Condensing residential water heaters are currently available from Laars Heating Systems, Polaris, and Voyager. All are typically installed as combination space and water heating units. Neither FEMP nor ENERGY STAR has water heating programs, although it was under consideration by the latter.

Energy Savings and Costs

The 34 gallon, 100,000 Btuh Polaris (Model PG10 34-100-2NV) sells for $1,800 plus installation. Because of its high recovery rate, we consider this unit equivalent to a larger conventional storage unit (we assume 80 gallon). We estimate $1,100 current incremental costs in residential applications. On the standard test cycle, gas consumption is reduced by 42% ($94/yr), after subtracting $8/yr for electricity used.

Key Assumptions Used in Analysis

We estimate an installed price of $600 for a base model (EF = 0.60 in 2004), and $800 incremental price for the condensing unit when products become more widely available. We assume that fuel *use* is proportional to the ratio of energy factors, e.g., 0.60/0.93. Then the combustion efficiency (95% advertised for both Polaris and Lennox CompleteHeat) multiplied by the "standby efficiency (100 – 5 – 1.5 = 93.5%) is an estimated EF of 0.89 as a water heater. Based on these assumptions, condensing water heaters are cost effective where projected natural gas prices are higher than $0.64/therm, so they should be attractive to all relatively large hot water users.

Recommended Next Steps

Even at the high incremental cost assumed for the condensing water heater, it is a cost-effective solution at today's gas prices for the *average* consumption pattern assumed by the DOE test procedure for most consumers (e.g., for a typical family of four). In addition, the combination of high efficiency and high recovery rate should make these ideal for light commercial applications such as commercial kitchens with dishes and silverware, some locker rooms, and some coin laundries. Condensing water heaters are a good candidate for programs that increase customer awareness (e.g., FEMP) and for gas utility incentive programs, since cost reduction will follow from sales volume increases. See also W-4, Integrated Home Comfort Systems, which deals with products such as the Lennox "CompleteHeat" and the Canadian ēKOCOMFORT™ program, which involves several additional manufacturers.

W1 Residential Condensing Water Heaters

Description	Nat. Gas/Propane WH that capture latent heat.		
Market Information:			
Market sector	RES		
End-use(s)	WH		
Energy types	GAS		
Market segment	NEW, ROB		
Basecase Information:			
Description	40 gallon natural gas storage water heater		
Efficiency	0.594	federal minimum January 20, 2004, 40 gal. Gas unit.	
Electric use	0	kWh/year	
Summer peak demand	0	kW	?
Winter peak demand	0	kW	?
Gas/fuel use	25.22		per formula in GAMA 2003 directory, p. 154
New Measure Information:			
Description	Condensing Water Heater (Polaris or equivalent)		
Efficiency	0.89		
Electric use	100	kWh/year	estimate for blower motor and igniter
Summer peak demand	0.013	kW	86% load factor
Winter peak demand	0.013	kW	
Gas/Fuel use	16.83		
Current status	COMM		
Date of commercialization	1995		Approx
Life	15	years	
Savings Information:			
Electricity	-100	kWh/year	
Summer peak demand	-0.013	kW	
Winter peak demand	-0.013	kW	
Gas/Fuel	8.4	MMBTU/year	
Percent savings	29%		
Feasible applications	70%		of gas storage water heaters
2020 Savings potential		GWh	
2020 Savings potential	217	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$500	2003 $	Mature market, at least $1100 now
Other cost/(savings)	$8	$/year	Annual cost of electricity for blower
Cost of saved energy	N/A	$/kWh	
Cost of saved energy	$6.39	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	high price, needs electric + gas hookups, needs to supplant separate WH + furnace		
Effect on utility			
Current promotion activity	Mfg promotion, but Energy Star shelved 1/04		
Rating	2	(1-5)	
Rationale	Very high savings, but substantial first cost barrier		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Meaningful Energy Star as basis for promotion		
Sources:			
Savings	GAMA 2003		
Peak demand			
Cost	Nadel 2002		
Feasible applications	RECS 2001 Table HC2-5a		
Measure life	Thorne, 1998		
Other key sources			
Principal contacts			
Notes			

W2 INSTANTANEOUS, GAS-FIRED, HIGH-MODULATING INSTANT WATER HEATERS

Description of Technology

In Canadian and U.S. single-family houses, storage water heaters are almost universal. The "instant" or "tankless" water heater is more popular in other countries. These units use a very high capacity gas burner or electric resistance element and sophisticated controls to heat water on demand. Because there is no tank, these units are small and frequently wall-hung. Conventional (100 amp) residential wiring can only support very small electric demand water heaters (up to about 1 gallon/minute [gpm] at 12 kW power supplied), but available gas water heaters, at ratings up to 199,000 Btuh, can support needs in some whole-house installations, at about 3 gpm (DOE 2003b). Advanced units use water mixing valves and/or modulating burners with electronic controls to maintain constant outlet temperature despite (seasonal or other) variations in inlet temperature and variable demand (e.g., number of faucets open and to what extent).

Current Status of Measure

Currently, instantaneous gas water heaters comprise 1% of the U.S. market for house-scale water heaters (DOE 2003b). DOE estimated that sales of these units are around 50,000 per year and sales are growing at 30 to 50% per year (DOE 2003b). DOE explored an ENERGY STAR labeling program for water heaters in 2003, which could have included instantaneous gas water heaters with energy factor (EF) of .82 (DOE 2003b), but decided against proceeding (DOE 2004).

Energy Savings and Costs

The EF proposed for ENERGY STAR was 0.82 for this technology. Comparing a unit with .82 EF with a 40-gallon tank (commonly used in residential homes) with .594 EF (federal minimum energy standard in 2004), energy savings are 28%. Greater savings would be attained if these units replaced oversized tanks in commercial applications (because of lower standby losses not accounted for by the rating method). Instantaneous gas water heaters currently cost $350–2,000, depending on capacity (Btuh) and features. Incremental cost is currently high—typically $900–1,000 for a whole-house unit.

Key Assumptions Used in Analysis

A typical U.S. home uses a 40-gallon water tank. Our baseline is the 2004 minimum efficiency 40 gallon storage water heater (EF=0.59). About 54% of residential homes use gas water heaters (EIA 2001). We assume a mature market price of $600; it is almost twice that today. At $600, the cost of saved energy for residential units ($8.32/MMBtu) is greater than the current cost of gas for the default consumer in the test procedure, but it would be less than $6/MMBtu if the incremental cost fell to $400. Since instantaneous gas water heaters currently in the market have maximum 3 gallons per minute capability, we assume that the units would be used in applications with high average use but low peak demand. For these applications, the average cost of saved energy drops to $5.90/MMBtu at 1.4 times the default daily use and $4.13/MMBtu at twice the default usage. Thus, they would be cost effective for many larger families and small commercial applications. For example, commercial buildings 10,001 to 100,000 ft^2 in size have the least natural gas intensity usage for water-heating (40.2 cf/ft^2) (CBECS 1999). These buildings consume approximately 39% of total natural gas for water-heating in the United States. To be conservative, our analysis is based on residential applications, with estimated 60% of installations feasible.

Recommended Next Steps

An ENERGY STAR endorsement would assist instantaneous gas water heaters to stand out in the market as a viable alternative to higher energy-consuming units. It may also encourage manufacturers and vendors to put more effort into developing and marketing lower cost units. Consumers need further education on the most appropriate uses of these units. Gas utilities may find this market attractive for efficiency programs directed at commercial users. It is also expected that price reductions would follow increasing sales.

W3 Residential Heat Pump Water Heaters

Description	Vapor-compression cycle water heaters, resistance supplemental		
Market Information:			
Market sector	RES		
End-use(s)	WH		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	50 gallon elec. Resistance storage water heater		
Efficiency	0.904	federal minimum January 20, 2004	
Electric use	4,857	kWh/year	per GAMA directory method
Summer peak demand	0.64	kW	86% load factor
Winter peak demand	0.64	kW	
Gas/fuel use	0		
New Measure Information:			
Description	Drop-in Integrated HPWH		
Efficiency	2.4	Nyle, as listed in April 2003 GAMA directory, p. 200	
Electric use	1,922	kWh/year	per GAMA directory method
Summer peak demand	0.26	kW	86% load factor
Winter peak demand	0.26	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2003		
Life	14.5	years	Comparable to elec. water heater (14 year) or refrigerator (19 yr).
Savings Information:			
Electricity	2,936	kWh/year	
Summer peak demand	0.39	kW	
Winter peak demand	0.39	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	60%		
Feasible applications	30%		of electric storage water heaters -- those with greatest use
2020 Savings potential	15,645	GWh	
2020 Savings potential	158	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$650	2003 $	Nadel, 2002
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.02	$/kWh	
Cost of saved energy	$2.16	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Mixed field record, high price		
Effect on utility	may dehumidify and provide minor AC benefits		
Current promotion activity	Manufacturer and DOE promoting, NYSERDA offers incentives		
Rating	3	(1-5)	Given barriers, a "3" at best
Rationale	20 years of effort have not increased sales.		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Energy Star would help validate, continued field demos, codes credit.		
Sources:			
Savings	EF ratio		
Peak demand	Russ Johnson, July 25 2003		
Cost	Nadel 2002		
Feasible applications	Estimated as the largest users of resistance heating today		
Measure life	ECRI site, FEMP		
Other key sources	Karl Mayer, karlm@dunkirk.com; http://www.ecrinternational.com/prod_wattersaver.asp		
Principal contacts	John Tomlinson, ORNL, tomlinsonjj@ornl.gov, 865-574-0291		
Notes	Russ Johnson, johnson.research@att.net, 860-633-9020		

W3 RESIDENTIAL HEAT PUMP WATER HEATERS

Description of Technology

The typical U.S. house today uses an insulated storage tank and heats water with a gas flame or electric resistance element. The former suffers large standby losses through the flue, and the latter has inherent inefficiencies of electricity generation. The heat pump water heater uses a vapor-compression refrigeration cycle, like a refrigerator or air conditioner, and the COP largely compensates for primary electricity conversion losses. HPWHs are commonly installed in basements, where they take heat from the air at a relatively low temperature and reject the heat at a higher temperature to the water tank; placement for slab-on-grade houses varies with climate. In the process, most units also cool and dehumidify the basement, which can be valuable. Efforts to commercialize the technology have waxed and waned for decades. Current U.S. annual sales are estimated as a few thousand units per year (Sachs 2002).

Current Status of Measure

Within the past few years, several manufacturers abandoned the market, and the only large-scale utility program for residential HPWHs in the continental United States was suspended after 4,000 installations, largely because utility funding was disrupted (DOE 2002e). However, two new residential products have been introduced, and there is substantial interest now. The “Watter$aver” from ECR International is designed to “drop in” to the same space as an existing 50 gallon resistance water heater and can be installed by a single trade. Its certified EF is 2.4 (GAMA 2003), compared with 0.95 for the best resistance units. NYSERDA offers $300 incentives for this unit. The alternative, an add-on unit, is exemplified by the Nyle Specialties Nyletherm 110 heat pump water heater. It is a wall-hung, 7,000 Btuh auxiliary unit designed to supplement an existing water heater by replacing the primary resistance element. Its power requirement, 7.25 amps at 120 v., can be met by a conventional wall socket. The unit is new, and there are no independent performance data yet. In the commercial sector, HPWHs have not grabbed a big market. However, DOE recently selected United Technologies Corp. to develop systems with higher water-delivery temperatures and wider operating range for commercial uses (DOE 2003d).

Energy Savings and Costs

The incremental cost of an integrated heat pump water heater today is in the range of $900–1,000 (Johnson 2003). At average electricity prices ($0.078/kWh), this would be a four-year simple payback. The add-on HPWH will likely have similar costs and benefits, but certified ratings are not yet available. In a mature, competitive market, the purchase price (without installation) will be about the same as that of the separate technologies, approximately resistance water heater plus a room air conditioner, or about $500–600. Installation should be the same cost as for a resistance water heater, unless a condensate pump and installation are required ($100).

Key Assumptions Used in Analysis

We assume: (1) HPWHs displace 30% of all resistance water heaters but no gas water heaters (estimated fraction of customers with electric water heaters and demand at test measure assumption, 66.3 gpd [DOE 2002d], rather than the national average of about 44 gpd [DOE 2001a, Figure 10.1]); (2) Field EF = 2.4, compared with 0.9 for electric resistance water heater; (3) Calculation using methods of GAMA (2003); and (4) Incremental installed cost of $800.

Recommended Next Steps

The first cost is high, and the products are not widely available. We recommend the following steps, *in parallel:* (1) Continued field demonstrations—if successful, progress toward rebates and contractor training as early MT promotion; (2) Disseminate information (technology, availability, savings calculation methods) to potential large-scale buyers, as FEMP is doing; (3) Work to be sure that ENERGY STAR residential programs encourage use of heat pump water heaters by uniformly providing incentives for EF>2.0, once the technology is well-proven and readily available.

W2 Instantaneous, Gas-Fired, High-Modulating Water Heaters

Description	Temperature controlled, continous flow, gas hot water systems with no standing pilot		
Market Information:			
Market sector	R&C		
End-use(s)	WH		
Energy types	GAS		
Market segment	NEW, ROB		
Basecase Information:			
Description	40 gallon storage water heater		
Efficiency	0.594	federal minimum January 20, 2004, 40 gal. Gas unit.	
Electric use	0	kWh/year	no electricity use
Summer peak demand	0	kW	
Winter peak demand	0	kW	
Gas/fuel use	25.22		per formula in GAMA 2003 directory, p. 154
New Measure Information:			
Description	Non-Condensing instantaneous water heater		
Efficiency	0.82	DOE draft Energy Star white paper.	
Electric use	190	kWh/year	8w standby, 60w motor@2000 hr/yr
Summer peak demand	0.025	kW	86% load factor
Winter peak demand	0.025	kW	
Gas/Fuel use	18.27		
Current status	COMM		
Date of commercialization	1990		Approx.
Life	20	years	Longer life than typical gas water heater, since no tank
Savings Information:			
Electricity	-190	kWh/year	
Summer peak demand	-0.025	kW	
Winter peak demand	-0.025	kW	
Gas/Fuel	6.95	MMBTU/year	
Percent savings	20%		
Feasible applications	60%		Est., sites with adequate gas cap., and large vent opportunity
2020 Savings potential		GWh	
2020 Savings potential	127	TBtu (source)	
Industrial savings > 25%	NO		light process industries only
Cost Information:			
Projected Incre. Retail Cost	$600	2003 $	Mature market, $900 - 1100 now
Other cost/(savings)	$15	$/year	electricity to power inducer fan, igniter, temp. controls, etc.
Cost of saved energy	N/A	$/kWh	
Cost of saved energy	$8.27	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	high price, needs electric + gas hookups		
Effect on utility	none		
Current promotion activity	Mfg promotion		
Rating	2	(1-5)	Due to marginal economics
Rationale	new const. Needs integration with heating; retrofit "looks like" two trades to integrate		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Meaningful Energy Star as basis for promotion		
Sources:			
Savings	GAMA 2003		
Peak demand	Very small electric load for inducer fan and ignitor.		
Cost	Extrapolated from manufacturer literature, to get mature market costs		
Feasible applications			
Measure life	Thorne, 1998		
Other key sources	GAMA 2003		
Principal contacts	Manufacturers		
Notes			

W4 INTEGRATED HOME COMFORT SYSTEMS

Description of Technology

Over the next decades, improved construction will decrease residential HVAC loads but raise the importance of mechanical ventilation. The results will be higher water heating loads relative to space heating loads and the addition of ventilation loads. Integrated appliances that provide space heat (and cooling), hot water, and ventilation services promise higher efficiency, lower costs, one-trade installation, and smaller space requirements. Already, space heating and water heating are the two largest energy uses in the average house (EIA 2003b). For high-efficiency fossil-fuel equipment, the core appliance is usually a high efficiency, fast-recovery water heater. It provides space heating by a water-to-air coil in an air handler that replaces the furnace and may also integrate a ventilation function. The Lennox CompleteHeat system exemplifies this approach. The American Water Heating "Polaris" high-recovery, condensing water heater is also frequently installed with a hot water coil and air handler integrated by the contractor. Integrated systems can also be built around space-conditioning heat pumps, either using a desuperheater to make hot water while the system runs, or as a full condensing water heater option. Both approaches are rare with air-source heat pumps but most residential ground-source heat pumps have desuperheaters that may provide half the water heating on an annual basis.

Current Status of Measure

Thorne (1998) estimated that the penetration of combined systems is less than 2% of U.S. houses and that the number of high-efficiency units is much smaller. Lennox CompleteHeat is marketed as a premium product, with many options (humidifier, heat recovery ventilator, etc). It is considered unlikely that sales have reached 10,000 units per year. In Canada, the government-industry "ēKOCOMFORT" effort is designed to hasten deployment of integrated appliances. The ēKOCOMFORT specification does not require condensing equipment, includes oil-fired units, and requires efficient fan motors for air distribution. The ēKOCOMFORT initiative currently works with five manufacturers (Gucciardo 2003). The Canadian Standards Association is developing rating methods and standards (Glouchkow 2003). Test systems are in 18 homes ranging from 1,200–4,000 sq. ft. in Ontario and Nova Scotia. About half of the homes have undergone tests for one season.

Energy Savings and Costs

The first ēKOCOMFORT units are still in field test; so purchase costs and energy savings are not available. Costs of CompleteHeat systems vary with size and by dealer. In a mature market, from bottom-up analysis of component prices we estimate the incremental cost of these systems as about $550 more than the cost of a separate base-model water heater and furnace. Counterbalancing the cost of the condensing water heater, hot water coil, and circulator motor is the cost reduction of deleting the gas burning apparatus, heat exchanger, and draft inducer motor in the furnace.

Key Assumptions Used in Analysis

Integrated units are rated by Combined Annual Efficiency (CAE, ASHRAE Standard 124). We assume that performance is equivalent to separate appliances with an EF of 0.90 in water heating, and 0.93 AFUE in heating (to account for losses in the additional heat exchanger and pump). Our electricity savings estimates are based largely on ACEEE decrements to GE estimates of ECM savings (Sachs and Smith 2003).

Recommended Next Steps

Wide deployment requires helping decision-makers understand implications of CAE for comparisons to conventional choices, and assuring that code officials are comfortable that potable hot water coils in furnaces do not introduce health hazards. Utility incentive programs for gas appliances need ways to accommodate integrated appliances to encourage adoption of units with appropriate performance. New construction applications are likely to be more common than replacements on burnout, since simultaneous failures of the water heating and space conditioning systems are infrequent.

W4 Integrated Home Comfort Systems

Description	Multi-Function ventilation, space heating, and water heating equipment		
Market Information:			
Market sector	RES		
End-use(s)	HEAT, WH, VENT, COOL		
Energy types	ELEC, GAS		
Market segment	NEW, ROB		
Basecase Information:			
Description	Gas furnace and waterheater		
Efficiency	0.594/0.8	Federal min EF / min AFUE	
Electric use	1,170	kWh/year	fan energy heating
Summer peak demand	0.13	kW	Continuous ventilation, no coincidence factor
Winter peak demand	0.06	kW	0.9 Coincidence Factor assumed, 50% of fan power
Gas/fuel use	101		Water heating and space heat
New Measure Information:			
Description	ECM motor, hot water coil in air handler, cond. WH		
Efficiency	0.89	CAE	
Electric use	472	kWh/year	
Summer peak demand	0.05	kW	Continuous ventilation, no coincidence factor
Winter peak demand	0.02	kW	0.9 Coincidence Factor assumed, 50% of fan power
Gas/Fuel use	85.7		combined space and water heating savings
Current status	COMM		
Date of commercialization	1995		
Life	15	years	Longer life than typical gas water heater (stainless steel tank)
Savings Information:			
Electricity	699	kWh/year	Average national fan energy savings (Sachs & Smith 2003)
Summer peak demand	0.080	kW	
Winter peak demand	0.036	kW	
Gas/Fuel	13.3	MMBTU/year	some extra gas use in winter; fan dissipates less electricity
Percent savings	18%		
Feasible applications	50%		gas space heating, gas water heaters (BGE data)
2020 Savings potential	816	GWh	
2020 Savings potential	43	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$800	2003 $	Mature market, $900 - 1100 now
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$3.79	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	First cost, Contractor & consumer unfamiliarity, metrics.		
Effect on utility	may reduce winter temperature swings		
Current promotion activity	Manufacturer, EkoComfort Program		
Rating	2	(1-5)	
Rationale	Few ROB oppy, new construction changes slowly		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Promote understanding of CAE (field demos), EnergyStar		
Sources:			
Savings	Sachs&Smith, 2003; ASHRAE Std. 124-91, GAMA 2003, GE 2001 ECM savings sheet		
Peak demand	Industry sources		
Cost	Gucciardo 2003, Gluchkow 2003,		
Feasible applications	ACEEE estimate		
Measure life	Thorne, 1998		
Other key sources			
Principal contacts			
Notes			

D1 ADVANCED APPLIANCE MOTORS

Description of Technology

Appliances are manufactured in very large volume, with stringent cost, reliability, and efficiency targets. In general, their motors are specialized, low-cost designs rather than general purpose "frame" motors. Most are fractional hp induction motors dedicated to producing rotary torques to turn washer or dryer drums, to pump water, or to drive fans. On the other hand, advanced technologies, particularly electronically commutated DC permanent magnet (DCPM, often called ECM or ECPM) and switched reluctance (SR) motors offer potential cost, performance, and/or feature set improvements. Both classes rely on electronics to provide precisely timed voltages to the coils and use rotation position sensors for timing.

Current Status of Measure

Both DCPM and SR motors are in commercial service in efficiency-regulated appliances today. The most conspicuous application of DCPM motors (for two decades) is to drive HVAC circulation fans, where they differentiate quieter and more efficient premium products (see also Measure D-3). Increasingly, DCPM motors are being used for condenser fans, inducer fans, and other applications. Switched reluctance motors are used for several hundred thousand premium clothes washers per year. One primary driver is their combination of high torque at low speed and very high speed range, which has allowed eliminating the conventional transmission, saving money and decreasing weight. Switched reluctance motors require high precision but have few parts and ordinary materials. They also need advanced design techniques and software. This combination suggests lower costs for high-volume motors. For washing machines in particular, the cost to manufacture a switched-reluctance motor machine may be less than current practice (at maturity), since the SR approach allows simplification of the mechanical drive train (Lloyd and Sood undated).

Energy Savings and Costs

Thorne, Kubo, and Nadel (2000) estimated savings potential in clothes washers as up to 50% from improved technology and less water use per cycle. From published efficiency data (Sood et al. undated), we now calculate 60% motor power savings in washing machines with variable loads (e.g., wash vs. spin; light vs. full load). Fixed-load appliance savings will be much lower, on the order of 15%.

Key Assumptions Used in Analysis

Our analysis uses washing machines as representative appliances, with 0.27 kWh/cycle and 392 cycles/year (DOE 2001a). Washing machine savings in kWh/yr will be higher than for appliances that draw less current and as a fraction will be higher than for appliances that have multiple electricity uses (such as water heating by dishwashers). We use DOE MEF conditions (0.27 kWh/cycle, 392 cycles/yr), and assume 3:1 ratio of time in wash to spin; savings would be larger if the wash to spin ratio was higher. Washing machine savings alone are only about 0.06% of 2020 buildings energy use, but highly cost effective ($0.002/kWh). This suggests that SR has the potential for application in other regulated appliances, including variable speed furnace inducers, air conditioner condenser fans, and dishwashers.

Recommended Next Steps

The principal barriers are relatively slow model turnover and the intense first cost pressures on most manufacturers today. Because these motors are commercialized now, universal application should be considered for baseline in all upcoming appliance standards. Only dishwashers and furnaces seem to be relatively near-term candidates. The improved efficiency of these motors also supports higher thresholds for market transformation programs for products such as dishwashers and washing machines in which the cost of motor energy is significant, since the cost of saved energy is extremely attractive.

D1 Advanced Appliance Motors

Description	Alternatives to conventional induction motors		
Market Information:			
Market sector	RES		
End-use(s)	DISH, LAUND, MOTOR, REF		
Energy types	ELEC		
Market segment	OEM		
Basecase Information:			
Description	North American 2-speed (4Pole/6Pole) split-phase or cap-start motor		
Efficiency	0.4 wash, 0.56 spin	Electricity to shaft	
Electric use	106	kWh/year	
Summer peak demand	0.0161	kW	Heterogeneous applications, conservative estimate
Winter peak demand	0.0161	kW	
Gas/fuel use	0		
New Measure Information:			
Description	Switched-Reluctance Motor		
Efficiency	0.45 wash, 0.69 spin		
Electric use	42	kWh/year	
Summer peak demand	0.0064	kW	
Winter peak demand	0.0064	kW	
Gas/Fuel use	0		
Current status	COMM		
Date of commercialization	2000		approx
Life	14	years	Nadel et al 1993
Savings Information:			
Electricity	64	kWh/year	
Summer peak demand	0.00974	kW	
Winter peak demand	0.00974	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	60%		
Feasible applications	80%		
2020 Savings potential	5,713	GWh	Est. for clothes washers, dryers, pool & circ. Pumps
2020 Savings potential	58	TBtu (source)	for all
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1	2003 $	Allows simpler drive and software controls
Other cost/(savings)		$/year	
Cost of saved energy	$0.002	$/kWh	
Cost of saved energy	$0.16	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Limited experience for appliances, cost (pumps)		
Effect on utility	Spins clothes better, removing more moisture, decreasing load on dryer		
Current promotion activity	High, as horizontal axis machines		
Rating	4	(1-5)	
Rationale	water savings and reduced manufacturing costs will drive change		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	More stringent EnergyStar, new programs (Standards pre-empted this decade)		
Sources:			
Savings	ACEEE estimate based on Sood et al		
Peak demand	Brown & Koomey, 2002		
Cost	ACEEE estimate based on Lloyd and Sood (undated).		
Feasible applications	ACEEE Estimate		
Measure life	Nadel et al 1993		
Other key sources			
Principal contacts			
Notes	Looks favorable for large US CW, less certain for other applications.		

D2 ADVANCED UNITARY HVAC COMPRESSORS

Description of Technology

In the United States, almost all residential and light commercial central air conditioners and heat pumps use single-speed reciprocating or scroll hermetic compressors. Compressor peak load efficiencies have improved by 50% since the mid-1960s, with signs of less improvement recently (DOE 2001a). In larger commercial packaged units, the norm has been to use two compressors of different sizes, to give three operation stages. Modulating compressors are more common in Asia for "mini-split" systems in which a single compressor supports multiple, independently-controlled evaporators. Modulating compressors give designers many alternatives for designing products that match varying sensible and latent loads well, particularly when coupled with modulating air handlers (treated in D-3, Advanced HVAC fan motors). Recently, U.S. attention has turned to multi-stage and modulating compressors to improve part-load performance of systems, the subject of this write-up.

Current Status of Measure

Bristol introduced the "TS" reciprocating compressor several years ago. It reduces capacity to 40% by idling one of its two pistons, yielding roughly 50% reduction in system capacity. Copeland has introduced the two-stage "UltraTech" compressor for U.S.-style residential split systems. It reduces capacity to 67% by using alternate bypass ports to introduce refrigerant. Several manufacturers now offer two-speed residential air conditioners with very high SEER levels; not all indicate the compressor source. With the current SEER rating method, products can be designed that use the first stage of the compressor for almost all of the test cycle, giving very high SEER values. This design approach does not improve high temperature performance, typically measured with EER. Thus, we expect modulating technology to dominate the market for SEER>14, unless stringent EER requirements are applied, as this approach seems more compact and less expensive than alternative approaches to raise SEER.

Energy Savings and Costs

Using the appropriate mark-ups, the data in the air conditioner Technical Support Document, or TSD (DOE 2001a) suggest that the retail price of the compressor for a SEER 13 air conditioner itself would be $77 more than for a SEER 10 unit. We use this value for the incremental cost. The 2-stage could reasonably be more costly; we estimate $150 retail for a commodity unit with only the 2-stage compressor added (based on "hints" from a manufacturer about OEM costs).

Key Assumptions Used in Analysis

We assume a SEER 12/EER 10 Baseline, and SEER 16.5/EER 12 new measure. We use the ENERGY STAR calculator for energy savings (Climate Zone 5), but correct for the relatively high saturation of BPM motors (measure D-3) in very high SEER equipment, decrementing savings by 200 kWh/yr (Sachs and Smith 2003). Peak reduction estimates are based on EER 12 vs. EER 10 baseline, decremented by 0.138 kW summer peak from BPM motor (D-3, this study). This implicitly assumes that the modulating compressor runs in Stage 2 (high) at 95ºF. We assume possible penetration of SEER 14 and above equipment as 35% of the market, which is almost twice the incentives-supported fraction of SEER 13 units today in New Jersey. This yields a cost of saved energy (CSE) of $0.040.

Recommended Next Steps

Modulating compressors are a branch point for market transformation programs. One path enables "SuperSEER" equipment that does not have EERs significantly above 12. These are likely to be cost effective on energy savings in hot areas without demand-based residential tariffs, but they will not help capacity-constrained utilities as much as alternative design strategies that boost EER as well as SEER. Equipment for such programs is likely to require advanced compressors, larger heat exchangers, optimized controls, and careful attention to all parasitics (such as the condenser fan).

D2 Advanced Unitary HVAC Compressors

Description	2-stage and fully modulating, high efficiency compressors		
Market Information:			
Market sector	R&C		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	Compressor for SEER 12/EER 10, 3-ton Residential Split AC System		
Efficiency	12, 10	SEER, EER	
Electric use	2,636	kWh/year	From EnergyStar "Calc_CAC-1" at $0.077/kWh
Summer peak demand	3.24	kW	0.9 coincidence factor assumed
Winter peak demand	N/A	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	2-stage Compressor for SEER 16.5/EER 12, 3-ton Residential Split AC System		
Efficiency	16.5, 12	SEER, EER	
Electric use	1,922	kWh/year	From EnergyStar "Calc_CAC-1" at $0.077/kWh
Summer peak demand	2.7	kW	EER = 12
Winter peak demand	N/A	kW	
Gas/Fuel use	N/A		N/A
Current status	COMM		
Date of commercialization	2000		(approx) Bristol TS, first of new generation
Life	18.4	years	AC-HP TSD, p. 5-67
Savings Information:			
Electricity	514	kWh/year	Subtract 200 kWh/yr summer savings for ECM fan
Summer peak demand	0.4	kW	decremented to not include fan savings from D-3.
Winter peak demand	N/A	kW	
Gas/Fuel		MMBTU/year	
Percent savings	19%		
Feasible applications	95%		High feasibility in long-summer regions, less elsewhere
2020 Savings potential	19,839	GWh	
2020 Savings potential	200	TBtu (source)	Predominantly Southern Region benefitting from hi SEER
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$150	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.025	$/kWh	
Cost of saved energy	$2.44	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	incremental cost, perceived commoditization, and limits EER gains		
Effect on utility	May or may not contribute to better humidity control		
Current promotion activity	manufacturers only		
Rating	3	(1-5)	
Rationale	Strong sense that manufacturers want to keep this "premium" and not too visible		
Priority / Next Steps			
Priority	Medium		Easier to gain SEER this way than EER with bigger HX
Recommended next steps	Rating method revision to better capture field value of each metric		
Sources:			
Savings	EPA 2003, EnergyStar calculator, Region 5, 0.084c/kWh		
Peak demand	ACEEE est., from EER definition, corrected for fan and diversity		
Cost	Extrapolated from TSD, bounded by industry conversations (calc below).		
Feasible applications	Estimated maximum feasible share of units with SEER 14 or above		
Measure life	TSD		
Other key sources	conversation with manufacturer		
Principal contacts	Mr. Hung Pham, Copeland		
Notes			

D3 ADVANCED HVAC FAN MOTORS

Description of Technology

Smaller HVAC systems typically use A/C fractional horsepower motors that directly drive the centrifugal fan, which is attached to the extended motor shaft. The market for conventional, baseline, residential split systems and furnaces is completely dominated by multi-tap permanent split capacitor (PSC) induction motors, which combine reasonable efficiency with the ability to select different speeds for heating, air-conditioning, and ventilating, or to match the external static pressure of a particular duct system. PSC motor efficiencies tend to run from about 35% (low speed) to 65% (high speed). In contrast, premium products (furnaces with AFUE greater than 91; air conditioners with SEER 14 or above) often use electronically commutated DC permanent magnet motors. These are continuously modulated and 10% (full load) to 100% more efficient (light load, as in ventilation/circulation) than PSC motors. Some units can be "tuned" to supply specified air flow or delivery, regardless of duct conditions.

Current Status of Measure

The DCPM is commercially available, with several hundred thousand units/year sold for HVAC applications. In general, these are "bundled" in premium models that combine high efficiency with other features, such as quiet starts and separate controls for temperature and humidity. DCPM are also becoming available for commercial terminal units and powered VAV boxes.

Energy Savings and Costs

ACEEE estimates average national savings for residential air handlers as 700 kWh/yr, 500 in heating and 200 in air-conditioning (Sachs and Smith 2003). One manufacturer estimated average savings twice as large (GE 2001), but this estimate seems to ignore incremental gas needed in heating season to replace electricity no longer dissipated as heat. ACEEE estimates that the incremental OEM cost of the DCPM motor will be $35 (1/2 hp), or $80 consumer price (using DOE TSD assumptions on price multipliers; Sachs and Smith 2003).

Key Assumptions Used in Analysis

Savings measures presented here are based on field measurements of HVAC fan energy consumption and external static pressures, such as Pigg (2003) and Proctor and Parker (2000), and laboratory evaluations of advanced systems (Walker, Mingee, and Brenner 2003). Estimates based on the ARI – DOE method of test are lower, because the external static pressures assumed in the rating method are less than half the average values seen in the field. Economic assumptions on motor costs are based on mature product in a competitive market and are justified by the observation that alternative technologies (multi-pole switched reluctance, optically commutated induction, etc.) may approach or equal the efficiency of the DCPM motor at lower cost (particularly switched reluctance).

Recommended Next Steps

There are at least two major barriers to market transformation: (1) Current test methods for standards do not properly reveal air handler energy use; and (2) Manufacturers use DCPM motors as part of premium products, differentiated by soft start/stop, system static pressure matching, and effective humidity control; they do not want air handler efficiency to be become a commodity in the market. Market transformation should be based on performance rather than prescriptive standards. Performance-based standards for air handlers require modest additional research on non-condensing furnaces, furnaces with large air handlers for Southern climates, and heat pump air handlers. This work should commence immediately. Market transformation programs coupled with condensing furnace programs in Northern climates are recommended today, and have been initiated in Massachusetts, Oregon, and Wisconsin (Sachs and Smith 2003). As quickly as possible, Methods of Testing for standards should be revised to incorporate more realistic external static pressures, which will encourage use of more efficient fans.

D3 Advanced HVAC Fan Motors

Description	DCPM and other alternatives to PSC multi-tap induction fan motors		
Market Information:			
Market sector	RES		
End-use(s)	HC, VENT		
Energy types	ELEC		
Market segment	NEW, ROB, OEM		
Basecase Information:			
Description	Multi-tap PSC motor, 1/2 hp		
Efficiency	35%, 65%	low speed, high speed - A033 estimates	
Electric use	809	kWh/year	
Summer peak demand		kW	
Winter peak demand		kW	
Gas/fuel use	0		
New Measure Information:			
Description	DCPM motor, 1/2 hp		
Efficiency	70%, 75%	low speed, high speed - A033 estimates	
Electric use	299	kWh/year	
Summer peak demand		kW	
Winter peak demand		kW	
Gas/Fuel use	2.2		Incremental gas use, since less electricity dissipated
Current status	COMM		
Date of commercialization	1983		Approx for GE ECM
Life	15	years	
Savings Information:			
Electricity	510	kWh/year	
Summer peak demand	N/A	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	-2.2	MMBTU/year	
Percent savings	36%		
Feasible applications	90%		
2020 Savings potential	11,068	GWh	
2020 Savings potential	112	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$80	2003 $	
Other cost/(savings)	$17	$/year	cost of added gas use
Cost of saved energy	$0.039	$/kWh	
Cost of saved energy	$3.82	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Present costs, Mfg. need to differentiate premium products		
Effect on utility	quieter, more even heat distribution		
Current promotion activity	Mfgs. market as premium, MT programs beginning.		
Rating	4	(1-5)	
Rationale	Increased efficiency (standards)and customer amenity		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	MT promotion, incorporate into Energy Star, efficiency standards		
Sources:			
Savings	Sachs and Smith 2003		
Peak demand			
Cost	Sachs and Smith 2003		
Feasible applications	ACEEE estimate		
Measure life	DOE *****		
Other key sources			
Principal contacts			
Notes			

D4 HIGH-EFFICIENCY POOL AND DOMESTIC WATER PUMP SYSTEMS

Description of Technology

Residential pools, spas, and water wells typically utilize pumps ranging in size from 1 to 3 hp. A vast majority of the installed pumps are standard-efficiency single-speed pumps. The efficiency and energy use of all three types of pumps can be improved by properly matching pumps to system flow and pressure head requirements. Anecdotal evidence suggests that many of these pumps are frequently oversized based on a "bigger is better" mentality. Coupling oversized pumps with undersized pumping results in inefficient pump operation. Part of the problem can be attributed to how pumps are labeled using "horsepower" and "service factor." Service factor is a measure of how much a pump motor can be under-sized without overloading the motor. For example, a 1 hp pump with a service factor of 2.0 draws about the same power as a 2 hp pump with a service factor of 1.0. The reasons for marketing high service factor pumps are unclear, but the practice creates confusion and contributes to inappropriate pump sizing.

Current Status of Measure

Available national energy use estimates (cited below) suggest that well pumping and pool pumping are roughly of the same magnitude. Spa pumping is difficult to disaggregate from total spa consumption since it is rarely submetered and some spa pump energy contributes to heating of the spa. Estimated market share and energy use are presented for each of the three categories.

Pool pumps: 5.5 million nationwide, 792 kWh/unit, 4.4 TWh (EIA 1997)

Spa pumps: 2.7 million nationwide, 600 kWh/unit (estimated), 1.6 TWh

Well pumps: 14.3 million nationwide, 315 kWh/unit, 4.5 TWh (Sanchez 1998)

Energy Savings and Costs

The combined energy *use* is on the order of 10 TWh, or 100 Tbtu (since total use is less than our threshold for *savings*, this measure is a low priority) of total residential and commercial building energy use. The pool and spa pump market is increasing at a much faster rate than well pumping and with its higher "per unit" usage is better suited for targeting. Estimated potential savings for pool and spa filter pumps is difficult since energy savings are dependent upon the pump system curve relating total system head to pump flow rate for a given pump. The goal of any efficient pumping program is to deliver the required amount of flow needed to maintain water quality at the most efficient point on the system curve. Two-speed pumping is an approach that allows for filtration to occur at low speed over a longer period of time, while having high-speed pump operation available for use with pool cleaning hardware. More efficient pumps are also on the market, some of which use electronically commutated motors (ECMs).

Key Assumptions Used in Analysis

The incremental cost for a 2 hp two-speed pump with controls is estimated at $580. Energy savings of 58% are projected based on typical applications (DEG 2003). As the market share of two-speed pumps increase, prices should fall, especially for the controls which are not currently readily available. The incremental cost of controls should approach zero, but the motor cost will remain about $200.

Recommended Next Steps

The principal barriers are lack of industry support, understanding of the benefits (education), and an installation infrastructure. Prototype demonstrations of various efficient pump options are needed to develop a database of projects throughout the United States. Utility rebates are another approach to educating homeowners and contractors. Initial utility targeting should focus on warmer climates where the pool season is longer, generating higher savings. By priming the pump in these areas, hopefully incremental costs will fall, improving economics in other parts of the country.

D4 High-Efficiency Pool and Domestic Water Pump Systems

Description	2-sp. Induction, variable sp. ECM, switched reluctance, etc.		
Market Information:			
Market sector	RES		
End-use(s)	MOTOR		
Energy types	ELEC		
Market segment	NEW,RET,ROB,OEM		
Basecase Information:			
Description	1.5 hp		
Efficiency			
Electric use	2,519	kWh/year	For warm regions with high operating hours
Summer peak demand	0.479	kW	
Winter peak demand	0	kW	
Gas/fuel use	0		
New Measure Information:			
Description	two-speed 1.5 hp pump		
Efficiency			
Electric use	333	kWh/year	
Summer peak demand	0.063	kW	
Winter peak demand	0	kW	
Gas/Fuel use	0		
Current status	COMM		
Date of commercialization	1990's		
Life	10	years	
Savings Information:			
Electricity	2,186	kWh/year	
Summer peak demand	0.416	kW	
Winter peak demand	0	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	87%		
Feasible applications	50%		Operating hours high enough to justify in ~1/2 of applications
2020 Savings potential	1,909	GWh	
2020 Savings potential	19	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$580	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.034	$/kWh	
Cost of saved energy	$3.40	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers			
Effect on utility	None		
Current promotion activity	Some utility incentives		
Rating	3	(1-5)	
Rationale			
Priority / Next Steps			
Priority	Special		
Recommended next steps			
Sources:			
Savings	DEG CASE Study on Pool Pumps, 2003		
Peak demand			
Cost	DEG CASE Study on Pool Pumps, 2003		
Feasible applications			
Measure life			
Other key sources			
Principal contacts			
Notes			

H1 ADVANCED ROOF-TOP PACKAGED AIR CONDITIONERS

Description of Technology

Commercial packaged roof-top air conditioners (often combined with gas furnaces) are commodity products. They use about 0.74 quads of energy, 54% of all energy used to cool commercial buildings, and cool about half of commercial space (Westphalen and Koszalinski 2001). The minimum legal federal efficiency rating for 10-ton units is EER 8.9. This measures steady-state operation of the refrigeration cycle and associated fans (condenser and circulating). It does not include the energy required for the same equipment to supply conditioned air to satisfy ASHRAE 62.1 ventilation requirements (dehumidification and cooling), and it excludes the regionally varying potential benefits of economizers and heat recovery. Several groups are developing or have produced advanced units with higher EERs, better controls, and integrated economizers. The conventional rating method does not recognize the field improvements in efficiency and operations attributable to these features.

Current Status of Measure

FEMP sponsored a federal procurement for advanced units with minimum life-cycle costs (FEMP Unitary Air Conditioner Procurement). The winning products included mid-efficiency entries by Lennox International, with capacities from 90,000 to 120,000 Btuh and EERs and ILPVs of 11.0/11.8 to 11.3/12.0, and high-efficiency units from Global Energy Group, with capacities of 88,000 and 115,000 Btuh and EERs/IPLVs of 13.5/13.9 and 13.4/14.0, respectively. Our analysis begins with the Global Energy unit, because of its advanced specifications. The 10-ton (120,000 Btuh) unit includes powered exhaust and an optional economizer with differential controller.

Energy Savings and Costs

Our baseline model is an ASHRAE 90.1-1999 ten-ton roof-top unit, with EER of 10.3. According to LBNL (2003), the cost of this unit is $4,855, but this seems to be for a 7.5-ton unit. The GEG 115,000 Btu unit proxy for advanced units has a federal price only $800 higher (Frankenfield 2003).

Key Assumptions Used in Analysis

We have assigned an incremental cost, counting shipping and installation, of $1500.

We assume that the ratings are good estimators of energy efficiency. We assume that the economizer will save an additional 20% percent of electricity use for the most efficient unit, and the base unit does not have a working economizer. No compensation is made for additional electricity use for continuous ventilation; the advanced unit has 2-speed compressor and fan, so it will run more nearly continually. Assumes FEMP default, 1,500 full load hours/yr.

Recommended Next Steps

Current incentive programs at CEE and ENERGY STAR do not recognize efficiency tiers beyond EER/IPLV 11.0/11.4 (CEE) and 10.0/10.4 (ENERGY STAR) in this size range. Higher performance tiers and extra incentives for reliable economizers are needed to encourage additional cost-effective products to enter the market. In addition, the Lennox GEG and other relatively efficient units should be used as a performance benchmark for standards processes.

H1a Advanced Roof-top Packaged Air Conditioners

Description	10-ton Roof-Top Unit (RTU) for commercial spaces (No Economizer)		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	10 tons, meets ASHRAE 90.1-1999		
Efficiency	10.3	EER	
Electric use	17,476	kWh/year	FEMP calculator
Summer peak demand	10.5	kW	.9 coincidence
Winter peak demand	1.3	kW	
Gas/fuel use			
New Measure Information:			
Description	GEG, FEMP procurement model		
Efficiency	13.4		
Electric use	13,433	kWh/year	
Summer peak demand	8.1	kW	.9 coincidence
Winter peak demand	1.0	kW	using same ratio as for basecase
Gas/Fuel use			
Current status	COM		
Date of commercialization	2003		
Life	15	years	
Savings Information:			
Electricity	4,043	kWh/year	
Summer peak demand	2.4	kW	
Winter peak demand	0.3	kW	
Gas/Fuel		MMBTU/year	
Percent savings	23%		
Feasible applications	38%		70% of packaged units
2020 Savings potential	7,986	GWh	
2020 Savings potential	81	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,500	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.036	$/kWh	
Cost of saved energy	$3.54	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	First cost, awareness, fast payback concerns		
Effect on utility	no decrease		
Current promotion activity	FEMP, Manufacturer		
Rating	3	(1-5)	
Rationale	Small firm, proprietary approach increases challenge		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Additional incentives for very high efficiency units		
Sources:			
Savings	FEMP 2003		
Peak demand	GEG power draw, diversity factor in side calculations		
Cost	Modera and others, 1999. LBL Report 43165		
Feasible applications	GEG FEMP procurement data, GEG for base and economizer		
Measure life	ACEEE Estimate		
Other key sources	FEMP 2003		
Principal contacts	Peter Jacobs, Architectural Energy (303) 444-4149; Cathy Higgins, NBI, (509) 493-4468,x11		
Notes	Guy Frankenfield, GEG; Brad Hollomon, PNL		

H1b Advanced Roof-top Packaged Air Conditioners

Description	10-ton RTU packaged unit for commercial spaces (With Economizer)		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	EER 10.3, 10 tons		
Efficiency	10.3	Consensus basis for 65-135 packaged equipment: 90.1-1999	
Electric use	13,981	kWh/year	
Summer peak demand	10.5	kW	.9 coincidence
Winter peak demand	1.3	kW	
Gas/fuel use	0		
New Measure Information:			
Description			
Efficiency	13.4		
Electric use	10,746	kWh/year	
Summer peak demand	8.1	kW	.9 coincidence
Winter peak demand	1.0	kW	using same ratio as for basecase
Gas/Fuel use	0		
Current status	COM		
Date of commercialization	2003		
Life	15	years	
Savings Information:			
Electricity	3,234	kWh/year	
Summer peak demand	2.4	kW	
Winter peak demand	0.3	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	23%		
Feasible applications	38%		
2020 Savings potential	7,986	GWh	
2020 Savings potential	81	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$2,035	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.061	$/kWh	w/o demand savings calculated
Cost of saved energy	$6.00	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	First cost, awareness, fast payback concerns		
Effect on utility	no decrease		
Current promotion activity	FEMP, Manufacturer		
Rating	3	(1-5)	
Rationale	Small firm, proprietary approach will increase challenge of increasing mkt. Pen.		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Additional incentives for very high efficiency units		
Sources:			
Savings			
Peak demand			
Cost			
Feasible applications			
Measure life			
Other key sources			
Principal contacts			
Notes			

H2 CROMER CYCLE AIR CONDITIONERS

Description of Technology

Air conditioners both cool the air (sensible heat reduction) and remove moisture (latent heat). With vapor compression systems, adequate moisture removal in humid climates requires reducing the evaporator coil temperature, which increases cooling energy and supplies air at temperatures too cold for comfort, thus requiring reheat. Over the past two decades, latent loads have increased relative to sensible heat loads, as building envelopes and systems (lighting) have improved, but unitary equipment has not changed the sensible heat ratio (Amrane and Hourahan 2003). Increasing efficiency and latent heat removal is difficult with conventional equipment, which generally decreases air flow (to cool the coil) to increase condensing. As an alternative to electric reheat, desiccants (drying agents that can scavenge moisture from a humid air stream and then give up the moisture to dryer air) can be employed for moisture removal. The proprietary Cromer Cycle packaged air conditioner combines desiccant and refrigerant cycle components to provide augmented latent heat capability for humid climates. In Cromer Cycle commercial equipment, building return air is warmed by a secondary condenser coil. It then passes through a rotating desiccant wheel, where it picks up moisture. This increases moisture removal by the evaporator coil. The cold, saturated air passes through the desiccant wheel, surrendering moisture, before being distributed to the space.

Current Status of Measure

DOE is supporting development by Trane and Solar Engineering Company. The goals include reaching a Sensible Heat Ratio of 0.5 to 0.4 (vs. 0.25 to 0.3 for conventional equipment) and 12% energy savings relative to heat pipes (60% relative to overcooling and reheat) in humid climates; work continues on prototypes. Lab results show goals met (Sand 2003).

Energy Savings and Costs

DOE's goals include a retail price increment of $200 for residential size equipment. This includes the desiccant wheel, its drive, a secondary refrigerant heat exchanger with controls, and system redesign. Airxchange believes this to be achievable (Wellford 2003). Although Trane suggests that the unit will cost twice as much as comparable commercial equipment without part-load humidity control (Hallford 2003) We use a mature market incremental cost of 50% of the baseline equipment cost, based on incremental content.

Key Assumptions Used in Analysis

We treat residential (H2a) and commercial (H2b) equipment separately. For baseline residential units, we use a SEER 12/EER 10 unit; for commercial units we use ASHRAE 90.1-1999 (EER 9.7, 20 ton). For residential units, we used DOE's $200 incremental cost goal. For 20-ton commercial packaged units, we have adjusted prices from the LBNL (2003) life-cycle cost analysis for a 15-ton unit, multiplying by the 20/15 size ratio. We assume 12% peak and energy savings for both commercial and residential applications. Because laboratory testing and simulations continue and no field tests have been carried out, all savings and performance numbers are estimates.

Recommended Next Steps

We anticipate four major barriers: First cost, education on the benefits for designers, owners, and contractors; continuing confusion about ventilation requirements for unitary equipment, and field experience to show reliability as well as savings. Building on existing performance rating methods for air-to-air heat exchangers (ANSI/ARI 2001), ARI has prepared Guideline V for calculating the efficiency of a unitary air conditioner or heat pump equipped with an air-to-air heat recovery device. ASHRAE is developing a Method of Test for combined desiccant/vapor compression systems (Sand 2003). Trane plans to introduce field test units in 2004, and may offer a commercial product in 2005 (Hallstrom 2003). Early field evaluations of these units will help show the value of the equipment and the Combined Efficiency metric. Additional simulations, calibrated by these field demonstrations, will help delineate the climate conditions in which Cromer Cycle equipment should be preferred. These steps, over the next 2–3 years, are required before program offerings can be considered. In addition, either more sophisticated savings calculations will be required or better documentation and higher savings (beyond 12%) will be needed for the products to succeed with the projected commercial equipment incremental cost.

H2a Cromer Cycle Air Conditioner - residential

Description	More efficient residential A/C for high humidity loads		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		RET uncommon
Basecase Information:			
Description	SEER 12 EER 10 A/C, 3 tons		
Efficiency	12	Consensus residential basis	
Electric use	4,558	kWh/year	Energy Star CAC calculator, region 9
Summer peak demand	3.24	kW	Capacity divided by EER, 0.9 coincidence
Winter peak demand	N/A	kW	
Gas/fuel use			
New Measure Information:			
Description	Baseline + dessicant wheel		
Efficiency	12		
Electric use	4,011	kWh/year	12% benefit of Cromer
Summer peak demand	2.85	kW	EER 12, 0.9 coincidence, 12% improvement as per energy
Winter peak demand	N/A	kW	
Gas/Fuel use			
Current status	PROTO		
Date of commercialization	2006		Estimated, inferred from Hallstrom
Life	18.4	years	Used TSD instead of OIT estimate
Savings Information:			
Electricity	547	kWh/year	
Summer peak demand	0.39	kW	
Winter peak demand	N/A	kW	
Gas/Fuel		MMBTU/year	
Percent savings	12%		
Feasible applications	60%		fraction that could adopt the product.
2020 Savings potential	2,065	GWh	South only
2020 Savings potential	21	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$200	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.031	$/kWh	
Cost of saved energy	$3.06	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	cost, awareness		
Effect on utility	increases comfort through better humidity control		
Current promotion activity	minor publicity through web		
Rating	3	(1-5)	
Rationale	improved comfort		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Field tests, metrics to document performance benefits		
Sources:			
Savings	OIT fact sheet		
Peak demand			
Cost	DOE - OIT, + Hallstrom (commercial), analyst judgment		
Feasible applications	DOE - OIT		
Measure life	DOE - TSDs (2003 presentation, comm, 2002 Res)		
Other key sources	See references in write-up		
Principal contacts	Cromer, C., FSEC; Wellford, B, AirXchange; Hallstrom, Trane		
Notes			

H2b Cromer Cycle Air Conditioner - commercial

Description	More efficienct commercial A/C for high humidity loads		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	RET, NEW, ROB		May include retrofit in regions with humidity problems
Basecase Information:			
Description	10		ton roof-top unit
Efficiency	10.3	EER, Consensus basis, large packaged equipment: 90.1	
Electric use	17,476	kWh/year	FEMP calculator
Summer peak demand	17.5	kW	from capacity, definition of EER, 0.9 coincidence
Winter peak demand	N/A	kW	
Gas/fuel use	0		
New Measure Information:			
Description			EER 10.3, 10-ton roof-top unit w. cromer/desiccant system
Efficiency	10.30	Same as baseline	
Electric use	15,379	kWh/year	12% better than baseline.
Summer peak demand	17.5	kW	Same as baseline
Winter peak demand	N/A	kW	
Gas/Fuel use	0		
Current status	PROTO		
Date of commercialization	2005		Estimated, inferred from Hallstrom
Life	15	years	From TSD for commercial unitary equipment
Savings Information:			
Electricity	2,097	kWh/year	
Summer peak demand	0.00	kW	
Winter peak demand	N/A	kW	
Gas/Fuel		MMBTU/year	
Percent savings	12%		
Feasible applications	36%		est. 40% of installations have humidity challenges
2020 Savings potential	1,554	GWh	South only
2020 Savings potential	16	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,500	2003 $	twice as much, per ton, as residential cromer
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.069	$/kWh	
Cost of saved energy	$6.82	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	cost, awareness		
Effect on utility	increases comfort through better humidity control		
Current promotion activity	minor publicity through web		
Rating	3	(1-5)	
Rationale	fear of litigation re mold		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Field tests, metrics to document performance benefits		
Sources:			
Savings	DoE 2001 (OIT)		
Peak demand	Developer claims		
Cost	DoE 2001 (OIT)		
Feasible applications	ACEEE estimate		
Measure life	ACEEE estimate		
Other key sources			
Principal contacts			
Notes			

H3 HEAT PIPES FOR CENTRAL AIR CONDITIONING DEHUMIDIFICATION

Description of Technology

Heat pipes are passive components used to improve dehumidification by commercial forced-air HVAC systems. They consist of refrigerant-filled tubes that transfer heat by evaporating the refrigerant at the hot end and condensing refrigerant at the cold end. Heat pipes are installed with one end upstream of the evaporator coil to pre-cool supply air and one downstream to re-heat supply air. This allows the system's cooling coil to operate at a lower temperature, increasing the system latent cooling capability. Heat rejected by the downstream coil reheats the supply air, eliminating the need for a dedicated reheat coil. Heat pipes can increase latent cooling by 25–50%, depending upon the application. Conversely, since the reheat function increases the supply air temperature relative to a conventional system, a heat pipe will typically reduce sensible capacity. In some applications, individual heat pipe circuits can be controlled with solenoid valves to provide improved latent cooling control. Primary applications are limited to hot and humid climates and where high levels of outdoor air or low indoor humidity are needed. Supermarkets, hospitals, and laboratories are often good heat pipe applications. Most of the units are being installed in new construction.

Current Status of Measure

Heat pipes have been available for over 30 years. Incorporating heat pipes also increases the air-side pressure drop through the duct system, and consequently increases fan energy consumption. With fan energy representing 32% of annual cooling and ventilation energy use (DOE 2003g), the added pressure drop may result in the fan penalty exceeding cooling savings in some applications with high part load use, unless bypasses are installed. Heat pipes are also being increasingly used as energy recovery devices on make-up air systems. By reducing the outdoor air load on cooling systems, heat pipe energy recovery devices can contribute to cooling system downsizing, reducing incremental costs. With ASHRAE Standard 62 promoting increased levels of outdoor air, both the energy and humidity-control benefit of heat pipes will increase.

Energy Savings and Costs

Potential heat pipe energy savings arise from better latent control, reheat savings, and higher supply water temperatures for central chilled water systems. Monitored energy savings of 10–15% have been documented in a high outdoor air application (EPA 1997), although typical savings are likely lower. Installed heat pipe costs are on the order of 65¢ per cfm (Meyers 2003).

Key Assumptions Used in Analysis

We have estimated cooling savings at 7% for typical applications. The heat pipe for a typical 50-ton packaged unit would cost approximately $13,000 without accounting for cooling equipment downsizing.

Recommended Next Steps

Principal barriers include lack of knowledge of heat pipe benefits and economics, including understanding preferred applications. Improved education for designers would help architects and design engineers understand applications. Further efforts in promoting heat pipe technology should focus on assessing the implications of increased outdoor air requirements on mechanical system sizing and annual operating costs. In addition, alternative humidity control options (such as desiccant systems) and energy recovery systems should be evaluated to determine applicability for each of these technologies.

H3 Heat Pipes for Central Air Conditioning Dehumidification

Description	Heat pipes used for enhanced dehumidification		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	10 ton packaged unit		(3000 ft2 building, 300 ft2 per ton sizing)
Efficiency	10.3	EER	
Electric use	10,500	kWh/year	3.5 kWh/ft2 (from Energy Databook, South region)
Summer peak demand	5.4	kW	
Winter peak demand	NA	kW	
Gas/fuel use			
New Measure Information:			
Description	Heat pipe for dehumidification		
Efficiency	n/a		
Electric use	9,765	kWh/year	
Summer peak demand	5.4	kW	
Winter peak demand	NA	kW	
Gas/Fuel use	NA		
Current status	COMM		
Date of commercialization	1970's		
Life	15	years	
Savings Information:			
Electricity	735	kWh/year	
Summer peak demand	0	kW	
Winter peak demand	N/A	kW	
Gas/Fuel		MMBTU/year	
Percent savings	7%		
Feasible applications	30%		Building types with high outdoor air requirements
2020 Savings potential	756	GWh	South region only
2020 Savings potential	8	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$2,100	2003 $	$.65 per cfm (as per mfg); assume 4% downsizing credit
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.28	$/kWh	
Cost of saved energy	$27.26	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	limited market (hot/humid climates, need for low indoor RH or high OA requirements)		
Effect on utility	improved indoor humidity control		
Current promotion activity	limited		
Rating	2	(1-5)	
Rationale	Niche market, difficult to target		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Education of design community and building owners, design tools+K27		
Sources:			
Savings	DEG estimate		
Peak demand	Brown and Koomey 2002		
Cost	Meyers 2003		
Feasible applications	DEG estimate		
Measure life	ASHRAE		
Other key sources	EPA 1997		
Principal contacts	Don Shirey, FSEC (321-638-1451); Charlie Meyers, HPT (352-367-0999 x24)		
Notes			

H4 FREE-STANDING EFFICIENT DEHUMIDIFIERS TO AUGMENT RESIDENTIAL CAC

Description of Practice

In humid climates, using a free-standing dehumidifier can augment the latent heat removal capacity of the central air conditioner. Humidity control in much of the United States is a major concern as typical central air conditioning units are unable to adequately dehumidify indoor air. This is increasingly true in newer, tighter houses with lower cooling loads and therefore less air conditioner (i.e., dehumidification) operation (Lstiburek 2002). Oversized air conditioning systems compound the problem by shortening the length of the operating cycle during which latent cooling can occur. Dehumidifiers improve indoor humidity levels not only during days when the central cooling system operates, but also during cooler, humid weather when dehumidification is still needed.

Inadequate dehumidification not only leads to uncomfortable indoor conditions, but also to higher cooling energy use when homeowners lower the thermostat set point to achieve improved comfort. Dehumidifiers allow occupants to raise the cooling set point due to improved moisture control and offer non-energy benefits by reducing indoor relative humidity below the 60–70% levels at which dust mites and mold grow. Increasingly, indoor mold concerns are becoming a primary driving force in the purchase of dehumidifiers. Free-standing dehumidifiers are compact packaged refrigeration systems that move indoor air first across low-temperature evaporator coils (removing excess moisture from the air) and then across the condenser coil, delivering dryer, warmer air to the space. Capacities of these units range from single-room units (typically used in basements) to units designed to handle entire houses.

The ENERGY STAR program currently lists dehumidifiers meeting minimum efficiency requirements. Some of the more efficient models have efficiencies as high as 2.75 liters/kWh, approximately two to three times higher than the baseline models commonly found in basements. Although these advanced units cost more than the baseline units, they are quieter, offer more sophisticated humidistat controls, and are designed to look like a piece of furniture. According to a key manufacturer, sales are highly dependent on summer weather conditions in the humid parts of the country (McConnell 2003).

Current Status of Measure

According to *Appliance Magazine* (2003), approximately 16% of U.S. households have a dehumidifier, although only a small fraction of these achieve a high operating efficiency, defined in terms of liters of moisture removal per kWh consumed. Not a priority.

Energy Savings and Costs

If we assume the base dehumidifier costs $250 and that the incremental cost of an ENERGY STAR unit is 15% ($38), then the CSE is $0.04/kWh. We are assuming only 5% savings due to the measure.

Key Assumptions Used in Analysis

The assumption that the units will save 5% is considered reasonable, as a measure of savings from raising the thermostat since comfort is achieved by lowering humidity.

Recommended Next Steps

The principal barrier is that systems are not designed or optimized for separate dehumidifiers as latent heat removal devices. Typically, the air conditioner is specified by the builder or contractor, while the dehumidifier is considered a free-standing appliance chosen by the consumer. Studies on the field performance of free-stranding dehumidifiers were not found, probably since these systems have only recently received notice as a potentially significant residential energy-consuming device. Field monitoring is needed to provide quantitative data on how consumers use the devices, how much energy they consume, and what impact they have on indoor humidity and cooling set points. In addition, efforts to promote more efficient units should be expanded. In the meantime, this is not an emerging technology, so it is not a priority.

H4 Free-Standing, Efficient Dehumidifiers to Augment Residential CAC

Description	DROP		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	RET, NEW, ROB		
Basecase Information:			
Description	3 ton central air conditioner and furnace, no separate dehumidifier		
Efficiency	12		
Electric use	2,899	kWh/year	South
Summer peak demand	3.24	kW	
Winter peak demand	1	kW	
Gas/fuel use			
New Measure Information:			
Description	Free-standing dehumidifier		
Efficiency			
Electric use	2,754	kWh/year	assume 5% savings
Summer peak demand	3.24	kW	
Winter peak demand	1	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	1960's		
Life	7	years	Appliance magazine
Savings Information:			
Electricity	145	kWh/year	
Summer peak demand	0	kW	
Winter peak demand	0	kW	
Gas/Fuel		MMBTU/year	
Percent savings	5%		
Feasible applications	19%		30% of central ducted systems nationwide (.3 x .63)
2020 Savings potential	531	GWh	South only
2020 Savings potential	5	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$38	2003 $	Est. 15% incremental cost
Other cost/(savings)		$/year	
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$4.43	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Cost		
Effect on utility	Significant indoor health benefits, improved comfort		
Current promotion activity	EnergyStar, national media mold reports promote technologies such as this		
Rating	3	(1-5)	
Rationale	Non-energy benefits can drive implementation		
Priority / Next Steps			
Priority	Not		
Recommended next steps			
Sources:			
Savings	DEG modelling estimate increased setpoint impact (12% cooling savings)		
Peak demand	n/a		
Cost	DEG estimate		
Feasible applications	DEG estimate		
Measure life	Appliance magazine		
Other key sources	http://www.energystar.gov/index.cfm?c=dehumid.pr_dehumidifiers		
Principal contacts	Phil McConnell, Thermastor (1-800-533-7533 x7805)		
Notes			

H5 RESIDENTIAL HVAC FOR HOT-DRY CLIMATES

Description of Technology

Residential cooling system design is largely dictated by the performance characteristics of available vapor compression equipment. HVAC manufacturers design and package refrigeration components to meet average outdoor and indoor conditions. This results in equipment designs that achieve sensible heat ratios (SHR) of about 0.75 to 0.80, resulting in latent cooling fractions ranging from 0.20 to 0.25. Unlike in humid climates where latent cooling is essential to indoor comfort, in hot-dry climates latent cooling does not contribute to improved comfort. Ideally hot-dry climate vapor compression equipment would have SHRs above 0.90 or 0.95 to achieve maximum efficiency. Two approaches can meet this goal. One is through a redesign of refrigeration components to achieve optimal performance at the high outdoor temperatures and low indoor relative humidities common to California and the Southwestern United States.

Current Status of Measure

Proctor Engineering has investigated the energy and demand savings potential of an improved hot-dry climate design (Proctor 1993). They are continuing to research technological improvements that will hopefully lead to new optimized system designs. A second, short-term, approach is to optimize the selection of available indoor and outdoor components to achieve better performance. Mahone (2004) has shown that EER is more tightly correlated with energy use than SEER in hot, dry climates, since so much of the energy consumption occurs when outdoor temperatures are above 90ºF.

Energy Savings and Costs

By increasing the supply airflow at the indoor unit, the sensible cooling capacity of a vapor compression system increases. For example, increasing the design airflow for a 3.5-ton unit from 350 cfm/ton to 450 cfm/ton increases the cooling capacity from 32.9 kBtu/hour to 36.7 kBtu/hour, an increase of ~12%. This translates into an increase in EER from 7.77 to 8.24, in sensible capacity, an increase in overall efficiency of 6%. This increase in efficiency and sensible capacity can be achieved by matching a 3.5-ton condensing unit with a 4-ton indoor unit (DX coil and air handler). In many situations, the added sensible capacity allows the outdoor unit to be downsized by half a ton. One major Northern California HVAC contractor is actively pursuing this strategy in virtually all of the new homes it is working on (DEG 2002). The added cost for indoor components is often countered by cost savings for the condensing unit. The one performance disadvantage of this approach is higher fan energy consumption.

Key Assumptions Used in Analysis

For this analysis, we are assuming 6% energy savings at zero incremental cost. Major national HVAC manufacturers show little interest in regional equipment and will develop and package systems that achieve improved performance in hot-dry climates only if they see a continuing growth in the trend of matching smaller condensing unit with larger indoor components.

Recommended Next Steps

The principal barrier to market introduction of hot-climate air conditioners is that the current rating method, focused on SEER, does not allow manufacturers to establish (with EER, for example) the benefits of regionally optimized equipment designs. In the short term, the practice of "mis-matching" indoor and outdoor components appears to be the best approach to improve on the sensible cooling capacity and overall efficiency of vapor compression equipment in hot-dry climates. Monitoring of these systems relative to standard designs would be useful in quantifying savings and benefits. Longer term R&D efforts are needed to lead to an improved system design that provides optimized performance in hot-dry climates. The California Energy Commission PIER program is funding development of an optimized hot-dry climate residential air conditioner.

H5 Residential HVAC for Hot-Dry Climates

Description	Low-latent fraction air conditioner systems		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW,ROB		
Basecase Information:			
Description	3 ton central AC/furnace		
Efficiency	12	SEER	
Electric use	1,594	kWh/year	Energy Databook, West region average
Summer peak demand	3.24	kW	10 EER on peak
Winter peak demand	NA	kW	
Gas/fuel use			
New Measure Information:			
Description	Low latent design		
Efficiency	12	12% higher sensible capacity, 6% more efficient	
Electric use	1,498	kWh/year	
Summer peak demand	3.05	kW	
Winter peak demand	NA	kW	
Gas/Fuel use	NA		
Current status	COMM		
Date of commercialization	2000		
Life	18.4	years	
Savings Information:			
Electricity	96	kWh/year	
Summer peak demand	0.2	kW	
Winter peak demand	0	kW	
Gas/Fuel		MMBTU/year	
Percent savings	6%		
Feasible applications	90%		
2020 Savings potential	1,095	GWh	West region only
2020 Savings potential	11	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$50	2003 $	Estimated $0 or small incremental cost
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$4.37	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Lack of knowledge, design tools		
Effect on utility	Higher airflow (improved comfort), reduction in peak latent cooling capacity		
Current promotion activity	Used as standard practice by major California HVAC contractor, PIER research		
Rating	4	(1-5)	
Rationale	No cost barriers; contractor education needed		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Contractor education, utility incentives, promote through energy codes, PIER R&D		
Sources:			
Savings	Manufacturer's data		detailed performance tables
Peak demand	DEG estimate		6% savings estimate
Cost	DEG estimate		tradeoff between air handler upsizing, cond unit downsizing
Feasible applications	DEG estimate		
Measure life	DOE TSD		
Other key sources	Proctor Engineering		
Principal contacts	John Proctor, Proctor Engineering (415-451-2480)		
Notes			

H6 ULTRAVIOLET GERMICIDAL IRRADIATION (UVGI) FOR HVAC SYSTEMS

Description of Technology

Microbes are vulnerable to light at wavelengths at or near 2,537 Angstroms (254 nanometers [nm]) due to the resonance of this wavelength with molecular structures. Visible light has wavelengths of about 400 to 700 nm. Ultraviolet (UV) light has wavelengths of 100 to 400 nm. The UV spectrum is further divided into A, B, C, and vacuum bands. The C band is called the germicidal bandwidth and lies between 200 and 280 nm, approximately. Microbes present in HVAC systems are destroyed by UVC and include bacteria, viruses, yeast, mold, and various spores. When applied to the exit face of a cooling coil, UVC has a cleaning effect and can reduce pressure drop as well as improve air quality.

Current Status of Measure

UVGI has been applied in hospitals and prisons since the early 1900s to sterilize the air supply. Application in other, more conventional HVAC systems is more recent. In-duct systems now have 27% of the market. The General Services Administration (GSA) issues standards for public buildings and includes a requirement for UVC downstream of all cooling coils and drain pans (GSA 2003).

Energy Savings and Costs

The energy saving benefit of cleaner cooling coils has only recently been recognized and is still considered to be developing. Typical claims for energy efficiency are a 30% reduction in fan energy and a two-year payback (see http://www.fptechinc.com/Links/UVGItechSum.pdf.). Another typical report comes from Iolani School in Honolulu, a 35,000 ft^2 office and classroom building. It consists of six AHUs totaling 45,000 cfm and used 20 UV lamps total. The lamps last 1.5 years, with a replacement cost of approximately $1,300/year. The installation eliminated mold growth and odor, there were fewer complaints of respiratory problems, and the facility manager is very satisfied. Maintenance savings are estimated at $8,000 per year (Kolderup 2003b).

Key Assumptions Used in Analysis

Because this measure did not demonstrate energy savings, we did no further work on it.

Recommended Next Steps

EPRI will study UVGI as part of its 2004 program, Element P17.005: Demonstrations and Case Studies of Applications of UVGI for Chiller Coils in Commercial Buildings. Results of these investigations may be available to EPRI members. A report is scheduled for March 2005 (EPRI 2003).

H6 Ultraviolet Germicidal Irradiation (UVGI) for HVAC Systems

Description	UV disinfection allows for the use of lower pressure drop filters		
Market Information:			
Market sector	COM		
End-use(s)	HC		
Energy types	ELEC		
Market segment	NEW,RET		
Basecase Information:			
Description	10 ton AHU		
Efficiency			
Electric use	2,461	kWh/year	300 sqft/ton, nat avg fan energy
Summer peak demand	1.4	kW	4000 cfm @ 350W/1000cfm
Winter peak demand	1.4	kW	
Gas/fuel use			
New Measure Information:			
Description	4 UV lamps		
Efficiency			
Electric use	2,215	kWh/year	
Summer peak demand	1.26	kW	
Winter peak demand	1.26	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	1980s		
Life	20	years	DEG estimate
Savings Information:			
Electricity	246	kWh/year	
Summer peak demand	0	kW	
Winter peak demand	0	kW	
Gas/Fuel		MMBTU/year	
Percent savings	10%		
Feasible applications	50%		
2020 Savings potential	1,853	GWh	
2020 Savings potential	19	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$2,000	2003 $	$200/ton
Other cost/(savings)	($600)	$/year	$1000/yr maint savings - $40/ton UVGI O&M
Cost of saved energy	$0.57	$/kWh	Measure justified by impact on IAQ, not on economics
Cost of saved energy	$56.53	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Knowledge, first cost, lack of documented energy savings		
Effect on utility	Improved IAQ; higher worker productivity		
Current promotion activity	Utility design assistance		
Rating	2	(1-5)	
Rationale	Not cost-effective on energy basis		
Priority / Next Steps			
Priority	Not		IAQ, not energy savings value
Recommended next steps			
Sources:			
Savings	DEG estimate		
Peak demand	DEG estimate		
Cost	Kolderup 2003		
Feasible applications	DEG estimate		
Measure life	DEG estimate		
Other key sources	EPRI 2003, www.fptechinc.com/Links/UVGItechSum.pdf		
Principal contacts	Erik Kolderup, Eley Associates (415-957-1977)		
Notes			

H7 ROBUST AIR CONDITIONERS AND HEAT PUMPS

Description of Technology

Residential air conditioners and heat pumps generally do not achieve the efficiency in the field implied by their SEER ratings (Neal 1998). Shortfalls arise from deficiencies in the national rating method, and from poor installation and maintenance. These factors include low charge (combined with low proportion with thermostatic expansion valves [TXVs]), incorrect air flow, leaky ducts, and oversizing. "Robust" units could largely compensate for charge losses and low air flow (25% cumulative). A new specification to achieve the equipment-related goals is within reach of existing designs. The "robust" air conditioner would be characterized by the highest SEER levels readily attained without modulating compressors (SEER 14), very good high-temperature performance (EER 12), an adaptive refrigerant metering device (TXV or better), and a fan assembly that adapts to the static pressure of the house's duct system. It would include a thermostat equipped with alarm functions, such as "check filter" and "call for service" (Sachs 2003).

Current Status of Measure

The robust air conditioner concept has been circulated among market transformation groups and selected manufacturers. No insurmountable obstacles or barriers have been suggested. Proposals in review now (by PIER and others) would lead to prototype development and field tests. After that, any of several market transformation mechanisms could be used to pull robust units into the market. For example, it might be attractive to some production builders, as a "hassle-avoidance" measure, or for federal procurement for military base housing and similar applications.

Energy Savings and Costs

From Neal (1998), the field-adjusted SEER is 25% lower than the rated value, bringing SEER 12 down to SEERFA (field-adjusted) 11.1. By correcting these problems, the robust unit at SEER 14 delivers SEERFA=13.9, for a saving of 19% through better air conditioning performance. This includes compensation for the 60% market penetration of TXVs among current SEER 13 and 14 units.

Key Assumptions Used in Analysis

Our baseline is the ET project minimum specification: SEER 12, EER 10, and HSPF 8.5 for heat pumps. We boost TXV or equivalent penetration to 100%, to assure good performance under faulty charge or air flow conditions. However, we reduce Neal's calculated value because 60% of SEER 13 and 14 units already have TXVs (DOE 2001a). Fan energy savings are based on Sachs and Smith (2003). HSPF potential savings relative to the ENERGY STAR baseline are taken as the same ratio used for air conditioning. We find national net average energy savings of 710 kWh/yr (heating and cooling together) and a peak demand reduction of 450 Watts relative to the existing stock. Incremental cost is estimated (bottom-up) as $270 over the baseline SEER 12 unit by adding the cost of components.

Recommended Next Steps

The principal barrier is the lack of a specification that manufacturers can meet and use for marketing. We recommend that PIER and other program developers explore the following steps: (1) reaching consensus among program operators and manufacturers on a feature set; (2) developing and demonstrating prototype equipment; and (3) launching market transformation activities, including working with manufacturers to encourage production. For example, this could become a next-generation ENERGY STAR program. As a carrot for manufacturers, a robust air conditioner program could require that all components (condenser, evaporator, furnace [if included], air handler [fan], and controls) be provided and guaranteed by a single source, to avoid finger-pointing in case of trouble.

H7 Robust Air Conditioners and Heat Pumps

Description	Units designed to maintain performance despite field challenges		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description			SEER 12 EER 10 A/C, 3 tons, no ECM, 60% TXV
Efficiency	11.1	SEERFA, 15% av. mis-charge, 60% of SEER 13 have TXV	
Electric use	2,850	kWh/year	EPA Region 5, decrement by SEERFA
Summer peak demand	3.24	kW	Capacity divided by EER, 0.9 coincidence
Winter peak demand	N/A	kW	
Gas/fuel use	0		
New Measure Information:			
Description	SEER 14, EER 12, TXV, ECPM, no refrig. Leaks, signals		
Efficiency	13.9	SEERFA	
Electric use	2,315	kWh/year	EPA Region 5
Summer peak demand	2.59	kW	from definition, using SEERFA
Winter peak demand	N/A	kW	
Gas/Fuel use	1.9		make-up for less electrical energy dissipated as heat.
Current status	RES		All parts are commercialized, not combined yet
Date of commercialization	2006		estimated
Life	18.4	years	
Savings Information:			
Electricity	1,135	kWh/year	A/C + fan (including heating season)
Summer peak demand	1	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	-1.9	MMBTU/year	
Percent savings	33%		
Feasible applications	85%		Central a/c portion of res. a/c use
2020 Savings potential	27,546	GWh	Does not include fan savings
2020 Savings potential	278	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$270	2003 $	
Other cost/(savings)	$15	$/year	increased gas use from less elec. Dissipation
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$3.82	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	cost, marketing strategy, consumer & dealer education needed		
Effect on utility	more even cooling		
Current promotion activity	concept stage		
Rating	3	(1-5)	
Rationale	Will manufacturers support?		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	field demos, test procedures that reflect field conditions better		
Sources:			
Savings	RECS 2003, corrected by SEER & SEERFA ratios		
Peak demand	analysis of Proctor 1998		
Cost	Estimated by Sachs based on cost of individual technology components		
Feasible applications	Analyst judgment		
Measure life	DOE 2001 (TSD)		
Other key sources			
Principal contacts	H. Sachs, ACEEE, 202-429-8873		
Notes			

H8 RESIDENTIAL GAS ABSORPTION CHILLER HEAT PUMPS

Description of Technology

Residential absorption heat pumps use an ammonia-water absorption cycle to provide heating and cooling. The heat pumps circulate ammonia and water through the system. Ammonia (the refrigerant) is sequentially absorbed, boiled out, condensed, and reabsorbed in water (the absorbent) to produce the heat pump action (Sauer and Howell 1983**Current Status of Measure**

Although cooling-only absorption units have existed for several decades, absorption heat pumps are still in the research stage. DOE has been funding Rocky Research and Ambian Climate Technologies to produce an absorption heat pump using the Generator Absorber heat eXchanger (GAX) technology. This technology uses the heat that is released when the ammonia is reabsorbed into the water. By using this heat, the efficiency of the unit is increased significantly. Ambian Climate Technologies is a consortium of utility investors, including Mississippi Energies, Inc., Southern California Gas, Southwest Gas, Texas Gas Pipeline, and others including the Gas Technology Institute.

Energy Savings and Costs

The new chiller/ heat pump technology developed by Rocky Research and Ambian uses GAX technology but also has a number of other innovations. These include a method for achieving high-efficiency vapor separation, ability to control variable refrigerant flow rates, the utilization of a low-emission, variable-capacity combustion process, and a new novel solution pump. The technology is currently in the development stage, soon to have prototypes in field tests (Anderson 2003).

These recent developments have resulted in a very efficient unit with a cooling COP of 0.7 at 95° F and a heating COP of 1.4 at a 47° F. However, since the technology allows for variable capacity, the efficiency seen during normal use should typically be higher, while cycling losses are significantly reduced. The 5-ton unit is expected to have a production cost target of $3,000 with a goal of entering the market in 2005 (Anderson 2003). It is anticipated that other capacities will become available as the product is commercialized.

Key Assumptions Used in Analysis

The most favorable applications for an absorption heat pump are in displacing conventional air conditioning systems in new construction applications. Retrofitting, although possible, is more difficult and costly, since it would be necessary to replace the refrigerant lines and the coil with a hydronic loop. Although the GAX technology is at a source energy performance disadvantage when compared to new 12 SEER cooling systems, the lower relative cost for gas (vs. electricity) results in homeowner cost savings, which will be amplified if time-of-day or demand rates are applied for residential tariffs. Maintenance requirements for the system are not yet clearly known, but the goal is to have requirements comparable to conventional HVAC equipment.

Recommended Next Steps

The GAX technology faces significant barriers since maintenance and field performance of the unit has not been well quantified. Once the technology is proven in the field, the gas industry can effectively market the technology. Additional ongoing research areas include incorporating a water heating option to reclaim cooling mode waste heat. Added cooling mode energy benefits will help in offsetting the fairly low cooling efficiency.

H8 Residential Gas Absorption Chiller Heat Pumps

Description	Absorption chillers/Hybrid absorp+mechanical chiller		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	GAS, ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	5 ton central AC/furnace		
Efficiency	80 AFUE / 12 SEER		
Electric use	3,538	kWh/year	Energy Databook avg national cooling x 5/3
Summer peak demand	5.4	kW	5 ton, .9 coincidence
Winter peak demand	0.8	kW	furnace fan
Gas/fuel use	108.3		Energy Databook avg national gas heating x 5/3
New Measure Information:			
Description	5 ton Absorption HP		
Efficiency	COP cooling, 1.40 COP heating		
Electric use	1,990	kWh/year	
Summer peak demand	1	kW	includes fan and system parasitics
Winter peak demand	1	kW	includes fan and system parasitics
Gas/Fuel use	110.8		
Current status	RES		
Date of commercialization	2005		
Life	20	years	
Savings Information:			
Electricity	1,548	kWh/year	
Summer peak demand	4.4	kW	
Winter peak demand	-0.2	kW	
Gas/Fuel	-2.5	MMBTU/year	
Percent savings	9%		
Feasible applications	14%		90% of large houses (30%) with gas (53%)
2020 Savings potential	6,260	GWh	
2020 Savings potential	41	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$900	2003 $	per 1998 study
Other cost/(savings)	$19	$/year	added gas use reflected in cost
Cost of saved energy	$0.07	$/kWh	
Cost of saved energy	$6.63	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Establishing distribution and service		
Effect on utility	None		
Current promotion activity	gas utility consortium		
Rating	2	(1-5)	
Rationale	Improved efficiencies needed		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Field tests to document performance, utility incentives to follow		
Sources:			
Savings	Anderson 2003		
Peak demand	DEG estimate		
Cost	Anderson 2003 for production cost, DEG estimate for retail cost		
Feasible applications	DEG estimate		
Measure life	Anderson 2003		
Other key sources	Ryan 2002, Babyak 2003		
Principal contacts	Joel Anderson, Ambien Climate Technologies (205-822-8740)		
Notes			

H9 ADVANCED COLD-CLIMATE HEAT PUMP/FROSTLESS HEAT PUMP

Description of Technology

Residential heat pumps lose capacity and efficiency when outdoor temperatures fall below the mid-30s°F. Fundamental thermodynamic effects combine with refrigeration systems and controls that often are not optimized for cold weather operation. Since building loads increase as temperatures fall, a standard air-source heat pump must rely on inefficient resistance heat to meet the capacity shortfall.

Current Status of Measure

Two R&D efforts are currently underway to improve the cold climate performance of air-source heat pumps. The EnerKon Corporation, in partnership with Nyle Special Products, is starting initial production runs of a "cold climate heat pump" that features two compressors (a two-stage compressor and a second booster compressor), intelligent controls, and a plate heat exchanger to improve low temperature performance. Preliminary test data indicate a fairly flat heating capacity and an HSPF of about 9.6 (EnerKon 2003), a 17°F heating COP of 2.7, and a 0°F heating COP of 2.3. Projected rated cooling efficiency is targeted at 16 SEER. In addition, Oak Ridge National Laboratory is working to improve air-source heat pump defrost performance. The current solution is to reverse the refrigerant flow through the heat pump allowing condenser heat to defrost the outdoor coil. This has numerous drawbacks including the need for indoor resistance heat. ORNL supplies a small amount of heat to the refrigerant accumulator to retard the formation of frost on the outdoor coil. However, this practice will only be effective at a temperature range of 41 to 32°F. Lab testing has shown that the small amount of heat that is added to the accumulator reduces the need for defrost cycling by a factor of 5. ORNL is currently working on commercializing the design with American Best.

Energy Savings and Costs

The EnerKon heat pump is currently in the initial production mode, and thus a near-term option for improved cold climate heat pump performance. Forty prototype units were tested in 2002–2003 by utilities in the Northeast and Midwest. Results were favorable and expected sales in 2004 are estimated at 2000 units (Constantino 2003). List prices range from $4,300 for a 3.5-ton unit to $5,600 for a 5-ton unit. Prices should decline with production economies and competition, but will remain hundreds of dollars/unit higher than for simpler units with a single fixed-capacity compressor.

Key Assumptions Used in Analysis

The chief barrier is believed to be the poor reputation of air-source heat pumps, particularly in cold climates. Even with accurate rating methods, consumers are likely to be wary of performance claims. High and volatile prices for alternatives (such as propane) will encourage adoption. Projected savings of 30% are assumed relative to a standard 6.8 HSPF unit, based on the HSPF ratios. Actual savings may be higher since the EnerKon unit will likely eliminate most of the resistance heat consumed during low temperature and defrost operation. The principal obstacle is the ability of the firm to establish solid distributor and dealer relationships and a strong reputation based on customer satisfaction.

Recommended Next Steps

Detailed monitoring of the EnerKon unit and conventional heat pumps would provide valuable data for evaluating performance. If promised performance levels are achieved, the EnerKon unit will demonstrate performance comparable to geothermal heat pumps at a much lower installed cost. With favorable results, winter-peaking utilities should evaluate incentives based on the expected demand reduction.

H9 Advanced Cold-Climate Heat Pump/Frost-less Heat Pump

Description	Add heat to refrigerant accumulator to lift suction pressure and temperature.		
Market Information:			
Market sector	RES		
End-use(s)	HEAT		
Energy types	ELEC		
Market segment	NEW		Can also replace elec furnaces, but few of these in North
Basecase Information:			
Description	Normal air-source heat pump, SEER=12, EER 10, HSPF=7.0		
Efficiency	7	CEE spec, comparable to using SEER 12 as baseline	
Electric use	12,519	kWh/year	EPA region 2 (cold)
Summer peak demand	3.24	kW	0.9 coincidence even for cold region
Winter peak demand	8.35	kW	Peak demand conversion taken from COP@17 assumed 1.2
Gas/fuel use			
New Measure Information:			
Description	HP, SEER 16, EER 12, HSPF 9.6, heated accum. or compressor + economizer		
Efficiency	9.6	Nyle claims HSPF 9.6 for its "CCHP", spec sheet at http://nyletherm.com/spaceheating.htm	
Electric use	10,805	kWh/year	Based on EPA climate region 2.
Summer peak demand	2.70	kW	0.9 coincidence even for cold region
Winter peak demand	3.71	kW	0.95 coincidence, From COP at 17F=2.7
Gas/Fuel use	NA		
Current status	COMM		Nyle, PROTO ORNL
Date of commercialization	2003		Nyle
Life	20	years	
Savings Information:			
Electricity	1,714	kWh/year	Region 2
Summer peak demand	0.540	kW	
Winter peak demand	4.640	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	14%		
Feasible applications	29%		Electric heat
2020 Savings potential	17,148	GWh	
2020 Savings potential	173	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,000	2003 $	soft estimate for NYLE relative to baseline
Other cost/(savings)		$/year	probably underestimate winter peak savings
Cost of saved energy	$0.05	$/kWh	
Cost of saved energy	$4.64	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Trust in product from niche manufacturer, development of market		
Effect on utility	Mechanical lifetime improvement (ORNL: less mechanical shock during defrost)		
Current promotion activity	COMM		NYLE (ORNL in field trials)
Rating	3	(1-5)	
Rationale	Signif. cost increase, but alteratives (GSHP, dual fuel) are much more expensive		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	verification through field tests		
Sources:			
Savings	Energy Star calculator, Calc_ASHP		
Peak demand	From principles, soft estimate of conventional COP at 17F		
Cost	Estimated from NYLE content by analyst		
Feasible applications	cold regions taken as Climate regions 1 - 5+, estimated as 50% population.		
Measure life	considered same as other residential HP, from TSD		
Other key sources	Web sites, NYLE Special Products and ORNL		
Principal contacts	Steve Constantino, EnerKom (877-363-7566)		
Notes	Conventional ASHP impose ca 10 kW/unit resistive demand on coldest days		

H10 GROUND-COUPLED HEAT PUMPS

Description of Technology

Ground-coupled heat pump systems (also called GeoExchange) consist of a hydronic loop for exchanging thermal energy between soil or groundwater and one or more heat pumps, providing space heating, cooling, and/or water heating to the conditioned space. In most applications the hydronic loop is a closed loop transferring heat with tubing located in the ground. Ground loops are typically vertical boreholes (~200–300 foot depth per ton of capacity) with U-tubes providing a flow path through the grouted borehole. Alternatives use groundwater that is returned to the same aquifer. By coupling the outdoor heat exchanger with the moderating influence of the earth, ground-coupled systems are able to achieve higher operating efficiencies than typical air-source heat pump equipment. Several key advantages of ground-coupled technology derive from the single-package design, which eliminates the outdoor heat exchanger. Due to the short refrigeration path within the indoor unit, the refrigerant charge is lower and can be accurately measured at the factory. The lack of outdoor components increases expected equipment life.

Current Status of Measure

Ground-coupled technology was aggressively promoted by DOE and EPA in residential and commercial applications through funding of the Geothermal Heat Pump Consortium (GHPC), headquartered in Washington, D.C. GHPC is implementing the National Earth Comfort Program with the goal of completing 400,000 ground-coupled installations nationally by 2007. Significant market penetration has been achieved in regions where severe climates and low electric rates (such as the South and Midwest), or the absence of competitively priced heating fuel(s), favor ground-coupled systems.

Energy Savings and Costs

In a study of nine commercial systems, the average GSHP system used 14.4 kWh/ft^2-year, vs. 22.7 for the alternatives considered for those buildings. Peak demand was also significantly lower: 4.7 W/ft^2 instead of 7.2 for the conventional systems modeled. For these buildings, the average return on investment was 19%, or a simple payback of 5.9 years (ASHRAE 1998). In some markets (e.g., schools in some regions), ground-coupled first costs may cost less than competing systems. They generally are competitive with 4-pipe chilled water systems—less expensive than chiller-VAV systems, but more expensive than simple roof-top equipment.

Annual residential energy cost savings vary with rates, climate, loads, conventional system type, and other factors, but tend to fall within the range of 20 to 60%, with the higher end of the savings range based on houses heated with resistance heat. In regions of the country where there is a lack of infrastructure, the ground loop installation cost can represent a substantial incremental cost premium over competing systems. Generally accepted ground-coupled added value features include enhanced comfort, quieter operation, lower maintenance, and extended equipment life due to more favorable operating conditions.

Key Assumptions Used in Analysis

For a commercial installation larger than 100 tons, we assume competitive costs. In most regions, residential installations will be much more expensive.

Recommended Next Steps

Where there is a reasonable infrastructure of informed designers, drillers, and mechanical contractors, GSHPs are competitive for commercial installations: more expensive than roof-tops, but less so than many chiller systems. In contrast, the primary barrier to increasing the penetration rate of residential ground-coupled technologies is the high installed system cost. Commercialization efforts should focus on reducing the installed cost in the production builder environment. One option is through financing programs or direct utility incentives.

H10a Ground Coupled Heat Pumps - commercial

Description	Heat pumps utilizing ground as a heat source/sink		
Market Information:			
Market sector	COM		
End-use(s)	HC,WH		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	Mixture of commercial systems (RTU, central), 50,000 sf. [ASHRAE 1998]		
Efficiency	22.7	kWh/yr-sf.	
Electric use	1,135,000	kWh/year	50,000 sf bldg.
Summer peak demand	359	kW	
Winter peak demand	0	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	ground source system average [ASHRAE 1998]		
Efficiency	14.4	kWh/yr-sf	
Electric use	720,000	kWh/year	
Summer peak demand	236	kW	
Winter peak demand	N/A	kW	In commercial buildings, winter peak usually smaller
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	1980		approx.
Life	18.4	years	ground loop should last >50 years
Savings Information:			
Electricity	415,000	kWh/year	
Summer peak demand	123	kW	
Winter peak demand	N/A	kW	In commercial buildings, winter peak usually smaller
Gas/Fuel	N/A	MMBTU/year	
Percent savings	37%		
Feasible applications	40%		Generally <50,000 sf, but not all geology feasible
2020 Savings potential	7,406	GWh	
2020 Savings potential	75	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1	2003 $	compared to 4-pipe chiller system.
Other cost/(savings)		$/year	
Cost of saved energy	$0.000	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Equipment costs and ground loop installation costs		
Effect on utility	Quieter operation, factory refrigerant charge, indoor HVAC components		
Current promotion activity	GHPC has promoted technology nationally level; 20 states have util./govt incentives		
Rating	2	(1-5)	
Rationale	Incremental cost is the primary barrier		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Focus on commercial sector, where benefits easier to quantify and costs lower		
Sources:			
Savings	ASHRAE 1998		
Peak demand	ASHRAE 1998		
Cost	ASHRAE 1998		
Feasible applications	This study		
Measure life	DOE TSD		
Other key sources	Geothermal Heat Pump Consortium (GHPC)		
Principal contacts	Wael El Sharif, GHPC (202-508-5013)		
Notes	DEG, 1999b		
	T.C. 6.8 is cognizant ASHRAE committee		

H10b Ground Coupled Heat Pumps - residential

Description	Heat pumps utilizing ground as a heat source/sink		
Market Information:			
Market sector	RES		
End-use(s)	HC,WH		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	3 ton central air-source heat pump with electric water heating		
Efficiency	2 SEER, 0.91 EF water heating		
Electric use	10,138	kWh/year	Midwest Electric HVAC+DHW
Summer peak demand	3.24	kW	0.9 coincidence assumed
Winter peak demand	10	kW	includes strip heat backup and DHW
Gas/fuel use	N/A		
New Measure Information:			
Description	3 ton ground coupled heat pump		
Efficiency	COP heating, 13.8 EER cooling		
Electric use	7,890	kWh/year	
Summer peak demand	2.95	kW	11 EER on peak
Winter peak demand	4.10	kW	
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	1980		approx.
Life	18.4	years	ground loop should last >50 years
Savings Information:			
Electricity	2,248	kWh/year	
Summer peak demand	0.29	kW	
Winter peak demand	5.90	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	22%		21% heating & cooling savings, 25% water heating
Feasible applications	15%		50% of electric heat (29%)
2020 Savings potential	26,417	GWh	
2020 Savings potential	267	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$3,400	2003 $	$800 per ton + $1000 for two-tank desuperheater
Other cost/(savings)		$/year	
Cost of saved energy	$0.13	$/kWh	not cost-effective??
Cost of saved energy	$12.64	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Equipment costs and ground loop installation costs		
Effect on utility	Quieter operation, factory refrigerant charge, indoor HVAC components		
Current promotion activity	GHPC has promoted technology nationally level; 20 states have util./govt incentives		
Rating	2	(1-5)	
Rationale	Incremental cost is the primary barrier		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Focus on commercial sector, where benefits easier to quantify and costs lower		
Sources:			
Savings	DEG, 1999a		
Peak demand	DEG estimate		
Cost	DEG, 1998		
Feasible applications	DEG estimate		
Measure life	DOE TSD		
Other key sources	Geothermal Heat Pump Consortium (GHPC)		
Principal contacts	Wael El Sharif, GHPC (202-508-5013)		
Notes	DEG, 1999b		
	T.C. 6.8 is cognizant ASHRAE committee		

H11 LEAKPROOF DUCT FITTINGS

Description of Technology

The majority of duct leakage in residential and small commercial HVAC systems is due to improperly sealed connections between ductwork and fittings. Even when duct connections are initially well-sealed, leakage may increase over time (Walker et al. 1998). Although the use of mastics and mechanical fasteners is becoming more widespread, a low cost, leakproof system will help to transform the market. The benefit of any duct remediation technology is greatest in climates with high cooling loads and attic ducts. Available round-section spiral sheet metal systems from Lindab and others are targeted to commercial applications in the United States. They are used for residences in Sweden, but cost about twice as much as conventional residential systems in the United States (Spartz 2004).

Current Status of Measure

In California, the installation of tight duct systems has increased significantly over the past three years as the Title 24 code has provided a credit for “tight” duct systems leaking less than 6% of system airflow. One approach to reducing duct leakage is the use of mastic, mechanical fasteners, and UL-181-approved duct tapes. An alternative approach is through the use of long-lasting leakproof duct connections that can be reliably field installed with a minimum of skill. Proctor Engineering Group has developed the Snap Duct system of fittings with support from DOE’s Small Technology Transfer program. The system consists of mechanically fastened fittings (couplings, boots, plenums, wyes) for flex and hard ducts that snap together to create a long-lasting seal. Testing of the fittings show that about 90% of the leakage within the duct system is eliminated (Proctor 2003).

Energy Savings and Costs

Various field studies indicate that mitigating residential duct leakage may reduce HVAC energy use by roughly 20% (Hammurlund 1992; Proctor 1993). The California Title 24 energy code assumes typical new residential duct systems leak 22% of HVAC system airflow (CEC 1999). Typical new construction costs for manual duct sealing are estimated as $250 per house. The Snap Duct technology is still in the prototype stage, but indications are that the system will be less expensive than current manual duct sealing techniques. Although the fitting cost will be more than standard fittings, labor savings is expected to more than offset the incremental cost. Duct pressurization testing is still necessary to insure proper installation.

Key Assumptions Used in Analysis

Based on laboratory testing data, we are assuming a 90% reduction in typical duct leakage. The Snap Duct system is principally a product for the new construction market. Estimated costs are assumed to be $100 for a typical house.

Recommended Next Steps

The proposed Snap Duct technology has not yet been commercialized. Proctor Engineering is working with a Midwestern regional manufacturer of duct fittings to produce the Snap Duct system. Some retooling is necessary to produce the improved fittings and the goal is to start production in the next six months. Two builders (one in Nevada and one in Chicago) have indicated interest in field-testing of the Snap Duct system. Successful field-test results coupled with lower costs than conventional sealing methods would likely lead to rapid growth of the Snap Duct system.

H11 Leakproof Duct Fittings

Description	Quick connect fittings that do not require mastic or drawbands		
Market Information:			
Market sector	R&C		
End-use(s)	HC		
Energy types	ELEC, GAS		
Market segment	NEW, ROB		
Basecase Information:			
Description	3 ton central AC/furnace		
Efficiency	80% AFUE, 12 SEER		
Electric use	2,123	kWh/year	Energy Databook, national average cooling
Summer peak demand	3.24	kW	
Winter peak demand	0.5	kW	
Gas/fuel use	65		Energy Databook, national average gas heating
New Measure Information:			
Description	Snap seal duct fittings		
Efficiency	NA	Eliminate 90% of estimated 23% base case loss	
Electric use	1,684	kWh/year	
Summer peak demand	2.8	kW	85% of base case
Winter peak demand	0.5	kW	
Gas/Fuel use	52		
Current status	PROTO		
Date of commercialization	2006		
Life	30	years	
Savings Information:			
Electricity	439	kWh/year	
Summer peak demand	0.49	kW	
Winter peak demand	0.00	kW	
Gas/Fuel	13	MMBTU/year	
Percent savings	21%		
Feasible applications	90%, 49%		90% of new homes, 90% of new commercial pkg units
2020 Savings potential	28,770	GWh	
2020 Savings potential	621	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$100	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.004	$/kWh	
Cost of saved energy	$0.36	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Manufacturing partner, need for volume manufacturing capability to achieve low cost		
Effect on utility	Improved IAQ due to reduced duct leakage		
Current promotion activity	None		
Rating	4	(1-5)	
Rationale	If cost targets can be achieved, the market is huge		
Priority / Next Steps			
Priority	High/Medium		
Recommended next steps	Building codes requiring tight ducts, field demonstrations, utility incentives		
Sources:			
Savings	Proctor 2003		
Peak demand	DEG estimate		
Cost	Proctor 2003		
Feasible applications	DEG estimate		
Measure life	DEG estimate		
Other key sources	Iain Walker, LBNL (510-486-4692)		
Principal contacts	John Proctor, Proctor Engineering (415-451-2480)		
Notes			

H12 AEROSOL-BASED DUCT SEALING

Description of Technology

Approximately 20% (Hammurlund 1992; Proctor 1993) of energy use in ducted residential space conditioning systems is associated with duct losses, with about half due to conduction and half due to leakage (Jump, Walker, and Modera 1996). Sealing ducts not only reduces annual heating and cooling energy use, but also significantly reduces air conditioning peak demand for systems with attic ducts. Although new homes can achieve leakage levels on the order of 5–10% (of HVAC airflow) through the use of improved materials and diagnostic testing, fixing existing home duct leakage is often problematic and expensive as ducts are often in hard or impossible to access locations such as small attics, crawl spaces, and duct chases. Manual duct sealing has been performed for many years, but it is messy, labor-intensive, and not always effective at eliminating a majority of the leakage.

Current Status of Measure

An aerosol duct sealing technology (Aeroseal) developed at Lawrence Berkeley National Laboratory can seal holes in ducts up to ¼″ in diameter from the inside by spraying atomized latex aerosol into a sealed duct system. By pressurizing the duct system while spraying the atomized aerosol, the material collects around small leaks in ductwork and seals them in a process similar to that used by canned flat tire sealers. A computer monitors and controls the atomization and duct pressurization process that typically lasts 40–90 minutes.

Energy Savings and Costs

A number of large-scale utility demonstration projects have documented the performance of the Aeroseal technology. The Sacramento Municipal Utility District (SMUD) (Kallett et al. 2000) found an average 81% reduction in leakage for a sample of 121 houses that underwent the Aeroseal process. A 1996 Florida study of 47 houses found an average 80% reduction in leakage (Modera et al. 1996). The average cost per house for the Sacramento study was slightly over $1,000, although other remediation work occurred at many of the sites. A better mature market cost estimate for Aeroseal remediation is in the range of $500 to $900 per site (Bourne et al. 1999).

In 2001 Aeroseal was acquired by the Carrier Corporation, which greatly increased the visibility and marketing of the technology. There are close to 80 Aeroseal franchises nationwide, which performed about 3,000 sealing jobs during 2002. The hottest markets for Aeroseal are Sacramento, Phoenix, southern California, and parts of Washington state and Illinois. Aeroseal is projecting 10,000 jobs per year by 2007. Some utilities are continuing rebate programs to partially offset some of the cost of performing Aeroseal remediation. In the Sacramento area, where about 100 jobs a month were completed in 2000 (Kallett et al. 2000), SMUD is currently offering a $300 rebate to residential customers.

Key Assumptions Used in Analysis

We focused on houses that use more energy than average, specifically 25% more than the U.S. average for A/C and heating, limiting the feasible applications to 32% (roughly the top 50% of single-family residences by consumption). We assumed existing houses, the primary target, with older HVAC equipment (AFUE 70, SEER 9), and that Aeroseal would eliminate 81% of the estimated 23% air leakage from the duct system.

Recommended Next Steps

No technical barriers exist to further commercialization of aerosol duct sealing, but the service is expensive relative to consumer expectations. The major barriers relate to educating consumers about duct leakage. A cable TV promotion effort currently underway will help spread the word. Utilities and state energy offices can serve as a valuable resource in educating consumers about the benefits of duct leakage remediation. Incentives to partially offset the incremental cost would also help in promoting the technology. As field experience is gained, it should become feasible to target house types with the greatest potential for savings (e.g., flex duct in attics) and to develop lower cost approaches to these types.

H12 Aerosol-Based Duct Sealing

Description	Spray-in ductwork sealant to minimize duct leakage.		
Market Information:			
Market sector	R&C		
End-use(s)	HC		
Energy types	ELEC, GAS		
Market segment	RET, NEW		
Basecase Information:			
Description	3 ton split system furnace/AC		
Efficiency	70% AFUE, 9 SEER	existing building stock is target market; high use homes	
Electric use	2,654	kWh/year	Energy Databook, national average cooling (+25%)
Summer peak demand	3.24	kW	
Winter peak demand	0.5	kW	
Gas/fuel use	81.3		Energy Databook, national average gas heating (+25%)
New Measure Information:			
Description	Aeroseal process		
Efficiency	NA	Eliminate 81% of estimated 23% base case loss	
Electric use	2,159	kWh/year	
Summer peak demand	2.8	kW	87% of base case
Winter peak demand	0.5	kW	
Gas/Fuel use	66		
Current status	COMM		
Date of commercialization	1999		
Life	25	years	
Savings Information:			
Electricity	494	kWh/year	
Summer peak demand	0.42	kW	
Winter peak demand	0.00	kW	
Gas/Fuel	15	MMBTU/year	
Percent savings	19%		
Feasible applications	32%		Top 50% central system htg/clg users nationally (63%)
2020 Savings potential	30,587	GWh	
2020 Savings potential	551	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$700	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.025	$/kWh	
Cost of saved energy	$2.47	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	First cost, public awareness		
Effect on utility	Improved indoor air quality		
Current promotion activity	Carrier, EnergyStar, some utility rebates		
Rating	3	(1-5)	
Rationale	Carrier marketing, high-tech appeal but substantial cost		
Priority / Next Steps			
Priority	High/Medium		
Recommended next steps	Increased utility incentives, promotion of tight ducts through building codes		
Sources:			
Savings	Kallett, et al, 2000		
Peak demand	DEG Estimate		
Cost	Bourne & Stein, 1999		
Feasible applications	DEG Estimate		
Measure life	DEG Estimate		
Other key sources	Modera et al, 1996		
Principal contacts	Mark Modera, Aeroseal (510-908-4300)		
Notes			

H13 MICROCHANNEL HEAT EXCHANGERS

Description of Technology

Microchannel heat exchangers transfer heat through multiple flat fluid-filled tubes containing small channels while air travels perpendicular to the fluid flow. Compared to current fin-tube heat exchangers, the air passing over the heat exchanger has a longer dwell time, increasing both the efficiency and the rate of heat transfer. This increase in heat exchanger effectiveness allows the microchannel heat exchanger to be smaller and yet have the same performance as a regular heat exchanger, or to get improved performance in the same volume as a conventional heat exchanger. The smaller size of the exchanger reduces the refrigerant pressure drop, improving overall compressor performance. Microchannel technology is very common for automotive air conditioning applications due to its small size, which indicates the technology has overcome the critical manufacturing hurdles.

Current Status of Measure

Modine Manufacturing is currently producing parallel flow (PF) heat exchangers for various applications within the automotive industry. Efforts to integrate PF heat exchangers in the HVAC field are still in the R&D stage. Issues to be resolved include evaporator design related to refrigerant flow and the ability of the evaporator coil to effectively shed condensate. The coil moisture retention problem is exacerbated by the small air passages in the PF design that allow condensate to cling to the evaporator coil. Several approaches to shedding water from the evaporator have been investigated; the simplest involves angling the heat exchanger so condensate is more easily shed. Purdue University researchers found that angling the exchanger resulted in improved heat pump efficiency, however, it actually reduced the ability of the exchanger to shed water (Groll 2003). More research needs to be done to fully solve technical problems before the technology can be integrated with HVAC equipment. Lennox purchased a key component manufacturing company in the microchannel field and it is not clear how that will affect technology development (Stephens 2004).

Energy Savings and Costs

Costs for these heat exchangers are still high with little available data from the manufacturer on anticipated costs for production heat exchangers. Energy savings greatly depend on the size of the heat exchanger, the application, and how other refrigerant components are optimized (cost and performance). In general, these heat exchangers are approximately 15% more effective than conventional fin and tube heat exchangers (Groll 2003).

Key Assumptions Used in Analysis

Limited advancements in microchannel technology in the HVAC field make performance and cost projections tenuous. For this study, we are assuming a 15% heat exchanger efficiency improvement translates to a 5% energy savings potential. Incremental costs are estimated at $100, but are highly dependent upon cost and performance optimizations.

Recommended Next Steps

Whether microchannel technology will enter the building HVAC arena is not clear at this time. A few technical problems exist, but they do not appear to be significant. Once these problems are addressed through additional research, microchannel heat exchangers could be introduced to HVAC manufacturers. In the interim, market transformation efforts are premature at best. There also are doubts about MT strategies that focus prescriptively on technologies instead of performance.

H13 Microchannel Heat Exchangers

Description	Compact, efficient HVAC refrigerant HX's		
Market Information:			
Market sector	ALL		
End-use(s)	HC		
Energy types	ELEC		
Market segment	OEM		
Basecase Information:			
Description	3 ton air source HP w/tube and fin HX		
Efficiency	R 10, HSPF 7		
Electric use	10,740	kWh/year	calc_ASHP, Region 5 cooling, Region 3 heating
Summer peak demand	3.24	kW	0.9 coincidence
Winter peak demand	10	kW	including resistive back-up
Gas/fuel use	N/A		
New Measure Information:			
Description	Heat pump w/microchannel heat exchanger		
Efficiency	performance (Babyak, 2000)		
Electric use	10,203	kWh/year	5% overall savings
Summer peak demand	3.1	kW	95% of base case
Winter peak demand	9.5	kW	
Gas/Fuel use	N/A		
Current status	COMM		for automobile AC's
Date of commercialization	1985		driven by R134a conversion inefficiency
Life	18.4	years	TSD
Savings Information:			
Electricity	537	kWh/year	
Summer peak demand	0.16	kW	
Winter peak demand	0.50	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	5%		
Feasible applications	75%		75% of HP's and CAC's
2020 Savings potential	13,030	GWh	
2020 Savings potential	132	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$100	2003 $	Assumed competitive with HX size increase, generous
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.016	$/kWh	
Cost of saved energy	$1.56	$/MMBtu	
Data quality assessment	C	(A-D)	little info on cost
Likelihood of Success:			
Major market barriers	Frost build-up issues and water shedding issues; Development work stalled		
Effect on utility	None		
Current promotion activity	Little		
Rating	2	(1-5)	
Rationale	Water shed problem solvable, Cost/performance tradeoffs need to be resolved		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Better assess technology status and potential		
Sources:			
Savings	Groll 2003		
Peak demand	5% energy savings through improved HX performance		
Cost	DEG estimate, Groll (2003)		
Feasible applications	DEG estimate		
Measure life	DOE TSD for residential AC/HP		
Other key sources	Modine web site, Stephens 2003		
Principal contacts	Groll, Purdue Univ. (765-494-2132), Modine Corp		
Notes	Commercialization reportedly delayed, no reason stated		

H14 SOLID STATE REFRIGERATION FOR HEAT PUMP AND POWER GENERATION

Description of Technology

Most conventional air conditioners and heat pumps rely on refrigerant-based, mechanical vapor compression cycles to provide space conditioning. Thermoelectric (TE) devices, such as Peltier Junctions, directly convert electricity to cooling. TE devices have long been used for special applications such as keeping medicine cold or cooling electronic components. Because of the low efficiency of these components, they have never been adopted on a large scale.

Current Status of Measure

A recent breakthrough in the field of TE heat pumps greatly increased their efficiency. Where traditional TE's are composed two electrodes bonded together, the Cool Chips™ product is constructed with a vacuum gap of 30 to 100 Angstroms between the electrodes. This gap is small enough to allow thermotunneling, or the passing of electrons across a very small space, which means the electric current can pass from one electrode to the other without the heat from the hot side conducting back to the cold side. This technology has the potential of achieving efficiencies up to 11 times that of current Peltier junctions and opening up a large field of heating and cooling applications. The current estimate is a 55% Carnot efficiency for the Cool Chips, relative to a 5% Carnot efficient for a standard Peltier junction and a 45% Carnot efficiency for vapor compression cycles (Magdych 2003). There are several potential configurations of HVAC systems using Cool Chips, including distributed systems and central systems using hydronic coils.

This technology is in the final phases of development. It is estimated that prototypes will be available for third-party testing during 2004 (Magdych 2003). Once the technology is fully developed in its raw form, it can be adopted to specific applications. If progress continues at the current pace, we can expect to see prototype TE HVAC systems in 2006 or 2007.

Energy Savings and Costs

The manufacturer claims that OEM costs will be around $0.10 per Watt (Magdych 2003). Under this assumption, a 3-ton unit would require over $1,000 of the Cool Chips product, and a 5-ton unit over $1,750. For perspective, a high-efficiency compressor for a 3-ton central air conditioner would cost the OEM about $167.25 (DOE 2001a). Depending on the configuration of the system, the compressor loop would be replaced with central or distributed hydronic loops and controls.

Key Assumptions Used in Analysis

Optimistically, this measure may incur no incremental cost in a mature market due to the replacement of the vapor compression loop, but for this study we are estimating a $2,000 incremental cost for a 3-ton system. A major assumption used for this analysis is that the theoretical energy savings targets will be reached once the development is complete. We assumed that the same efficiency increase would be seen for heating as for cooling. We assumed an 18% increase in Carnot efficiency for both heating and cooling operation, relative to the Carnot efficiency of 45% for the base case air-source (mechanical) heat pump.

Recommended Next Steps

TE technology will first be used in automotive and aerospace applications. Adapting it to building HVAC configurations will require significant research and adaptation in order to take advantage of TE's unique benefits. Once the technology has been integrated into prototype HVAC equipment and field-testing has been completed, the savings and cost estimates should be updated. At that time it would be reasonable to pursue market transformation efforts based on monitored system performance and overall economics.

H14 Solid State Refrigeration for Heat Pumps & Power Generation

Description	Solid-state "Thermotunneling" technology for cooling, space heat &/or electricity		
Market Information:			
Market sector	R&C		
End-use(s)	HC		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	3 ton air source HP		
Efficiency	45%	Carnot	
Electric use	5,883	kWh/year	HP national avg
Summer peak demand	3.24	kW	
Winter peak demand	3	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	Coolchip © thermoelectrics with thermotunneling technology		
Efficiency	55%	Carnot	
Electric use	4,813	kWh/year	
Summer peak demand	2.7	kW	
Winter peak demand	2.5	kW	
Gas/Fuel use			
Current status	RES		
Date of commercialization	2008		
Life	18.4	years	unknown but could be longer than conventional
Savings Information:			
Electricity	1,070	kWh/year	
Summer peak demand	0.589	kW	
Winter peak demand	0.545	kW	
Gas/Fuel		MMBTU/year	
Percent savings	18%		
Feasible applications	29%		electric heat
2020 Savings potential	10,477	GWh	
2020 Savings potential	106	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$2,000	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.158	$/kWh	
Cost of saved energy	$15.63	$/MMBtu	
Data quality assessment	D	(A-D)	Much uncertainty on cost and performance
Likelihood of Success:			
Major market barriers	Must adopt HVAC application over to this technology		
Effect on utility	Simplifies Zoning and retrofit, since no ducts (just walls and wire)		
Current promotion activity	Developing prototypes for testing in 2004		
Rating	2	(1-5)	
Rationale	HVAC applications a long way off, aerospace and auto first		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Continue with development, get 3rd party verification, develop HVAC applications		
Sources:			
Savings	Magdych 2003		
Peak demand	DEG Estimate		
Cost	Magdych 2003, DEG estimate		
Feasible applications	DEG Estimate		
Measure life	DOE TSD for residential AC/HP		
Other key sources			
Principal contacts	Jim Magdych, Cool Chips PLC (408-621-6125)		
Notes	Data all theoretical.		

H15 PRACTICES FOR DESIGN FOR LOW PARASITICS

Introduction

This practice complements PR2, Ultra Low Energy Commercial Building Designs (50% > codes) and PR3, Integrated Commercial Building Design LEED Level (30% > Code) by focusing on the improvements in the air and fluid handling systems as technical measures for achieving the benefits of integrated design. In buildings with chilled water systems, energy distribution from the mechanical areas may require as much energy as the chiller itself (Higgins 2003; Westphalen and Koszalinski 1999, Figure 5-17). Although few in number, the buildings with these systems are large and may account for 20–25% of California's commercial cooling capacity, for example (Higgins 2003). Improvements of at least 25% are feasible, from roughly 1.7 kWh/ft^2-yr to 1.3 kWh/ft^2-yr.

Current Status

Whole building simulation—required by LEED (2003) and in some cases for compliance with ASHRAE 90.1-1999—encourages designers to look carefully at parasitics for both demand reduction and energy savings. The forthcoming ASHRAE Guides being developed by Special Project 102 may move the practice even further into the mainstream. (These are best described as quasi-prescriptive guidance for mechanical designers and aim for performance 30, 50, and 75% better than ASHRAE 90.1. The first, for office buildings smaller than 20,000 ft^2, is to be issued in 2004, with accompanying training programs.)

Energy Savings and Costs

In five monitored buildings, Higgins (2003) found that fan energy represents 20 to 50% of the total HVAC electrical energy use, or 10 to 30% of the total building electrical energy use, and can be more than the chiller. Higgins claimed potential fan energy savings of 50% or more, or total building energy savings of 12%. Better approaches will increase design costs (at first) but reduce equipment and duct size and cost; we project no cost net increase.

Key Assumptions

Following Westphalen and Koszalinski (1999), we assume that the base case operated as simulated, without field degradation. Actual savings are thus likely to be larger if more efficient systems are also better installed and maintained (See PR4, Retrocommissioning). We adopt the Westphalen analysis, including its regional and equipment distribution assumptions. Because the total number of LEED-certified buildings is still very small, we infer very low market penetration of sound design practices.

Barriers and Recommended Next Steps

The principal barriers are institutional: present limitations in training, fee basis, and risk-reward trade-offs within mechanical design firms do not support efforts to go beyond minimum requirements and present experience. Good system design requires more training and may take more time. Revising fee structures so designers are not paid a fraction of the value of the mechanical contract is probably required to align incentives with sound practices. We also recommend continued support of LEED, ASHRAE, and other MT efforts to highlight the savings potential of exemplary *system* designs.

H15 Practices for Design for Low Parasitics

Description	Integrated designs to reduce fan/pumping losses in commercial buildings		
Market Information:			
Market sector	COM		
End-use(s)	HC		
Energy types	ALL		
Market segment	NEW, RET		
Basecase Information:			
Description	105,000		sqft, water-cooled chiller VAV system, parasitics only
Efficiency	1.04	kWh/ft.sq.-yr, parasitics (40% of cooling + vent)	
Electric use	109,200	kWh/year	Westphalen and Koszalinski 199, Figure 5-17
Summer peak demand	126	kW	Westphalen and Koszalinski 199, Figure 5-17
Winter peak demand	101	kW	assumed air handling load dominated by ventilation
Gas/fuel use	0		
New Measure Information:			
Description	50%		parasitics reduction
Efficiency	0.52	kWh/ft.sq.-yr, parasitics	
Electric use	54,600	kWh/year	parasitics only
Summer peak demand	88	kW	30% demand reduction, vs. 50% energy (parasitics only)
Winter peak demand	71	kW	Westphalen and Koszalinski 199, Figure 5-17
Gas/Fuel use	0		
Current status	COMM		
Date of commercialization	2000		approximate
Life	20	years	ASHRAE Handbook, conservative est. from components
Savings Information:			
Electricity	54,600	kWh/year	
Summer peak demand	38	kW	
Winter peak demand	30	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	50%		
Feasible applications	24%		90% of 27% comm space w. central systems, W&K, Figure 1-4
2020 Savings potential	9,358	GWh	40% of cooling and vent
2020 Savings potential	94	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0	2003 $	Smaller equipment but more design cost
Other cost/(savings)		$/year	
Cost of saved energy	$0.00	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	awareness and time limits of designers;		
Effect on utility	quieter system on average, better control		
Current promotion activity	LEED, etc.		
Rating	4	(1-5)	
Rationale	Will be attractive to owners, architects, and mechanical designers		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Support LEED and ASHRAE efforts, promote efficient fans and pumps		
Sources:			
Savings	Westphalen and Koszalinski 1999		
Peak demand	Westphalen and Koszalinski 1999		
Cost	ACEEE		
Feasible applications	ACEEE		
Measure life	ASHRAE Handbook, Applications, 2003, ch. 36, Table 3		
Other key sources	Higgins ed. 2003		
Principal contacts	H. Sachs, ACEEE, 202-429-8873		
Notes	Asume that experience rises and costs drop, so 90% will have been retrofitted		

H16 HIGH EFFICIENCY GAS-FIRED ROOFTOP UNITS

Description of Technology

The majority of current commercial gas-fired rooftop air conditioning units are single-speed noncondensing units with combustion efficiencies in the range of 78–82%. Newer high efficiency units using condensing heat exchangers or pulse combustion can boost this efficiency to 89-97%. Another method of increasing energy efficiency is modulating the burner and combustion air flows. This modulating approach provides greater control over temperature and eliminates much of the cycling losses, resulting in higher seasonal efficiencies.

Current Status of Measure

There are currently several manufacturers producing high efficiency units, with modulating units being more common. Condensing furnaces are not commonly specified: The commercial market tends to focus on first cost, and manufacturers are concerned about freezing conditions affecting weatherized unit flues. Of the major national manufacturers, only Lennox produces pulse combustion heaters (on a custom basis). Trane and other major manufacturers produce modulating units. Lennox, in a joint venture with CME, produces custom multi-zone units. A two-stage modulating gas heater controls the heating, with heat also recovered with multiple economizer units.

Energy Savings and Costs

A typical 20-ton Trane GasPak unit typically costs about $12,000, while a 30-ton Trane Intellipak unit with the modulating gas burner would cost $35,000, resulting in a cost premium of about $500/ton (Crumley 2003). Lennox multi-zone units cost $35,000–40,000 and are only built on a custom basis (Brotnov 2003). Most of the applications are for retrofitting aging multi-zone units. Only 300–400 units are sold per year, with many of these units installed on schools. To date, most units are not used for new installations due to the custom nature of the units. The potential for cost reduction appears significant if production volumes increase.

Key Assumptions Used in Analysis

An incremental cost of $1,000 per unit was assumed since typical condensing furnace upgrade costs include a step up in the manufacturer's product line. Preferred applications include high heating load buildings located in cold U.S. climates.

Recommended Next Steps

Commercial package unit condensing furnaces are rarely installed, with less than 5% of Intellipak units sold with the modulating gas option (Crumley 2003). With such a small market, the incremental cost is fairly high. However, the high "per unit" savings potential indicates that the market share should grow if first costs are lower. Utility incentives or a golden carrot program with manufacturers may be the best way to promote the technology. Education of architects and design engineers in cold climates would also be beneficial in conveying the economics of specifying condensing furnace technology.

H16 High-Efficiency Gas-Fired Rooftop Units

Description	Rooftop packaged unit with condensing furnace		
Market Information:			
Market sector	COM		
End-use(s)	HEAT		
Energy types	GAS		
Market segment	NEW, ROB		
Basecase Information:			
Description	10 ton gas-fired rooftop packaged unit		
Efficiency	80%	steady state efficiency	
Electric use	NA	kWh/year	
Summer peak demand	NA	kW	
Winter peak demand	NA	kW	
Gas/fuel use	178.5		Midwest (Energy DataBook), high user (+25%)
New Measure Information:			
Description	10 ton gas-fired condensing rooftop packaged unit		
Efficiency	95%	steady state efficiency	
Electric use	NA	kWh/year	
Summer peak demand	NA	kW	
Winter peak demand	NA	kW	
Gas/Fuel use	150.3		
Current status	COMM		
Date of commercialization	1990's		
Life	15	years	
Savings Information:			
Electricity	0	kWh/year	
Summer peak demand	N/A	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	28	MMBTU/year	
Percent savings	16%		
Feasible applications	11%		25% (high user) of 45% (commercial package and furnace heating)
2020 Savings potential		GWh	
2020 Savings potential	20	TBtu (source)	Need to use formula with ROB included
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,000	2003 $	Incrmemental price of premium feature, estimated
Other cost/(savings)		$/year	
Cost of saved energy	NA	$/kWh	
Cost of saved energy	$3.42	$/MMBtu	For high-users
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High first cost, niche market, cold climate installation issues		
Effect on utility	None		
Current promotion activity	some utility incentives		
Rating	2	(1-5)	
Rationale	Long paybacks		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Golden carrot for manufacturers, utility incentives		
Sources:			
Savings	Based on nominal efficiencies		
Peak demand	n/a		
Cost	Crumley 2003, Brotnov 2003		
Feasible applications	DEG estimate		
Measure life	ASHRAE		
Other key sources	Crumley 2003, Brotnov 2003		
Principal contacts			
Notes			

H17 SOLAR PRE-HEATED VENTILATION AIR SYSTEMS (SOLARWALL™)

Description of Technology

A transpired solar collector is a vertical unglazed collector consisting of a perforated metal absorber that can be mounted to the exterior surface of a building. Air is heated by a thin stagnant air-film on the surface of the absorber and then drawn into the building ventilation system through 1/32" diameter holes spaced 1 cm apart. On a sunny day, the collector can raise the incoming air temperature by 30–50°F with an operating efficiency of up to 75%. The collector both pre-heats incoming ventilation air and eliminates heat loss through the portion of the building shell covered by the collector. During cooling season, ventilation air is drawn directly from outside through a bypass damper and heated air in the collector is rejected through vents at the top of the collector plenum.

Current Status of Measure

Conserval Engineering currently manufactures a transpired solar collector called SolarWall, which has been used on many building types including warehouses, industrial buildings, and multifamily high-rises. They also have a large international market, including those who use the collectors for crop drying. In warehouses and industrial buildings, the collectors provide a separate outside air supply through diffusers such as a bag duct. For multifamily buildings, the collectors provide tempered outside air to pressurize hallways. Although not emphasized, the collectors can also be used in residential situations where outside ventilation air is required. The heated air can be delivered directly into a space or can supply a heat recovery ventilator or furnace.

The metal absorber is manufactured in either steel or aluminum with a dark colored coating, typically a polyvinyl fluoride such as Kynar, used for standing seam metal roofs. There were initial concerns regarding corrosion in the steel absorber. However, after six years of exposure there has been no sign of corrosion, perhaps due to the drying effect of the air as it is drawn through the holes (Nadel and others 1998). Although the dark color of the collectors can be acceptable as replacement for industrial and warehouse wall cladding, the integration of a large area of dark metal into a commercial facade can be problematic.

Energy Savings and Costs

SolarWall panels cost \$3 per ft^2 for steel and \$4 per ft^2 for aluminum. With fans, ducts, and controls the installed cost is on the order of \$12 per ft^2 (Hollick 2003). The incremental cost can be lower if the collectors are installed in lieu of an expensive cladding. In retrofit situations the collector can protect aging cladding such as brick or stucco. Each square foot of collector can deliver 1–7 cfm of preheated air depending on the air temperature rise desired. Annual savings are estimated by the manufacturer at 2 to 4 therms per ft^2 (Hollick 2003), but will vary with climate.

Key Assumptions Used in Analysis

The key assumption used in this analysis was an average annual savings estimate of 3 therms/ft^2. It was also assumed that many more industrial buildings (warehouses, manufacturing facilities) than commercial buildings could use the thermal solar cladding due to the absence of windows and less of concern for aesthetic appearance.

Recommended Next Steps

Although SolarWall offers significant savings potential in cold climates, there are significant aesthetic issues and complications involved with integrating SolarWall with the HVAC control system. Mechanical designers need to be educated on how best to optimize control of the SolarWall with the existing mechanical system. Improved design assistance and additional monitored demonstration projects are needed to develop a better understanding of system performance.

H17 Solar Pre-heated Ventilation Air Systems (SolarWall™)

Description	Solar pre-heating of commercial building ventilation air.		
Market Information:			
Market sector	COM		
End-use(s)	HEAT		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	50,000		ft2 office
Efficiency			
Electric use	N/A	kWh/year	
Summer peak demand	NA	kW	
Winter peak demand	NA	kW	
Gas/fuel use	1,430		28.6 kBTU/sqft (natl avg)
New Measure Information:			
Description	2000 ft2 transpired solar collector		
Efficiency	75%	Solar collection efficiency	
Electric use	N/A	kWh/year	
Summer peak demand	0	kW	
Winter peak demand	0	kW	
Gas/Fuel use	830		
Current status	COMM		
Date of commercialization	1994		
Life	20	years	
Savings Information:			
Electricity	0	kWh/year	
Summer peak demand	N/A	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	600	MMBTU/year	
Percent savings	42%		
Feasible applications	8%		50% industrial, 5% other commercial, northern climates
2020 Savings potential	191	GWh	
2020 Savings potential	9	TBtu (source)	new construction
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$18,000	2003 $	$9 /ft2 incremental cost
Other cost/(savings)		$/year	
Cost of saved energy	NA	$/kWh	
Cost of saved energy	$2.41	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Building community not familiar with product, aesthetics, complexities		
Effect on utility	None		
Current promotion activity	10% federal tax rebate		
Rating	3	(1-5)	Requires changes in practices by architects and engineers
Rationale	Although product technology is mature, not typically on the radar screen		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Education of building community and designers; need to sreamline HVAC integration.		
Sources:			
Savings	Hollick 2003		
Peak demand	N/A		
Cost	Hollick 2003		
Feasible applications	DEG Estimate		
Measure life	Hollick 2003		
Other key sources	DSIRE 2003		
Principal contacts	John Hollick, Conserval Engineering, Inc., 416-661-7057, www.solarwall.com		
Notes			

H18 VENTILATION CONTROLLED BY IAQ SENSORS

Description of Technology

Since 1916, CO_2 level controls have been recommended to ensure sufficient ventilation in buildings, but it wasn't until the late 1990s that an accurate, reliable, and affordable CO_2 sensor was developed for integration with zoned commercial HVAC systems. By 2000, some manufacturers' controller product lines were 100% compatible with demand-controlled ventilation (DCV). Using CO_2 to trigger ventilation in areas of commercial buildings where significant occupancy fluctuations occur can result in significant fan energy and ventilation load savings over standard "cfm/occupant" (or per ft^2) sizing rules. The standard method involves estimating the number of occupants, usually the maximum, and constantly supplying an amount of ventilation air sufficient for maximum occupation, regardless of the actual occupation at any given time. DCV only operates when CO_2 levels indicate ventilation is needed, adapting to the occupancy of critical areas, such as conference rooms, board rooms, cafeterias, and other spaces with changing occupancy. ASHRAE 62-2000 allows this method of ventilation control.

Current Status of Measure

Major manufacturers of commercial HVAC control systems supply CO_2 controls as an option to their standard product line. There has recently been an upsurge in adoption of this technology partly due to the increased interest in indoor air quality and a resulting increase in fan energy use. Once design engineers are educated on the potential benefits of this technology, market penetration should increase rapidly.

Energy Savings and Costs

A DCV system can save 100% of the energy used for ventilation of a underused space anytime that space is not being used and will always be saving energy anytime the space has less than the design occupancy present. One manufacturer estimated that converting critical spaces to DCV could save 20–30% (Shaw 2003) of the overall ventilation air energy use. The cost for adding this functionality is approximately $575 per zone (CEC 2002).

Key Assumptions Used in Analysis

A 50,000 ft^2, two-story office building with 6 control points was assumed for the analysis. A 20% ventilation energy savings was assumed at a cost of $575 per control point.

Recommended Next Steps

The key barrier to increased use of CO_2 controls is perceived complexity and concern about reliability among designers, architects, and building owners. The technology has proven to be increasingly robust and increased visibility and case studies will further support the technology. Recommended next steps include introducing the technology to design engineers and local building jurisdictions. Monitoring studies documenting savings could be used to develop case studies on the performance of CO_2 control.

H18 Ventilation Controlled by IAQ

Description	Utilizing CO2 to control outdoor air ventilation rate		
Market Information:			
Market sector	COM		
End-use(s)	VENT		
Energy types	ALL		
Market segment	NEW,ROB		
Basecase Information:			
Description	50,000		ft2 office building, standard ventilation
Efficiency	0.8	Energy Databook national avg vent EUI (kWh/yr-ft2)	
Electric use	40,000	kWh/year	ventilation energy
Summer peak demand	16	kW	
Winter peak demand	16	kW	
Gas/fuel use	214.5		Energy Databook (ventilation contribution to annual heating)
New Measure Information:			
Description	50,000		ft2 office building with CO2 control in six key zones
Efficiency	0.64	20% savings	
Electric use	32,000	kWh/year	
Summer peak demand	15.2	kW	Peak Demand
Winter peak demand	15.2	kW	Peak Demand
Gas/Fuel use	171.6		
Current status	COMM		
Date of commercialization	2000		
Life	15	years	
Savings Information:			
Electricity	8,000	kWh/year	
Summer peak demand	0.8	kW	Peak Demand
Winter peak demand	0.8	kW	Peak Demand
Gas/Fuel	42.9	MMBTU/year	
Percent savings	13%		
Feasible applications	54%		90% of larger (60%) cooling units
2020 Savings potential	4,002	GWh	
2020 Savings potential	163	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$3,450	2003 $	Six zones at $575 per zone for controls/installation
Other cost/(savings)		$/year	
Cost of saved energy	$0.03	$/kWh	
Cost of saved energy	$2.69	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Unfamiliar in the design community, perceived complexity, cost		
Effect on utility			
Current promotion activity	Presentations to engineers		
Rating	4	(1-5)	
Rationale	Technology is available and proven		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Education, incentives		
Sources:			
Savings	Shaw 2003		
Peak demand	DEG estimate		Derived from annual usage and operating hours
Cost	CEC 2002		
Feasible applications	DEG estimate, AEC 2001		
Measure life	Shaw 2003		
Other key sources	Lauria 1998, Shell,Turner and Shim 1998		
Principal contacts	Jonathan Shaw, Carrier Corp (315-432-3147)		
Notes			

H19 UNDERFLOOR VENTILATION WITH LOW STATIC PRESSURE

Description of Technology

Displacement ventilation is a process by which air (usually 100% outdoor air) is introduced under the floor, or at floor level, at a low velocity and at a temperature just slightly lower than the desired room temperature. Occupants, office equipment, and external cooling loads then warm the air. The buoyancy of the warmed air causes it to rise, where it is removed through a ceiling-mounted exhaust grill. The warm air carries the CO_2 and other contaminants away from the occupants and is replaced by the freshly supplied cool air. There are many benefits to this type of system, including IAQ improvement (with 100% outside air) and energy savings from reduced fan energy and higher supply air temperature. This technology has been in use for decades in Europe, especially Scandinavia, but is still not widely seen in the United States or Canada.

Current Status of Measure

Displacement ventilation is often assumed to be synonymous with underfloor ventilation, which has been gaining popularity due to its zoning flexibility. However, most U.S. underfloor systems still use induction rather than displacement ventilation. Several projects have been constructed both in the Northeast and the Southwest as early as 1995 and have been considered a great success. Currently there are several manufacturers promoting displacement ventilation in the United States, and the design practice is gaining increased interest based on expected energy savings. PIER is funding a project on design guidelines in California schools with Architectural Energy Corporation and the Halton Company (Stubee 2004).

Energy Savings and Costs

Energy savings from displacement ventilation vary greatly and are highly dependant on climate, building type, occupancy characteristics, and system design. The performance of displacement ventilation was compared to conventional VAV systems using DOE-2 for four California locations, with projected savings found to vary from 29 to 57% (Bourassa et al. 2002). Other studies found the energy savings to be between 10 and 30% (Hensen and Hamelinck 1995) and 20–35% (Loftness et al. 2002). Available cost comparisons indicate equal or lower first cost for displacement ventilation system relative to conventional system designs (Loftness et al. 2002). Additional cost and performance data are needed to better understand the performance and economics of these systems.

Key Assumptions Used in Analysis

The building used in the Bourassa et al. (2002) modeling study was very generic and did not take into consideration isolating designs appropriate for displacement ventilation, nor were any locations outside of California studied. A classroom was chosen since the first of these systems in the United States went into classrooms. Based on the prior modeling studies, a conservative savings estimate of 20% was assumed for our analysis. Zero incremental cost was assumed for the displacement ventilation system, based on available data.

Recommended Next Steps

The principal barriers are lack of information and inertia. For example, owners may not understand the marketing advantages of easy reconfiguration. Education is needed to familiarize architects and design professionals with the benefits and design constraints of displacement ventilation. At least in California, current performance-based energy codes do not provide incentive to design underfloor systems because the code compliance methods do not properly account for the energy savings of these systems (Stubee 2004). ASHRAE is expected to release a design guide for displacement ventilation in 2004, which will assist mechanical designers (Bauman 2003). Additional monitoring of installations and development of case studies would help document the cost and performance of the technology. Utilities can assist in supporting demonstration projects and providing incentives.

H19 Underfloor Ventilation with Low Static Pressure

Description	Low-velocity air distributed via under-floor plenums with ceiling returns		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	50,000		sqft conventional VAV office building
Efficiency	10.3	EER	
Electric use	128,919	kWh/year	Energy Databook (national avg cooling and ventilation)
Summer peak demand	67	kW	22% load factor
Winter peak demand	7	kW	Fans only
Gas/fuel use	NA		
New Measure Information:			
Description	50,000		sqft displacment ventilated office
Efficiency	N/A		
Electric use	103,135	kWh/year	
Summer peak demand	54	kW	
Winter peak demand	6	kW	
Gas/Fuel use	NA		
Current status	COMM		
Date of commercialization	1995		
Life	15	years	
Savings Information:			
Electricity	25,784	kWh/year	
Summer peak demand	13	kW	
Winter peak demand	1	kW	
Gas/Fuel	NA	MMBTU/year	
Percent savings	20%		
Feasible applications	22%		Fraction of larger office & education.
2020 Savings potential	1,096	GWh	
2020 Savings potential	11	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0	2003 $	limited available data suggest no incremental cost
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.00	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Engineers unfamiliar with concept , negative perceptions		
Effect on utility	May increase amenity, decrease sound, provides flexibility in zoning		
Current promotion activity	Manufacturers of equipment are advertising at trade shows and conferences.		
Rating	3	(1-5)	
Rationale	Potential for non-energy cost savings		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Educate engineers and architects, design assistance, demonstration projects		
Sources:			
Savings	Bourassa, Haves, and Huang 2002, HBI 2001, Hensen and Hamelinck 1995		
Peak demand	Bourassa, Haves, and Huang 2002; Brown and Koomey 2002		
Cost	Glicksman (MIT) 2003		
Feasible applications	DEG estimate		
Measure life	Glicksman (MIT) 2003		
Other key sources	Glicksman (MIT) 2003		
Principal contacts	Glicksman, MIT (617-253-2233)		
Notes			

H20 ADVANCED CONDENSING BOILERS (COMMERCIAL)

Introduction and Description of Measure

Commercial gas boilers (larger than 300,000 Btuh) are used in larger buildings. Applications include perimeter radiative heating, reheat for air-conditioning humidity control, and general space heating with forced air or hydronic systems. The maximum steady-state efficiency of conventional gas boilers is about 83%, to allow enough heat to escape to support gravity venting and to avoid local condensation that would cause corrosion problems. In contrast, condensing boilers are built of corrosion-resistant materials and designed to utilize energy from condensing water vapor in the exhaust gases. This requires a heat sink (returning water) less than 140ºF—preferably less than 120ºF. In turn, this requires controls (and often an operating sequence) designed for low-temperature operation whenever possible. Most condensing boilers of 500,000 Btuh capacity and above have modulating outputs. Some residential boilers are used as "lead" boilers in smaller commercial boiler trains that may have up to 10 units (one or two condensing boilers, the rest non-condensing for winter conditions). In multi-boiler applications, outdoor temperature reset is used to reduce capacity and distribution loop temperature in mild weather, so the unit has as much latent heat recovery capacity as possible. As outdoor temperatures fall, supply temperatures must rise to meet heat losses; when the boiler no longer condenses, the system will dispatch a non-condensing boiler or let the condensing boiler lapse into non-condensing mode. The technology does not include oil-fired equipment.

Current Status of the Measure

At least six brands (33 models) of commercial-scale condensing boilers were available in 2001 (CEE 2001), in sizes ranging from 300,000 to 3.3 million Btuh. CEE (2001) estimated that commercial and residential condensing boilers were about 2% of their respective markets, at 750 +/- 250 and 7,000 +/- 700 units, respectively. The total stock of gas-supplied commercial buildings larger than 5,000 ft^2 and equipped with boilers is only about 132,000 units, or 3% of the total stock of commercial buildings and 6% of the gas-supplied commercial buildings (from data in CBECS 2002).

Available Information on Measure Savings and Costs

Commercial-scale condensing boilers may cost up to three times as much as baseline non-condensing models (CEE 2001). On the other hand, as components of systems the incremental cost is lower, 19% and 23% in two case studies (CEE 2001). High performance requires using effective controls.

Key Assumptions Used in the Analysis

We assume the same life expectancy as for steel water tube boilers (ASHRAE 2003). Costs and savings based on high school retrofit case study in CEE (2001). We assume that the median installation has 2.5 boilers, so that 40% could be selected as "lead" condensing boilers.

Recommended Next Steps

The principal barrier is the small number of larger buildings that use boilers for heat. This limits the market and assures high prices from low volume. Another barrier is that many older systems use steam and lack distribution capacity for hot water conversion. The secondary barriers are lack of awareness and the skills required to design the system to optimize performance. CEE (2001) concluded that programs for market transformation are most likely to succeed in the Northeast and Midwest (cold climates and common hydronic systems) and that schools and federal facilities that look at life-cycle economics are the most likely market segments. Additional technical and marketing information and also training for system designers are likely to increase technology uptake rate.

H20 Advanced Condensing Boilers (Commercial)

Description	Condensing Commercial Boilers (>300MBtuh) that recover latent heat of combustion		
Market Information:			
Market sector	COM		
End-use(s)	WSH		
Energy types	GAS		
Market segment	NEW, RET		ROB unlikely (system implications); retrofit happening in NE
Basecase Information:			
Description	3 conventional @ ~ 11.5MMBtuh each, Waltham HS Case Study in CEE 2001		
Efficiency	68%	Imputed from seasonal consumption in CEE 2001	
Electric use	77,000	kWh/year	if 1% (site) of gas energy used
Summer peak demand	21	kW	estimate (inducer, circulator, controls) for service hot water
Winter peak demand	105	kW	estimate, probably early morning warm-up
Gas/fuel use	26,267		CEE 2001; Waltham HS Case Study
New Measure Information:			
Description	5 condensing @ 2.0 MMBtuh each, Waltham HS Case Study in CEE 2001		
Efficiency	90%	CEE 2001; minimum. Max. = 97%	
Electric use	57,900	kWh/year	if 1% (site) of gas energy used
Summer peak demand	6	kW	estimate (inducer, circulator, controls) for service hot water
Winter peak demand	32	kW	estimate, probably early morning warm-up
Gas/Fuel use	19,759		CEE 2001; Waltham HS Case Study
Current status			COMM
Date of commercialization	1985		Est., common in Europe, too.
Life	24	years	ASHRAE 2002, steel boilers as proxy for condensing.
Savings Information:			
Electricity	19,100	kWh/year	estimated
Summer peak demand	15	kW	estimated
Winter peak demand	73	kW	estimated
Gas/Fuel	6,508	MMBTU/year	Waltham HS Case Study in CEE 2001
Percent savings	33%		
Feasible applications	11%		fraction of htd. Comm. buildings >5000 ft.sq. with gas boilers
2020 Savings potential	0.2	GWh	1% of national gas
2020 Savings potential	23	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$57,565	2003 $	Waltham HS retrofit (system-basis, boiler alone not available)
Other cost/(savings)		$/year	
Cost of saved energy	$0.01	$/kWh	
Cost of saved energy	$0.62	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	First cost, lack of information infrastructure		
Effect on utility	Improved, by modulating terminal unit temperature, less overheating		
Current promotion activity	Manufacturers, some utility help (MA)		
Rating	3	(1-5)	
Rationale	Large manufacturers are involved, gas prices are escalating		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Market Transformation for Midwest and NE school and federal; new and retrofit		
Sources:			
Savings	CEE 2001		
Peak demand	extrapolated from gas/electricity ratio		
Cost	CEE 2001		
Feasible applications	CBECS 1999, Table B21 source for calculations		
Measure life	ASHRAE 2003. Handbook, Applications, Steel water-tube boilers as proxy		
Other key sources	Manufacturers.		
Principal contacts	Harvey Sachs, ACEEE, 202-429-8873x706		
Notes	Winter peak roughly estimated, summer peak very small.		

L1 HIGH EFFICIENCY PREMIUM T8 LIGHTING (100 LUMENS/WATT)

Description of Technology

T8 electronic ballasts and lamps were introduced in the early 1980s with the promise of significantly reducing lighting energy use in commercial and institutional buildings. Since that time, manufacturers have continuously improved T8 performance, particularly with regard to reliability and features. At the same time, the product cost has decreased. However, system efficacy has remained at 85 to 88 lumens/Watt for a typical system consisting of F32T8 lamps with instant start ballasts (NLPIP 2000). The recent emergence of high efficacy Super T8 lighting systems marks real improvement when compared with generic T8s and particularly with the T12 lighting systems that were estimated to account for 75% of the U.S. commercial fluorescent lighting energy use as late as 2000 (DOE 2002b).

Current Status of Measure

In 2002, both GE Lighting and Osram Sylvania introduced Super T8 lighting systems with a claimed system efficacy of about 100 lumens/Watt; Phillips now has systems too. Ballasts are available in both 120V and 277V and will soon be available in 347V for the Canadian market. Additional advantages over standard T8 systems include higher lamp lumen maintenance and, if long-life products are selected, an extended lamp life of up to 30,000 hours vs. the standard 20,000 hours. Savings are achieved through delamping, using low ballast-factor ballasts, or through installation of fewer fixtures. Otherwise the high efficacy systems will use the same amount of energy as the conventional T8 systems, while producing a higher lighting level. Super T8s were introduced after the 1998 ET study, but have already reached market penetration well beyond 2% (Sardinsky and Benya 2003), so they are no longer emerging technologies. Thus, the super T8 is not included in our statistics. This summary is kept because many are unaware of the products and their potential.

Energy Savings and Costs

Super T8 systems (lamp and ballast) can show up to 81% improvements in efficacy (lumens/Watt) relative to T12s and 31% relative to generic T8s (Sardinsky and Benya 2003). However, the wide range of applications discussed above means that actual energy savings are generally more modest, in the range of 15–20% relative to standard T8 systems (Thorne and Nadel 2003), implying roughly 27–36% relative to older T-12s. U.S. incremental costs are in the range of $1/bulb and $1 to $5 for the best ballasts (Sardinsky and Benya 2003).

Key Assumptions Used in Analysis

We consider the Super T8 for both new construction and retrofit applications assuming a two-lamp fixture with an operation of 3,400 hrs/year (DOE 2002b). For new construction, the Super T8 fixture is assessed against a two-lamp F32T8 fixture with an instant start ballast with an incremental material cost of $5/fixture and a 20-year life. For a retrofit, the Super T8 fixture is assessed against a T12 fixture and a full cost of $36/fixture (for ballasts and lamps, but not the fixture itself) including labor and material.

Recommended Next Steps

The main barriers to the adoption of Super T8 fluorescent lighting system are lack of awareness by end-users, confusion over similar-sounding options, and incremental cost over standard T8 fluorescent lighting. Awareness of the benefits of Super T-8 systems relative to generics is much lower, however. Collaborative promotion and awareness generation by government, utilities, and trade allies is necessary to make the Super T8 lighting fixture the preferred choice in the market. In particular, awareness is necessary of the need to use low BF ballasts or otherwise adjust the for higher-light output. End-user and trade ally education efforts, as well as limited financial incentives, may be needed for a few years until the market takes off.

L1 High Efficacy Premium T8 Lighting (100 Lumens/W)

Description	Super T8 lighting product that offers maximum efficacy and increased lamp life		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	2 Lamp F32T8 fixture with instant start electronic ballast BF 0.9		
Efficiency	60	Watts/fixture	
Electric use	216	kWh/year	3600 hrs - DOE ballast TSD
Summer peak demand	0.050	kW	
Winter peak demand	0.044	kW	
Gas/fuel use			
New Measure Information:			
Description	2 Lamp F32T8 XGEN fixture with 30,000 hrs. "super" lamps, BF of .78		
Efficiency	48	Watts/fixture	
Electric use	173	kWh/year	
Summer peak demand	0.040	kW	
Winter peak demand	0.036	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2002		
Life	15	years	for ballast
Savings Information:			
Electricity	43	kWh/year	
Summer peak demand	0.010	kW	
Winter peak demand	0.009	kW	
Gas/Fuel		MMBTU/year	
Percent savings	20%		
Feasible applications	85%		of commercial fluorescent lighting applications.
2020 Savings potential	34,430	GWh	
2020 Savings potential	348	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$5	2003 $	Current cost, will decline. (Marbek)
Other cost/(savings)	($0.12)	$/year	lamp savings
Cost of saved energy	$0.009	$/kWh	
Cost of saved energy	$0.91	$/MMBtu	
Data quality assessment	A	(A-D)	
Likelihood of Success:			
Major market barriers	Incremental price over standard T8 lighting, most users not familiar with product		
Effect on utility	Improved lighting quality, longer lamp life		
Current promotion activity	Some utilities are promoting technology		
Rating	4	(1-5)	
Rationale	Very cost-effective which should help make this product the standard choice		
Priority / Next Steps			
Priority	Dropped: Market penetration > 2% Benya)		
Recommended next steps	Continued promotion, and education of contractors & users		
Sources:			
Savings	Sardinsky and Benya 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Manufacturer product information - don't we have info from Jim Benya too?		
Feasible applications	ACEEE Estimate		
Measure life	DOE ISD for ballast life		
Other key sources			
Principal contacts	Jim Benya, (503)519-9631, jbenya@benyalighting.com		
Notes			

L3 General Service Halogen IR Lamp

Description of Technology

Halogen infrared reflecting (HIR) lamps look like conventional incandescents but contain a tungsten halogen filament with a multi-layer film coating on the inside of the halogen capsule. The coating reflects infrared energy back onto the lamp filament, which makes the lamp burn hotter and in turn increases lamp efficacy. HIR lamps have been available for reflector lamps since the early 1990s and are now sold in sufficient quantities to no longer be considered an emerging technology in reflector-lamp applications. This analysis focuses on general service, screw-in, globular, HIR replacements for conventional A-lamp incandescent bulbs, which are appropriate in low to medium-use residential applications (higher-use applications should generally use CFLs).

Current Status of Measure

In the late 1990s, the U.S. Environmental Protection Agency and Department of Defense made informal offers to major manufacturers, such as General Electric, Osram Sylvania, and Philips, to manufacture the technology. However, the manufacturers showed little interest (Rubinstein 2003). The government agencies sent out a Request for Technical Proposal (RFTP) to manufacturers, but did not receive any serious bids. A European procurement initiative also did not result in any serious offers to develop the product. Osram Sylvania did eventually develop an HIR A-lamp, but has had difficulty selling the product. The lamps are priced at $6–7 each, significantly more than a typical incandescent, which sells for $1 or less. Sylvania has unsuccessfully marketed the product based on energy savings for direct replacement of high wattage lamps (Bockley 2003). General Electric has also developed HIR A-lamps, but it is uncertain if the company will proceed in commercializing the product in the near future. The large incremental cost (~$5.50/lamp) relative to incandescent lamps is a major concern for the company (Shepard 2003).

Energy Savings and Costs

This analysis assumes that the HIR A-lamps would be applicable in 100% of current low-use residential applications (i.e., less than 3 hours per day). Low-use applications represent 35% of residential lighting energy use (Vorsatz et al. 1997). In computing savings, Sylvania compared the energy use of HIR 60 Watt A-lamps to the energy use of standard 75 Watt incandescents. HIR 60 Watt A-lamps can provide 20–25 lumens per Watt, higher than most 75 Watt incandescents. Energy savings at 3 hr/day amount to 16 kWh/year when compared to a 75 Watt incandescent.

Key Assumptions Used in Analysis

General service HIR A-lamps were expected to be used in cases where CFLs would not be cost effective due to low operating hours. However, as CFLs become smaller and cheaper, they are becoming real alternatives to standard incandescent lamps, even for low-use applications. For the about the same price, one can buy a CFL that has twice the lumens/Watt and a longer life than a HIR A-lamp. HIR A-lamps face great challenges as prices for CFLs decline (Rubinstein 2003). For HIR A-lamps to compete, their costs will have to come down substantially, but manufacturers do not consider this likely.

Recommended Next Steps

At this time, manufacturers have little interest in pursuing this technology. As CFLs become more competitive with incandescent lamps, the business case for developing the technology is not very strong. We do not have any recommended next steps for this technology at this time.

L3 General service halogen IR reflecting lamp

Description	Screw-in lamp, IR coating reflects energy to filament; replaces incandescents			
Market Information:				
Market sector	RES			
End-use(s)	LIGHT			
Energy types	ELEC			
Market segment	NEW, ROB, RET			
Basecase Information:				
Description	Standard 75 Watt lamp			
Efficiency	75	watts, 15 LPW		
Electric use	82	kWh/year	3 hours/day	
Summer peak demand	0.005	kW		
Winter peak demand	0.015	kW		
Gas/fuel use				
New Measure Information:				
Description	Lamp with IR coating that reflects energy onto filament			
Efficiency	60	watts		
Electric use	66	kWh/year	3 hours/day	
Summer peak demand	0.004	kW		
Winter peak demand	0.012	kW		0.0348
Gas/Fuel use				
Current status	COMM		Carried in GE catalogue as "decorative,"	
Date of commercialization	ca. 2000		Because of CFL competition, mainstream unlikely	
Life	5	years	Estimated, based on Lighting Market Sourcebook 1997	
Savings Information:				
Electricity	16	kWh/year		
Summer peak demand	0.001	kW		
Winter peak demand	0.003	kW		
Gas/Fuel		MMBTU/year		
Percent savings	20%			
Feasible applications	12%		Low-medium level use in residential applications (< 3hrs/day)	
2020 Savings potential	7,356	GWh		
2020 Savings potential	74	TBtu (source)		
Industrial savings > 25%	NO			
Cost Information:				
Projected Incre. Retail Cost	$5.5	2003 $	HIR lamps are $6-7	
Other cost/(savings)	($1.00)	$/year	Less bulb changing	
Cost of saved energy	$0.025	$/kWh		
Cost of saved energy	$2.44	$/MMBtu		
Data quality assessment	B	(A-D)		
Likelihood of Success:				
Major market barriers	Current price is too costly; Prices have come down for CFLs, its competition			
Effect on utility	Less frequent bulb changing			
Current promotion activity	None			
Rating	2	(1-5)		
Rationale	High cost, competition with CFL			
Priority / Next Steps				
Priority	Low			
Recommended next steps	None			
Sources:				
Savings	Vorsatz et al 1997; DOE 2002			
Peak demand	HMG 1999, PGE 2000			
Cost	Vorsatz et al. 1997			
Feasible applications	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003			
Measure life	Vorsatz et al. 1997			
Other key sources	E-STAR; F Rubenstein, LBNL, 510-486-4096, E Bockley, Sylvania, 978-777-1900			
Principal contacts	Mark Shepard, GE 216-266-3595			
Notes	HIR lamps are appropriate in all low- and med-use residential applications where they can compete with CFLs.			

L4 COST-EFFECTIVE LOAD SHED BALLAST AND CONTROLLER

Description of Technology

This report focuses on devices that respond to utility peak demand reduction efforts, approximately 100 hours per year. Around 80% of dimming ballasts are instant-start, providing electrode-heating voltage during starting or operation (Bierman 2003; LRC 1999). The California Energy Commission's PIER Lighting Program is currently developing an instant-start ballast that would receive a signal from a controller to dim light fixtures during peak demand periods. The controller device would communicate with an outside source, such as a utility or customer energy management system, and then send the signal to the ballast to dim the lights.

Current Status of Measure

Several models of dimming ballasts are currently available. A laboratory prototype of a demand-limiting controller was to be completed in the fall of 2003, according to the Lighting Research Center (LRC), the manager for the PIER project (Bierman 2003). LRC has had discussions with OSRAM/Sylvania to manufacture a limited number of load shed ballasts for further tests and field demonstrations. However, the manufacturer has not committed to commercializing the product. LRC is also actively seeking a manufacturer for the control device that would work with the ballast and is now discussing the possibility with a New York State manufacturer. To facilitate manufacturers' acceptance of the technology, the New York State Energy Research and Development Authority (NYSERDA) has awarded a grant to develop the controller. NYSERDA is also providing funding for a demonstration project that will show how the dimming system works. LRC's goal is to have the ballast and controller system commercialized no later than 2008.

Energy Savings and Costs

An economic study performed by LRC estimates that the incremental cost of the load shed ballast and its accompanying controller is about $9 per lighting fixture relative to the cost of an instant start, non-dimming ballast (LRC 2003a). Each controller can send PLC (power line carrier) signals to ballasts located in a 10,000 square foot area. For new construction, no additional installation costs would be needed since the load shed ballast would simply replace the regular ballast found in the lighting fixture. LRC estimates a simple payback to the customer of 2.57 years for new construction. However, payback years will depend on local utility rate structure and the customer's use of dimming. As a pure peak-shaving measure, it would save virtually no energy, leading to a CSE of $0.43/kWh. We recommend that the peak shaving feature be combined with other aspects of dimming control (e.g., daylighting) to share its costs across both energy and demand.

Key Assumptions Used in Analysis

In this analysis, we assumed that the technology would be applied to assembly, classrooms, dining, and office areas. Feasible applications are 80% of these spaces in the commercial sector. The LRC study assumed that the lamps would be dimmed by about 30% for 100 hours per year during peak demand periods in the summer time (LRC 2003a). When using a standard two-lamp T8 fluorescent fixture with electronic ballast, LRC estimates a 20 Watt demand reduction during peak. We implicitly assume that the devices operate in parallel with customer controls such as daylighting, with utility-required dimming having priority.

Recommended Next Steps

Further commitment from manufacturers is needed to commercialize the product. A NYSERDA-funded demonstration project will show building owners and lighting designers to learn more about the product. Workshops and seminars directed to decision makers would also help. Both utilities and customers can benefit from the technology through reduced cost for peak electricity. Analysis by LRC (2003a) suggested that the new construction version is cost effective through demand reduction for California utilities. From this we infer that incentives would be very effective in transforming the market.

L4 Cost Effective Load Shed Ballast and Controller

Description	Step dimming ballast that can receive a signal to dim during times of peak demand.		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	General purpose recessed lensed fixture w/ 2 T8 lamps		
Efficiency	60	watts total - 2 32Watt lamps w/ electronic ballast	
Electric use	249.6	kWh/year	kwh/yr assuming 4160 hrs (16 hrs/day-5 days/wk/52 wks)
Summer peak demand	0.050	kW	PGE 2000
Winter peak demand	0.044	kW	PGE 2000
Gas/fuel use			
New Measure Information:			
Description	T8 lamps with load shed ballast dimmed at 30%, 100 hrs/year		
Efficiency	60	watts total - 2 32Watt lamps w/ electronic ballast	
Electric use	247.6	kWh/year	kWh, 20W estimated demand reduction, 100 peak hrs/yr, dimmed to 30%
Summer peak demand	0.050	kW	PGE 2000, with coincidence
Winter peak demand	0.044	kW	PGE 2000, with coincidence
Gas/Fuel use			
Current status	PROTO		
Date of commercialization	2008		
Life	15	years	
Savings Information:			
Electricity	2	kWh/year	
Summer peak demand	0.000	kW	
Winter peak demand	0.000	kW	
Gas/Fuel		MMBTU/year	
Percent savings	1%		
Feasible applications	31%		Assembly, classroom, dining, & office commercial spaces
2020 Savings potential	109	GWh	
2020 Savings potential	1	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$9	2003 $	per 2-lamp fixture including ballast & controller
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.434	$/kWh	But will be marketed based on peak demand savings
Cost of saved energy	$42.93	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Utility and manufacturer commitment; Difficulty ascertaining non-energy benefits; high cost		
Effect on utility	Should not affect worker productivity		
Current promotion activity	Developing demo projects; PIER Lighting Program/LRC initiatives		
Rating	3	(1-5)	
Rationale	Program receiving support from manufacturers & NYSERDA		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Get manufacturer commitment; Educate building designers; Utilities offer incentives		
Sources:			
Savings	LRC 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	LRC 2003		
Feasible applications	DOE 2002, LRC 2003		
Measure life	Vorsatz et al 1997		
Other key sources	DOE 2002		
Principal contacts	A. Bierman, LRC, 518-687-7128; J. Porter, PIER (Architectural Energy), 800.450.4454		
Notes	Ballast targets peak demand only, reducing output 30-50% for a short period of time. Could work with other daylighting controls to reduce peak demand during the day, but not current focus (Bierman 2003)		

L5 ADVANCED/INTEGRATED DAYLIGHTING CONTROLS (ADCS)

Description of Technology

In most office spaces, lighting has traditionally been designed to provide equal amount of light for all occupant spaces. However, lighting may not be needed in all spaces; part-time occupancy and daylight may eliminate lighting needs. Individual workers needs and expectations also vary. New lighting control products allow individuals more flexibility in setting light levels for their spaces. Most allow workers to change lighting levels using their computers or remote control devices. Four models of advanced daylighting controls are currently available in North America: the Ergolight by Ledalite, which uses PC screens; the PerSONNA by Lutron, which works with a handheld device; LightBug by StarField Controls, which uses a direct-wired desktop dimmer; and the IRC 1000 by the Watt Stopper, which can be operated with a handheld remote control (Krepchin and Stein 2000). The Lighting Research Center has also developed a prototype of a self-commissioning photosensor and control device and is now seeking a partner to commercialize the product (LRC 2004). WattStopper is developing a self-commissioning photosensor through a PIER project (Stubee 2004).

Current Status of Measure

ADCs have been installed in large offices around the country. LRC has installed the self-commissioning photosensor and control device in private offices in Connecticut and plans to monitor the sites for six months. LRC also monitored Ergolights in New York (Stubee 2004). In a study done in offices at the National Center for Atmospheric Research (NCAR), most workers preferred the model used with desktop computers, such as Ledalite's Ergolight (Krepchin and Stein 2003). Ledalite has seen increases in the number of units sold in the last few years. The company now has more than 10,000 Ergolights in various locations. The World Resources Institute installed Ergolight in 140 individual workstations in Washington, D.C. with positive results (Krepchin and Stein 2000). BC Hydro also installed 195 Ergolight systems at one of their facilities. The British Columbia utility company is now seeing monthly savings of 65–80% (Campbell 2002). At its facility in Tewskbury, Massachusetts, Raytheon Company replaced 697 fixtures (combination of two-lamp and four-lamp T12s) with 503 Ergolights and has seen similar savings. Raytheon has since added more units and now has about 3,000 of the fixtures. Ledalite will be releasing a new version of the Ergolight in the near future.

Energy Savings and Costs

ADCs cost $125 to $400 per unit, depending on available features. Fully integrated systems with occupancy sensors, such as Ergolight, cost around $400 or $2–3/ft^2. As the volume of sales increase, these prices will likely come down. Standard T8 lamps cost around $1.75/ft^2 to install. For this analysis, we estimated that the incremental cost for the user is about 50¢/ft^2 over a standard T8 fixture. Compared to using standard T8 lamps, we compute energy savings of 46%.

Key Assumptions Used in Analysis

ADCs have been used in office workstations, private offices, conference rooms, classrooms, and hospitals. Together, these commercial spaces account for approximately 26% of lighting energy consumed in this sector (DOE 2002b). For this analysis, we estimate that feasible applications are two-thirds of this total.

Recommended Next Steps

Principal barriers include difficulty in predicting energy savings (Krepchin and Stein 2000) and relatively high costs. Even with large energy savings, simple payback period could be up to 14 years, an unacceptable time frame for most organizations (Krepchin and Stein 2000). Increased productivity and other non-energy benefits are the more likely motivation for businesses that are considering ADCs. Measuring productivity improvements would, if feasible, improve the value proposition. We recommend that such studies be attempted. If the results are favorable, employers, building owners, lighting designers, and other building professionals would need to trained and educated about these benefits. Some good case studies need to be developed and presented to these groups.

L5 Advanced/Integrated Daylighting Controls (ADCs)

Description	Improved combination occupancy-sensing, daylight-sensing & dimming		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	General purpose recessed lensed fixture w/ 2 T8 lamps w/ electronic ballast		
Efficiency	0.92	watts per sq ft.	
Electric use	3.8	kWh/year	kwh/yr/sq.ft. assuming 4160 hrs (16 hrs/day-5 days/week)
Summer peak demand	0.001	kW	per sq.ft, PGE 2000
Winter peak demand	0.003	kW	per sq.ft, PGE 2000
Gas/fuel use			
New Measure Information:			
Description	Advanced/integrated lighting control w/ occupancy & daylight sensors		
Efficiency	0.5	watts per sq. ft.	
Electric use	2.1	kWh/year	kwh/yr/sq.ft. assuming 4160 hrs (12 hrs/day-5 days/week)
Summer peak demand	0.0005	kW	per sq ft, PGE 2000, with coincidence
Winter peak demand	0.0005	kW	per sq ft, PGE 2000, with coincidence
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2003		
Life	20	years	
Savings Information:			
Electricity	1.7	kWh/year	per sq. ft.
Summer peak demand	0.000	kW	
Winter peak demand	0.003	kW	
Gas/Fuel		MMBTU/year	
Percent savings	46%		
Feasible applications	35%		2/3 of lighting -classroom, retail, healthcare, & office
2020 Savings potential	7,936	GWh	
2020 Savings potential	80	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0.50	2003 $	per sf
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.023	$/kWh	
Cost of saved energy	$2.27	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Education; Incremental cost; Benefits are largely non-energy related		
Effect on utility	Increased occupant comfort and flexibility w/ lighting scenarios		
Current promotion activity	Demonstration cases; some utility incentives		
Rating	3	(1-5)	
Rationale	Takes time for benefits to be appreciated.		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Case studies on employee productivity with dimming controls; utility incentives		
Sources:			
Savings	Marbek 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Marbek 2003		
Feasible applications	DOE 2002		
Measure life	Marbek Resource Consultants estimate		
Other key sources	Krepchin and Stein 2000		
Principal contacts	Ron Scott, Ledalite, 604-888-6811 x405, Guliano Todesco, Marbek 613-523-0784		
Notes			

L6 LOW WATTAGE CERAMIC METAL HALIDE LAMP

Description of Technology

Advances in metal halide (MH) lamp technology have led to the production of ceramic metal halide (CMH) lamps that use ceramic rather than quartz arc tubes typical of most MH lamps. Ceramic arc tubes can tolerate a higher temperature than quartz, resulting in improved color rendering and color temperature and the warm tones desired in retail and other color-sensitive applications. Furthermore, CMH lamps can provide the concentrated beams required for accent lighting both in retail and other architectural applications. CMH lamps represent an attractive alternative to the halogen PAR lamps commonly used in these applications because they have a much longer life and use just half of the energy.

Current Status of Measure

All major lamp manufacturers currently offer CMH lamps in the 39 to 400W range. CMH lamps are most common in wattages of 39 to 150W. A 39W CMH lamp produces 2,200–2,400 lumens, a higher output than both the 100W halogen-infrared PAR lamps (2,070 lumens) and the 100W halogen PAR lamps (1,400 lumens) typically used in retail and other commercial applications. Unlike halogen sources, CMH lamps require a ballast to operate.

Energy Savings and Costs

CMH lamp systems use less than half the energy of HIR PAR lamps to produce a similar light output. In addition to energy savings, CMHs last three to four times as long as halogen-IR PAR lamps (9,000 to 12,000 hours versus 3,000 hours) and can reduce the number of fixtures required to illuminate a space. In a typical retail application, replacement of each 100W halogen-IR PAR lamp with a 39W ceramic metal halide (lamp plus ballast uses 44W) saves roughly 225 kWh per year. For retrofits, current costs are approximately $175 per fixture including lamp, fixture, and ballast costs. However, in many cases—particularly where halogen PAR lamps have not been upgraded to halogen-IR—fewer than one-to-one fixture replacements are required, reducing the overall retrofit project costs. For new construction and remodeling projects, the current incremental cost relative to halogen-IR lamps is approximately $140 (Thorne and Nadel 2003a).

Key Assumptions Used in Analysis

For this analysis, we estimate energy savings for replacement of a 100W halogen-IR lamp with a 39W CMH lamp system. According to DOE (2002b), operating hours for lighting in retail applications total roughly 4,000 hours per year and approximately 32% of retail lighting energy is consumed by incandescent light sources. Additional savings opportunities exist in other color-sensitive environments such as museums. We assume future incremental costs of one-half the current costs as the technology matures and adoption increases.

Recommended Next Steps

The major barriers to greater adoption of CMH lamp technology are high first costs; limited experience with the technology resulting in uncertainty regarding lamp performance; and unawareness of the technology among end-users, lighting suppliers, and contractors that specify lighting in many retail applications. We recommend greater documentation of in-field performance through demonstrations and development of case studies. Additional educational materials to illustrate the benefits of the technology in specific applications would also be of use—this has proven a successful strategy for other new lighting technologies. Finally, targeted incentives to help lower first costs could increase adoption, build the market, and result in overall price declines.

L6 Low Wattage Ceramic Metal Halide Lamps

Description	Low-wattage replacements for halogen lamps in retail applications		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	100W Halogen-IR PAR lamp		
Efficiency	100		
Electric use	402	kWh/year	assumes 11 hours/day or 4015 hours/year (DOE 2002)
Summer peak demand	392	kW	
Winter peak demand	392	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	39W Ceramic metal halide lamp		
Efficiency	44	lamp plus ballast	
Electric use	177	kWh/year	assumes 11 hours/day or 4015 hours/year (DOE 2002)
Summer peak demand	173	kW	
Winter peak demand	173	kW	
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	2000		
Life	7	years	Typical life of retail lighting system
Savings Information:			
Electricity	225	kWh/year	
Summer peak demand	220	kW	
Winter peak demand	220	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	56%		
Feasible applications	6%		PAR lamps are 10% of comm'l ltg; CMH can replace 60%
2020 Savings potential	12,861	GWh	
2020 Savings potential	130	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$90	2003 $	incr. cost lamp (2), fixture, ballast
Other cost/(savings)	($13)	$/year	longer life reduces maintenance and lamp replacement cost
Cost of saved energy	$0.03	$/kWh	
Cost of saved energy	$2.75	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High first costs, low awareness, limited experience w/technology		
Effect on utility	Longer life reduces maintenance		
Current promotion activity	Incentives offered by limited number of program operators		
Rating	3	(1-5)	
Rationale	Barriers addressable through promotion, demonstrations, & incentives		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Demonstrations, case studies, education & training, incentives		
Sources:			
Savings	Thorne and Nadel 2003; manufacturer literature		
Peak demand	PG&E 2000		
Cost	Thorne and Nadel 2003; ACEEE estimate of future cost		
Feasible applications	DOE 2002; Thorne and Nadel 2003; Walerczyk 2003		
Measure life	Thorne and Nadel 2003		
Other key sources			
Principal contacts	Stan Walerczyk, independent lighting consultant, 925-944-9481		
Notes	Tom Nelson, Philips Lighting, 732-563-3215		

L7 HOSPITALITY BATHROOM LIGHTING

Description of Technology

One of the largest energy end-uses in hotels is bathroom lighting, largely due to guests leaving the bathroom light on as a nightlight. WattStopper has developed a hotel bathroom night light that takes advantage of new high intensity LEDs and motion sensors to efficiently provide a night light for hotel guests. The nightlight is an integrated unit that fits into a standard wall switch plate. A high intensity LED lights the bathroom until motion is detected. At this point the lights in the bathroom are turned on providing illumination. The nightlight has an adjustable time delay allowing the light to stay on from 15 minutes to 2 hours.

Current Status of Measure

This product is currently in production and in use in a limited number of hotels. However, since the unit is considerably more expensive than a regular light switch ($38 compared to $6), it has met some resistance. Lawrence Berkeley National Laboratory (LBNL) monitored numerous hotel rooms and determined that the bathroom light was a significant source of energy consumption (Page and others 1997). The LBNL study led to the installation and monitoring of WattStopper units in a Sacramento hotel under a program promoted by the Sacramento Municipal Utility District's (SMUD) (Bisbee 2003).

Energy Savings and Costs

Installation in the Sacramento Hotel cost about $20,000, or $50 per room for 400 rooms. With energy savings of 166 kWh per room per year, the energy savings are valued at $8000 per year. This yields a simple payback of 2.5 years (Bisbee 2003). In addition, maintenance costs were reduced due to the longer lamp lifetimes.

Key Assumptions Used in Analysis

For the analysis, it was assumed that bathroom lights are left on for 4 hours per day and that that a fluorescent light is used as the main fixture in the bathroom. The analysis is based on a $0.12/kWh electricity rate.

Recommended Next Steps

The principal barriers are lack of understanding of the magnitude of bathroom lighting energy use and also high first cost compared to standard light switch. We recommend that prior to education, further study be done on lighting usage in hotels to verify usage statistics gained by LBNL. We recommended that information be prepared in a case study format and disseminated to the hotel/motel industry. Utility incentives and state building standards would also help to increase penetration of this technology.

L7 Hospitality Bathroom Lighting

Description	Combined nightlight, occupancy sensor, replaces bathroom light as night light		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	RET,NEW		
Basecase Information:			
Description	Normal hotel bathroom lighting		
Efficiency	240	Watts (four 60W lamps)	
Electric use	350	kWh/year	4 hours a day
Summer peak demand	0	kW	Affects only off-peak hours
Winter peak demand	0	kW	Affects only off-peak hours
Gas/fuel use	0		
New Measure Information:			
Description	Hotel bathroom lighting with motion sensor installed		
Efficiency	240	Watts (four 60W lamps)	
Electric use	189	kWh/year	Based upon 46% reduction in operation hrs (LBNL)
Summer peak demand	0	kW	Affects only off-peak hours
Winter peak demand	0	kW	Affects only off-peak hours
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2003		
Life	10	years	
Savings Information:			
Electricity	161	kWh/year	
Summer peak demand	0	kW	
Winter peak demand	0	kW	
Gas/Fuel		MMBTU/year	
Percent savings	46%		
Feasible applications	2%		lodging = 8% of comm, bath lighting (est) 20% of lodging
2020 Savings potential	2,817	GWh	
2020 Savings potential	28	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$50	2003 $	Lower for new construction
Other cost/(savings)		$/year	
Cost of saved energy	$0.040	$/kWh	
Cost of saved energy	$3.98	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Cost		
Effect on utility	decreases heat load while still providing night light, longer lamp lifetimes		
Current promotion activity			
Rating	3	(1-5)	
Rationale	Higher installation and product cost		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps			
Sources:			
Savings	Page (LBNL) 1999, Dave Bisbee (SMUD)		
Peak demand	DEG estimate		
Cost	Page (LBNL) 1999, Dave Bisbee (SMUD)		
Feasible applications	DEG Estimate		
Measure life	DEG Estimate		
Other key sources			
Principal contacts	Page (LBNL), Dave Bisbee, SMUD (916-732-6409)		
Notes			

L8 UNIVERSAL LIGHT DIMMING CONTROL DEVICE

Description of Technology

MaxLite, a lighting products manufacturer, recently developed DimALL, a device that can dim fluorescent, incandescent, or halogen lamps without the installation of a special ballast. The device has a microprocessor that is attached to a lighting circuit. The microprocessor regulates the circuit's operation and voltage to maintain the lamp's dimming operations. The actual dimming capability depends on the quality and variety of lamps supported by the circuit (E Source 2003). The best dimming capability (down to 10% of full output) is attained when the circuit is connected to high-quality lamps with similar characteristics. Dimming power is reduced when the circuit supports a mix of incandescent and fluorescents fixtures. DimALL will be available in 200 and 1,000 Watt circuit capacity. The manufacturer claims that the product can be installed without the need for special wiring.

Current Status of Measure

MaxLite is currently refining the technology and expects to release the product in the fall of 2004 (Kang 2003). The manufacturer is working on increasing the dimming capacity for CFLs (currently to 45% of full output) and broadening the list of CFL models for which the technology can work. MaxLite is also developing an infrared remote control to use with the device. MaxLite hopes that commercial consumers would be able to use the product to dim linear fluorescents, such as T8 and T10 lamps, used in conference rooms and hotel dining rooms, where lighting control needs are high. For residential purposes, the manufacturer feels that, with the product, consumers would be willing to switch to CFLs from incandescents for lighting needs in their living rooms and dining areas. DimALL does not need a dimming CFL lamp or special ballast, and can be used with a standard wall-dimmer switch (Kang 2003).

Energy Savings and Costs

A DimALL device capable of supporting 1,000 Watts, ideal for commercial use, will cost $200 each, according to manufacturer estimates (Kang 2003). Dimmable ballasts, currently selling at around $20 incremental, would be more cost effective for commercial use. A lower 200 Watt device that would be used in residential homes would cost $40–50. We estimate that installation cost would be around $25 each. The manufacturer plans to give a 5-year warranty for the product.

Key Assumptions Used in Analysis

For this analysis, we assumed that the universal dimming capability from the technology would facilitate the conversion from incandescents to CFLs for certain residential spaces, such as dining and living room spaces. Together, these spaces account for 36% of lighting energy consumed in this sector (DOE 2002b). Feasible applications are estimated at 50% of these spaces in the residential sector. Additional savings could also be realized from the light dimming itself. According to the manufacturer, dimming fluorescent lamps on average by 50% with DimALL could result in additional energy savings of 30% (Kang 2003). For commercial spaces, the technology is currently not competitive with dimmable ballasts, which cost around $20.

Recommended Next Steps

The technology would be attractive for consumers who are already considering CFL replacements for their incandescent lamps. DimALL could serve as an additional incentive to purchase CFLs for certain residential uses. Utilities could offer additional financial incentives to their customers who purchase the device with CFLs.

L8 Universal Light Dimming Control Device

Description	A dimming device that attaches to a lighting circuit to dim any type of lighting		
Market Information:			
Market sector	RES		Not Cost effective for Commercial
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	Standard A-line lamp		
Efficiency	75	Watts, 15 LPW	
Electric use	82	kWh/year	3 hours/ day
Summer peak demand	0.005	kW	includes coincidence
Winter peak demand	0.015	kW	includes coincidence
Gas/fuel use			
New Measure Information:			
Description	Standard compact fluorescent w/ universal dimming device		
Efficiency	18	Watts, 55 LPW	
Electric use	20	kWh/year	3 hrs/day
Summer peak demand	0.001	kW	includes coincidence
Winter peak demand	0.004	kW	includes coincidence
Gas/Fuel use			
Current status	PROTO		
Date of commercialization	2004		
Life	20	years	~20,000 hrs
Savings Information:			
Electricity	62	kWh/year	
Summer peak demand	0.004	kW	
Winter peak demand	0.011	kW	
Gas/Fuel		MMBTU/year	
Percent savings	76%		
Feasible applications	4%		frac of total household fixtures with dimmers (California)
2020 Savings potential	9,611	GWh	
2020 Savings potential	97	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$71	2003 $	Inc.dimmer, CFL, installation cost, residential only
Other cost/(savings)	($1.00)	$/year	Less bulb replacement
Cost of saved energy	$0.081	$/kWh	
Cost of saved energy	$8.05	$/MMBtu	
Data quality assessment	C	(A-D)	Uncertainties on cost and life
Likelihood of Success:			
Major market barriers	Cost, dimming capability varies, depending on quality and type of lamp		
Effect on utility	More options in lighting scenarios for consumer		
Current promotion activity	Lightfair International; appearance in technical newsletters		
Rating	1	(1-5)	
Rationale	Easy use & installation; manufacturer will offer 5-year warranty		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Further research on dimming capability on various CFLs and ways to reduce cost		
Sources:			
Savings	Kang 2003		
Peak demand			
Cost	Kang 2003		
Feasible applications	DOE 2002; Kang 2003, ET Currents 2003; Heschong Mahone Group 1999		
Measure life	Kang 2003		
Other key sources	ET Currents 2003; Kendall and Scholand 2001; Jennings et al, 2000		
Principal contacts	Steve Kang, MaxLite, 973-244-7300 x107		
Notes	According to manufacturer, the device itself has an estimated life of 30,000 hours. Manufacturer is offering a 5-year warranty. Manufacturer does not recommend use with HID. Technology may be used in some commercial applications, but dimmable ballasts, which are currently available, are most cost effective. For residential, additional energy savings could be realized from actual light dimming.		

L9 ADVANCED HIGH INTENSITY DISCHARGE LIGHT SOURCES

Description of Technology

Conventional high intensity discharge light sources are commonly used in outdoor applications such as street lighting, parking garages, and other places where high levels of light are needed over large areas. They are also popular in indoor, high-ceiling applications such as warehouses, gymnasiums, arenas, and even banks. HID lamps use an electrical arc column across tungsten electrodes to produce light. Typically, the arc column uses 90% of the electric power, with the remaining 10% dissipated as electrode losses. About 57% of the electric power that penetrates the arc column escapes as heat, and 33% is utilized to produce visible light (EPRI 2002)—roughly three times the efficiency of incandescents. Advanced HID lamps, currently under research, would shift some energy (infrared) from the arc to near UV or visible emission, improving efficiency. The research goal is to raise lumens per Watt up to 40% above the current rate.

Current Status of Measure

The Electric Power Research Institute, Los Alamos National Laboratory, the National Institute of Standards & Technology, the University of Wisconsin, General Electric, and Phillips Lighting are currently engaged in a research program to develop advanced HID light sources. The ALITE II program has made good progress in developing the technology, but needs additional funding to conduct additional experiments (EPRI 2002). The program is scheduled to be completed at the end of 2005. If the research goes well, the lamp companies will then develop a product and begin commercialization, which will take 2–3 years (Gough 2003).

Energy Savings and Costs

Most HIDs used today in existing buildings are white, probe-start, metal halide lamps that are between 100 and 400 Watts (Gough 2003). The 400 Watt lamps are commonly used in indoor, high-ceiling commercial or industrial buildings (ABTP 2003). These lamps have efficacies of about 70 mean lumens per Watt and use magnetic ballasts (NLPIP 2003). The lamps currently cost an average of $60 and ballasts range from $70 to $130. Advanced HID lamps would increase average efficacy rating about 40%, with an incremental cost of 20–30% on the lamp. To get the 40% energy savings, the lamps would likely need to run on electronic ballasts, which currently cost twice as much as magnetic ballasts (Gough 2003.)

Key Assumptions Used in Analysis

Advanced HIDs are estimated to have similar rated life hours as regular metal halide HID lamps (about 15,000 hours). Conventional HID (metal halide) lamps currently consume about 9% of commercial lighting electricity, excluding outdoor applications (DOE 2002b). For this analysis, we assumed that feasible applications for AHID would be 70% of current lighting energy consumed by HIDs. Advanced HID lamps would provide about 40% energy savings. This is perhaps 10–15% savings relative to pulse start MH with electronic ballasts.

Recommended Next Steps

The ALITE program, which is developing advanced HID lamps, continues to work with lamp companies and national laboratories to come up with a prototype. However, additional funding seems to be the barrier to completing the necessary research. The program is currently seeking additional funding from utilities, the Department of Energy, and the National Science Foundation for further research (Gough 2003). Once a prototype has been developed and commercialization has begun, incentive programs can help promote the technology to consumers. If the research goals are achieved, advanced HID lamps would provide the same amount of light with 40% less in electricity and have total life-hours similar to regular lamps. The substantial incremental cost of 30% would be a good investment at 4¢/kWh cost of saved energy.

L9 Advanced High Intensity Discharge (HID) Light Sources

Description	HID that turns more of the arc heat into usable light		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	400 Watt HID Probe-start, Metal Halide Lamp		
Efficiency	448	with magnetic ballast; 70 mean LPW	
Electric use	1,652	kWh/year	10.1 hours/day avg. for 365 days/year
Summer peak demand	0.372	kW	
Winter peak demand	0.332	kW	
Gas/fuel use			
New Measure Information:			
Description	Advanced HID lamp		
Efficiency	269	with electronic ballast; 40% improvement in LPW	
Electric use	991	kWh/year	10.1 hours/day avg. for 365 days/year
Summer peak demand	0.223	kW	
Winter peak demand	0.199	kW	
Gas/Fuel use			
Current status	RES		
Date of commercialization	2007		
Life	4.1	years	15,000 hours
Savings Information:			
Electricity	661	kWh/year	
Summer peak demand	0.149	kW	
Winter peak demand	0.133	kW	
Gas/Fuel		MMBTU/year	
Percent savings	40%		
Feasible applications	6%		Est. at 70% of HID use (HID 9% of commercial lighting)
2020 Savings potential	9,646	GWh	
2020 Savings potential	97	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$118	2003 $	Est. inc. lamp cost 30% ($18) & ballast cost 100% ($100).
Other cost/(savings)		$/year	No other savings; AHIDs expected to last the same
Cost of saved energy	$0.049	$/kWh	
Cost of saved energy	$4.85	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Research still needed; Incremental cost is high - 2/3 more, including ballast		
Effect on utility	No change		
Current promotion activity	EPRI's -ALITE research program		
Rating	2	(1-5)	
Rationale	Annual funding needs to be increased to perform additional experiments; has not been resolved yet.		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Research needs to be completed, which needs more funding		
Sources:			
Savings	Gough 2003		
Peak demand	Gough 2003		
Cost	Gough 2003		
Feasible applications	DOE 2002		
Measure life	Advanced Buildings Technologies & Practices 2003		
Other key sources			
Principal contacts	Al Gough, EPRI, 828-692-1904; Jennifer Thorne, ACEEE, 202-429-8873		
Notes	LPW used is average; Current HIDs can have up to 90 LPW; Lamp companies are working to raise this to 150 LPW, a 40% increase		

L10 HYBRID SOLAR LIGHTING

Description of Technology

Hybrid solar lighting (HSL) combines roof-top sunlight collectors, light pipes (optical fibers), and special luminaries that augment fluorescent lighting with sunlight. An HSL system has a solar dish collector that tracks the sun and focuses it into large optical fibers that deliver most of the light to “hybrid” luminaires. The fixtures are connected to lighting controls that automatically reduce the amount of electric light used depending on the amount of available sunlight coming in. Commercially available recessed fluorescent luminaries can be retrofitted to include solar illuminant dispersing devices.

Current Status of Measure

HSL is currently being tested at Oak Ridge National Laboratory (ORNL) in Tennessee. Ohio University also has a partial system installed in one of its buildings. The HSL system is also to be tested in an office complex in Alabama and in a classroom in Mississippi. The Sacramento Municipal Utility District has decided to try out the HSL for one of its lobby areas as well. Wal-Mart, one of the program’s partners, is considering installing a system in one of its “Neighborhood Markets,” which are smaller stores with lower ceiling heights (Tarricone 2003.) Some prototypes have shown a greenish cast to the light from the hybrid collector (Brodrick 2004).

Energy Savings and Costs

The target price for an HSL system is $4,700, which includes the retrofitting of up to 16 fluorescent luminaries. ORNL estimates that a 1.5-meter dish collector can deliver roughly 100,000 lumens to 12–16 light fixtures covering 1000 ft^2 on the top floor of a building (Muhs 2003a). Payback time would be moderate (about 4 years) for the Sunbelt areas, since electricity savings are over 50%. However, for areas in the Northeast or the Midwest, payback time would be twice as long (Muhs 2003b).

Key Assumptions Used in Analysis

The technology would be feasible in low-rise (up to two floor) commercial buildings located in the southern and western United States. Together, low-rise floor space in these regions comprises about 56% of all low-rise commercial floor space in the United States (Census 1999b). HSL can also be used on the upper two floors of multi-story buildings, but the losses in available low-cost light fibers are too great for applications more than two floors below the light collector. Additionally, HSL systems work best in spaces with low ceilings (up to 11 feet), such as spaces in schools or small government buildings (Muhs 2003b). Considering these factors, we estimate the feasible applications to be 60% of low-rise, commercial floor space in the southern and western United States.

Recommended Next Steps

Current activities are directed at refining the technology. Research is being done to reduce the number of moving parts on the collector, improve the fiber optics, and improve luminaire retrofits. The Illuminating Engineering Society of North America (IESNA) has not recommended a specific type of retrofitted luminaire at this time (Muhs 2003b). The technology has good potential in the Sunbelt states, but the longer payback period for the Midwest and Northeast markets may make market penetration more difficult in these regions. In addition to the issue of the number of sunny days, additional maintenance costs due to snow accumulation on the collector and its moving parts would also play a factor. Further research is needed regarding these issues.

L10 Hybrid Solar Lighting

Description	Uses natural light to illuminate inside of buildings through dish collectors & "hybrid" luminaires		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET		
Basecase Information:			
Description	General Purpose Recessed Lensed fixture w/ 2 T8 lamps		
Efficiency	720	12 60-watt (Two 32W T8s w/ ballast) fluorescent fixtures	
Electric use	2,995	kWh/year	kwh/yr assuming 4160 hrs (16 hrs/day-5 days/wk/52 wks)
Summer peak demand	0.598	kW	includes coincidence
Winter peak demand	0.533	kW	includes coincidence
Gas/fuel use			
New Measure Information:			
Description	HSL system, one dish collector with 12 retrofitted "hybird" luminaires		
Efficiency	346	watts total - 12 "hybrid" luminaires	
Electric use	1,438	kWh/year	4160 hrs (12 hrs/day-5 days/week)
Summer peak demand	0.287	kW	includes coincidence
Winter peak demand	0.533	kW	No winter savings
Gas/Fuel use			
Current status	PROTO		
Date of commercialization	2006		Estimated
Life	15	years	
Savings Information:			
Electricity	1,558	kWh/year	
Summer peak demand	0.311	kW	
Winter peak demand	0	kW	
Gas/Fuel		MMBTU/year	
Percent savings	52%		
Feasible applications	22%		1/3 of low-rise (up to 2 floors) commercial buildings
2020 Savings potential	26,759	GWh	southern and western U.S.
2020 Savings potential	270	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$2,132	2003 $	$4,700 less 12 4-lamp luminaires w/ 2 electronic ballasts each
Other cost/(savings)	$300	$/year	Estimated maintenance cost; fewer bulb changing
Cost of saved energy	$0.265	$/kWh	
Cost of saved energy	$26.26	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	High incremental cost; Best in sunbelt areas only		
Effect on utility	Natural light which most people prefer		
Current promotion activity	Research done by ORNL; Prototypes in several locations		
Rating	2	(1-5)	
Rationale	Market feasibility in sunbelt areas only; payback is long		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Research on reducing moving parts, luminaires & snow accumulation effects		
Sources:			
Savings	Muhs 2003		
Peak demand	Muhs 2003		
Cost	Muhs 2003		
Feasible applications	Muhs 2003; Census 2003		
Measure life	Vorsatz et al 1997		
Other key sources			
Principal contacts	Jeff Muhs, ORNL, 865-946-1281		
Notes	Feasible application and west/SW proportion estimated from U.S. Census data 1999		

L11 LED LIGHTING

Description of Technology

Light emitting diodes (LEDs) are solid-state devices that convert electricity to light, potentially with very high efficiency and long life. They are generally monochromatic, so early applications have been for (red) exit signs and for traffic signals. Recently, lighting manufacturers have been able to produce "cool" white LED lighting indirectly, using ultraviolet LEDs to excite phosphors that emit a white-appearing light.

Current Status of Measure

Red and green LED traffic signals are now mainstream. White LED products are entering niche markets including retail displays, building exterior illumination, task lighting, elevators, kitchens (under-cabinet), and backlighting for liquid crystal displays. LumiLeds has released a warm white, incandescent-equivalent LED lamp with average light output of 22 lumens and 50,000 hr. life at 70% of initial brightness (LumiLeds 2003). For comparison, a typical 60 Watt incandescent bulb has an output of around 800 lumens and lasts about 1,000 hr. GE has announced white LED lighting products with an efficacy of 30 lumens/Watt and 50,000 hour life (Talbot 2003). For comparison, current CFLs generally exceed 70 lumen/Watt (IESNA 2000), with life expectancy of several thousand hours. Technical Consumer Products, Inc, a lighting manufacturer, recently released an $89, five-Watt LED desk lamp (TCP 2003). When compared to a typical 60-Watt incandescent lamp, the LED desk lamp offers over 90% in energy savings (David 2003). In California, the PIER Lighting program expects to have LED fixture prototypes ready in the fall of 2003 that could be used for residential porches, commercial entry ways, and other exterior illumination needs (Porter 2003). PIER is also working on low profile fixtures, for elevators, kitchen cabinets, and similar applications. The products are expected to reach marketable stage towards the end of 2004. Much current research is focused on improving the efficacy and light quality of white LEDs.

Energy Savings and Costs

Currently, white LEDs are estimated to cost about 20¢/lumen (Craford 2002; Ton, Foster, and Calwell 2003). But this number could continue to go down if the design of LED systems components also improves (Ton, Foster, and Calwell 2003). There are also other technical challenges related to semiconductors used in LEDs (Simmons 2003). Currently, thermal management is a key issue that needs to be resolved for LED systems. Although they do not radiate as much as heat as other lighting sources, LEDs still need an appropriate heat sink so that light output and life span do not decrease.

Key Assumptions Used in Analysis

For this analysis, we assumed that white LED lighting could be used in both residential and commercial applications. For residential use, white LED lighting could replace incandescents (and halogens) used in kitchens (such as under-cabinet shelf), task lighting, porches, backyards, and other applications requiring less than two hours of use per day. Most rooms (except kitchen, utility, dining, living, utility, and outdoor areas) have lighting used 2.0 hours or less ([DOE] 2002b, Table 5.9). For commercial use, white LED lighting could be used for various exterior illumination, retail merchandise and display, and signage. These applications comprise roughly 21% of commercial lighting energy, in part because the daily duty time is long. In the long term, additional applications will become feasible, but over the next five years (the timeframe of this report), white LEDs will likely be limited to these niches.

Recommended Next Steps

LED lighting has made major advances/ toward broader applications. However, further improvements are needed for LEDs to compete with other lighting sources. At 20¢/lumen, LED lighting currently costs at least five times more than compact fluorescents. Average efficiency of LED lighting is around 25 lumens/Watt, which is higher than incandescents and halogens but still much lower than fluorescent lighting. Because LEDs emit light directionally, their light output is also difficult to accurately compare in the photometric system (lumens/Watt) used in traditional lighting sources. DOE maintains an active research program in this area at (see http://www.netl.doe.gov/ssl). Current incentive programs for LED lighting only focus on exit signs and traffic signals. As more LED products are introduced into the market, commercial and residential lighting programs should include educational activities as well as financial incentives.

L11a Residential LED Lighting

Description	For porch fixtures, under-cabinet lighting, under-shelf lighting, and task lighting		
Market Information:			
Market sector	RES		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	Standard A-line lamp		
Efficiency	75	watts w/ 1150 lumens or 15 LPW	
Electric use	82	kWh/year	Assumes 3 hours/ day for res usage for 365 days/yr
Summer peak demand	0.005	kW	
Winter peak demand	0.015	kW	
Gas/fuel use			
New Measure Information:			
Description	White LED lamp		
Efficiency	28.75	Watts @ 40 LPW	
Electric use	31	kWh/year	Assumes 3 hours/ day for res usage for 365 days/yr
Summer peak demand	0.002	kW	
Winter peak demand	0.006	kW	
Gas/Fuel use			
Current status	PROTO/FLDTEST		
Date of commercialization	2004		
Life	13	years	or 10,000 hrs
Savings Information:			
Electricity	51	kWh/year	
Summer peak demand	0.003	kW	
Winter peak demand	0.009	kW	
Gas/Fuel		MMBTU/year	
Percent savings	62%		
Feasible applications	12%		Percent of lighting energy use apps < 3hrs/day
2020 Savings potential	22,682	GWh	
2020 Savings potential	229	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$58	2003 $	Currently at $.20/lumen. Estimated to go down to $.05/lumen by 2010
Other cost/(savings)	($1)	$/year	Avoided lamp replacement costs
Cost of saved energy	$0.114	$/kWh	
Cost of saved energy	$11.26	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High inc.cost; thermal management, LED systems & components design		
Effect on utility	Less bulb changing		
Current promotion activity	PIER, DOE, Manufacturers selling to selected commercial/industrial reps		
Rating	2	(1-5)	
Rationale	Manufacturer support, but high incremental cost; Other markets likely to be more attractive for LEDs		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Continue research on improving white color & raising LPW for white; develop business case; education for lighting des		
Sources:			
Savings	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Peak demand			
Cost	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Feasible applications	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Measure life	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Other key sources	Sandy David-TCP, Inc. 330-995-6111; Vernica Martinez-LumiLeds, 408-435-6111		
Principal contacts	Judie Porter, PIER Lighting Progam, 800.450.4454; Jerry Simmons, Sandia National Laboratory, 505-844-8402; Suzar		
Notes	Price likely to come down in the long run; thus primarily a long-term measure.		

L11b Commercial LED lighting

Description	Commercial LED for institutional entry, perimeter lighting and display lighting.		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET, ROB		
Basecase Information:			
Description	Halogen PAR Lamp		
Efficiency	75	watts w/ 1050 lumens or 14 LPW	
Electric use	274	kWh/year	Assumes10 hours/ day for comm usage for 365 days/yr
Summer peak demand	0.062	kW	
Winter peak demand	0.056	kW	
Gas/fuel use			
New Measure Information:			
Description	White LED Lamp		
Efficiency	26.25	Watts @ 40 LPW	
Electric use	96	kWh/year	Assumes 10 hours/ day for comm usage for 365 days/yr
Summer peak demand	0.022	kW	
Winter peak demand	0.019	kW	
Gas/Fuel use			
Current status	PROTO/FLDTEST		
Date of commercialization	2004		
Life	6	years	or 20,000 hrs
Savings Information:			
Electricity	178	kWh/year	
Summer peak demand	0.040	kW	
Winter peak demand	0.036	kW	
Gas/Fuel		MMBTU/year	
Percent savings	65%		
Feasible applications	7%		Est. portion of commercial incandescent lighting for Landscape, Merchandise, Signage, Structure, Task
2020 Savings potential	17,429	GWh	
2020 Savings potential	176	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$53	2003 $	Currently at $.20/lumen. Estimated to go down to $.05/lumen by 2010
Other cost/(savings)	($6)	$/year	Avoided replacement costs, including labor
Cost of saved energy	$0.030	$/kWh	
Cost of saved energy	$2.93	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Incremental cost; thermal management; LED systems & components design		
Effect on utility	Less bulb changing		
Current promotion activity	PIER, DOE, Manufacturers selling to selected commercial/industrial reps		
Rating	3	(1-5)	
Rationale	Manufacturer support, but high cost; perceived as trendy & new		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Continue research on improving white color & raising LPW for white; develop business case; education for lighting designers, consumers		
Sources:			
Savings	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Feasible applications	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Measure life	Based on Ton et al 2003, Kendall & Scholand 2001, LumiLed 2003, DOE 2003		
Other key sources	Sandy David-TCP, Inc. 330-995-6111; Vernica Martinez-LumiLeds, 408-435-6111		
Principal contacts	Judie Porter, 800.450.4454; Jerry Simmons, 505-844-8402; Suzanne Foster, 970-259-6802		
Notes	Price likely to come down in the long run; thus primarily a long-term measure.		

L13 HIGH QUALITY RESIDENTIAL COMPACT FLUORESCENT PORTABLE PLUG-IN FIXTURES

Description of Technology

Residential portable fixtures include table lamps, desk lamps, floor lamps (torchieres), and other plug-in fixtures typically found in living rooms, home offices, and family rooms. Together they consume roughly 20% of total annual household lighting energy (Calwell et al.1999b). Although energy-efficient compact fluorescents (CFLs) are available for use with these fixtures, most users still prefer lower cost incandescent lamps. However, many manufacturers have now developed residential portable fixtures designed specifically for pin-based CFLs. When used, these CFL-dedicated fixtures guarantee energy savings, since they are incompatible with incandescents.

Current Status of Measure

Depending on the region of the country, CFL residential portable fixtures can be purchased in furniture stores, lighting specialty stores, home improvement stores, hardware stores, department stores, and national discount stores (RER 2000) but availability is limited in home improvement stores and large discount stores. Additionally, a recent study in California showed that many retailers are not very knowledgeable about fluorescent lighting fixtures (HMG 1999b). Also, replacement bulbs are not widely stocked or readily available. Currently, several initiatives are underway to encourage lighting manufacturers and designers to create better portable CFL fixtures. The Consortium for Energy Efficiency (CEE), the American Lighting Association (ALA), and the U.S. Department of Energy (DOE) have partnered to sponsor *Lighting for Tomorrow*, a national competition for lighting fixture designs. The sponsors have selected several portable CFL fixtures as finalists and honorable mentions based on paper designs. Some of the portable fixtures are estimated to cost less than $100 retail. Manufacturers and lighting designers who made the final round are due to submit their prototypes in January 2004. The California Energy Commission (CEC) also recently started the ENERGY STAR Residential Fixture Advancement Project, which reimburses manufacturers for 50% of their cost to design higher-end table or floor lamps. Program managers estimate that products will be out in the market by mid-2004.

Energy Savings and Costs

Energy savings from portable CFL fixtures could be more than 70% over traditional incandescent fixtures. A 27-Watt CFL fixture is equivalent to a typical 100-Watt incandescent table lamp (ENERGYGuide 2003). However, the incremental retail cost of the fixture is high, almost $40 (including replacement bulbs). For cost as well as aesthetic reasons, consumers have been slow in accepting CFL table lamps. CFL floor lamps are growing in popularity, however, as a replacement for halogen torchieres, which have been shown to be unsafe (Calwell et al. 1999b).

Key Assumptions Used in Analysis

For this analysis, we estimate feasible applications to be 50% of the portable fixture market. Incremental cost is assumed at $22 (decreased from $30 in Nadel et al. 1998) plus $16 for two replacement bulbs over the life of the fixture.

Recommended Next Steps

CFL portable fixtures can provide large energy savings potential to consumers. However, consumers complained about poor quality and design in the past (HMG 1999b; RER 2000). Further outreach programs need to take place to educate both retailers and consumers on the value (both energy and non-energy related) of the fixtures. A special effort must be made to reach large home improvement and discount stores where most consumers go for their lighting needs. Some utilities give discounts directly to their customers for ENERGY STAR products (without having to apply for rebates). ENERGY STAR incentive programs should also be made available through retailers. Programs can work to improve stocking of replacement bulbs, locally and /or on the Internet.

L13 Very High Quality Residential Compact Fluorescent Portable (Plug-in) Fixtures

Description	Table and floor lamps that use pin-based CFLs (lamps include ballasts)		
Market Information:			
Market sector	RES		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	Standard A-Line Table Lamp		
Efficiency	100	One 100-Watt lamp w/ 15 LPW	
Electric use	85	kWh/year	2.5 hours per day average for 340 days/year
Summer peak demand	0.007	kW	
Winter peak demand	0.020	kW	
Gas/fuel use			
New Measure Information:			
Description	Compact fluorescent table lamp		
Efficiency	27	Watt CFL pin-based lamp w/ 65 LPW (including ballast)	
Electric use	25	kWh/year	2.5 hours per day average for 340 days/year
Summer peak demand	0.002	kW	includes coincidence
Winter peak demand	0.005	kW	includes coincidence
Gas/Fuel use			
Current status	COMM		Commercialized, but many under research also
Date of commercialization	2000		
Life	12	years	
Savings Information:			
Electricity	60	kWh/year	
Summer peak demand	0.0051	kW	
Winter peak demand	0.0146	kW	
Gas/Fuel		MMBTU/year	
Percent savings	71%		
Feasible applications	10%		Based on references below
2020 Savings potential	21,410	GWh	
2020 Savings potential	216	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$30	2003 $	per 1998
Other cost/(savings)	($2.00)	$/year	per 1998
Cost of saved energy	$0.032	$/kWh	
Cost of saved energy	$3.13	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High incremental cost; Availability for residential customers		
Effect on utility	Less bulb changing		
Current promotion activity	Utility rebates; Manufacturer competitions		
Rating	3	(1-5)	
Rationale	Retailers are not yet stocking on regular basis		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Need retailer/consumer education; incentives		
Sources:			
Savings	ENERGY STAR 2003; ENERGY STAR Lights Catalog 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Retail market research on chains; Energy Lights Catalog		
Feasible applications	Bardhi 2003; NRDC 1999		
Measure life	Vorsatz 1997; ENERGY STAR		
Other key sources	Megan Hoye, ICF Consulting		
Principal contacts	Peter Bardhi, National Grid, 508-421-7214; Rebecca Foster, CEE, 617-589-3949		
Notes			

L14 ONE-LAMP LINEAR FLUORESCENT FIXTURES WITH HIGH PERFORMANCE LAMPS

Description of Technology

One-lamp fixtures for fluorescent lamps can reduce lighting electricity consumption for most commercial buildings, especially for those with small or oddly dimensioned offices, spaces with some daylighting, and offices where computer-oriented tasks predominate. In many commercial buildings, general lighting levels are set around 50 foot-candles, typically more light than needed to perform tasks using desktop computers. The Illuminating Engineering Society of North America has recommended that decreasing ambient lighting levels to about 30 foot-candles would reduce excess lighting and improve worker comfort and productivity (IESNA 2000). One way that high energy savings and 30 foot-candles can be attained is by using one-lamp fixtures with super T8 lamps and high-output electronic ballasts (ballast factors of 1.18 to 1.26). Using one-lamp indirect T5 fixtures is also an option.

Current Status of Measure

Despite the IESNA recommendation of and the potential energy savings for one-lamp lighting design, installing one-lamp fixtures is still not common. Some major utilities do recognize the energy savings potential and currently offer financial incentives for one-lamp lighting system designs. National Grid currently offers $10 per fixture and an additional $5 for using Super T8 lamps on new construction projects. However, the number of proposals for one-lamp fixture designs has generally been low (less than 5% of total number of proposals in the last year) (Hagspeil 2003). The utility has received proposals to replace many two-lamp fixtures in school classrooms, but has not seen many for offices. Xcel, Pacific Gas & Electric, and Portland General Electric (for existing buildings) are also offering financial incentives for lighting designs that reduce energy consumption, for which one-lamp fixtures would qualify (Portland General Electric 2003; Savings by Design 2003; Xcel Energy 2003).

Energy Savings and Costs

Energy savings can add up to 204 kWh/yr per unit or 72% by using two one-lamp fixtures with super T8 lamps instead of two two-lamp fixtures with standard T8 lamps. When replacing a T12 system, savings will be greater. T8 and T12 fluorescent lamps comprise more than 50% of total lighting energy use in commercial buildings (DOE 2002b). We estimate that the feasible application for this technology is 50% of T8 and T12 use in the commercial sector.

Key Assumptions Used in Analysis

High-efficiency one-lamp fixtures cost about the same as two-lamp fixtures, about $100 (from several lighting distributors). Super T8 lamps cost approximately $1–2 more than standard T8 lamps (BPA 2003; Thorne and Nadel 2003a). But two one-lamp fixtures could share one high-power electronic ballast that costs about $50. For some detail tasks, task lighting may be necessary. For new construction and major remodeling, there are no incremental costs to the consumer. However, for retrofit projects, the installation of one-lamp systems would require the additional costs of rewiring electrical sources and retiling ceilings.

Recommended Next Steps

One-lamp lighting systems can provide large energy savings for the consumer. However, many lighting designers are still reluctant to step away from conventional systems. Lighting designers and contractors in the commercial sector need to be given guidance regarding using this design in office spaces. Program managers should develop easily accessible materials outlining energy and non-energy benefits. Other tools that help designers are guidelines (spacing, etc.), generic submittal sheets, and easy-to-assimilate training materials. This information may be targeted to building owners and managers as well. Decision-makers also need to be aware of financial incentives that many utilities offer for one-lamp fixture designs. Utility programs should more explicitly promote one-lamp fixture designs and generally phase-out incentives for three-lamp and four-lamp fixtures, except in high-bay applications.

L14 One-Lamp Linear Flourescent Fixtures with High Performance Lamps

Description	One-lamp linear flourescent fixtures w/ high performance lamps		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW, RET		
Basecase Information:			
Description	Two 2-lamp T8 fixtures, electronic ballast		
Efficiency	134	watts total	
Electric use	557	kWh/year	kwh/yr assuming 4160 hrs (16 hrs/day-5 days/wk/52 wks)
Summer peak demand	0.111	kW	includes coincidence
Winter peak demand	0.099	kW	includes coincidence
Gas/fuel use	0		
New Measure Information:			
Description	Two 1-lamp Super T8 Fixtures with high-power electronic ballast		
Efficiency	78	watts (including ballast)	
Electric use	324	kWh/year	kwh/yr assuming 4160 hrs (16 hrs/day-5 days/wk/52 wks)
Summer peak demand	0.065	kW	
Winter peak demand	0.058	kW	
Gas/Fuel use	0		
Current status	COMM		
Date of commercialization	2002		
Life	15	years	
Savings Information:			
Electricity	233	kWh/year	
Summer peak demand	0.046	kW	
Winter peak demand	0.041	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	42%		
Feasible applications	13%		50% of lighting in classrooms, healthcare and office
2020 Savings potential	21,274	GWh	
2020 Savings potential	215	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$20	2003 $	2-lamp fixtures cost roughly the same as 1-lamp fixtures-see note below;
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.008	$/kWh	
Cost of saved energy	$0.82	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Buyer awareness, contractor and supplier ignorance & conservativism		
Effect on utility	May need task lights for demanding tasks		
Current promotion activity	Some utilities have incentive programs		
Rating	3	(1-5)	For offices & schools-less problems w/ glare on CRTs
Rationale	Lighting designers would need to be educated about value of technology		
Priority / Next Steps			
Priority	High		
Recommended next steps	More outreach programs to educate lighting designers and contractors; refine & exapand utility incentives		
Sources:			
Savings	Thorne & Nadel 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Home Depot 2003; Prolighting 2003; Bulbs.com 2003;		
Feasible applications	DOE 2002 & ACEEE estimate		
Measure life	Vorsatz et al 1997		
Other key sources	Thorne & Nadel 2003		
Principal contacts	Anita Hagspiel, NGrid, 508-421-7221;		
Notes	Jeannine Komonowsky, PG&E, 415-973-8850		
	Super T8 cost $1-2 more than regular T8, but 2 1-lamp fixtures would share one high power electronic ballast; this results in retail cost savings. Additional cost may include task lights for demanding tasks		

L15 Scotopic Lighting

Description of Technology

Conventional design practice ignores color temperature and spectral balance, and only considers the light output and efficacy for most commercial applications. Research over the past decade has established substantial subtlety in how eyes respond to different parts of the spectrum, opening new opportunities for efficiency. In particular, "scotopic" lighting, which stimulates the eyes' photoreceptors called rods, makes pupils contract, increasing visual acuity. Although it may have lower measured efficacy than "photopic" illumination (which activates photoreceptors called cones), well-chosen scotopic lighting can provide greater efficiency, diminished glare (at computer screens), and greater user comfort. In test situations, scotopically enhanced lighting appears slightly bluer, but also brighter to occupants even when light levels were reduced. Lawrence Berkeley National Laboratory has determined that fluorescent and HID lamps with high correlated color temperature (CCT≥ 5,000 kelvin) give the clearest vision. When compared with lamps with lower CCTs and same wattage, these deliver greater visual effectiveness per Watt used. The visual acuity does not diminish when lights are reduced or dimmed somewhat, thus providing the opportunity for energy savings.

Current Status of Measure

Well-grounded research has been published for over a decade, but the findings have not yet affected the IESNA *Lighting Handbook* or practice in the field (Berman 2000).

The DOE continues to provide some funding for research on scotopic lighting. Pacific Gas & Electric has adopted the practice in some of its facilities and will soon release the results of its study (Rubinstein 2003). A smaller study is being done at the Bay Area Air Quality District in California (Jewett 2003).

Energy Savings and Costs

In the mid-1990s, Intel Corporation retrofitted its facilities in Hillsboro, Oregon, replacing 34W T12 lamps with a CCT of 3,500K with 32W T8 lamps with a CCT of 5,000K. Lighting levels went down from 65 foot-candles to 45 foot-candles without adverse effects on the occupants. Average Watts used per luminaire went from 144 W to 62 W, resulting in 57% energy savings (Berman 2000). Somewhat lower energy savings could result from the replacement of T8 lamps with low CCTs instead of T12s. Fluorescent lamps with high CCTs cost approximately the same as their counterparts with lower CCTs.

Key Assumptions Used in Analysis

The practice would be feasible in commercial applications where T8 and T12 lamps are used. Together, these lamps account for about 50% of lighting electricity consumed in the commercial sector. For this analysis, we assumed a base case of two 32W T8 lamps with CCT of 3,500k, commonly used in commercial applications, compared with two 32W T8 lamps with CCT of 6,500k. According to a study by LBNL, T8 lamps with CCT of 6.500k can operate at 64% of the power density of T8 lamps with 3,500k CCT and produce the same amount of scotopic lumens (Berman 2000). A DOE-funded study suggested 20% savings (Brodrick 2004). The practice would be most useful in office environments where the work focus is mainly on the computer. Eye strain and computer glare can be reduced by adjusting ambient light.

Recommended Next Steps

This practice needs evaluation and recognition by the Illuminating Engineering Society to gain acceptance among mainstream lighting designers. Standards for labeling lamps with their spectral balance (scotopic/photopic [S/P] value) need to be developed. Manufacturers need to make information on the spectral balance (S/P value) of lighting sources available to designers and engineers. Lighting engineers need to receive further education on incorporating the CCT and S/P ratio into their work. In parallel, more demonstrations with documentation could bolster the case for the technology. DOE has funded a project in this area, being carried out by the firm "After Image+space." They are producing a report proposing next steps, and they find savings of about 20%, with occupants noting no difference in the lighting system (Brodrick 2004).

L15 Scotopic Lighting

Description	Lamps with high scotopic/photopic lumens (higher CCT and bluer)		
Market Information:			
Market sector	COM		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	NEW,ROB		
Basecase Information:			
Description	Two 32W T8 Lamps with 3500K, electronic ballast w/ 2850 initial lumens		
Efficiency	60	watts	
Electric use	250	kWh/year	4160 hrs (60 hrs/week for 52 wks)
Summer peak demand	0.050	kW	
Winter peak demand	0.044	kW	
Gas/fuel use			
New Measure Information:			
Description	Two 32W T8 Lamps with 5000k, electronic ballast w/ 2700 initial lumens		
Efficiency	42	Fixtures farther apart and/or low BF ballast	
Electric use	175	kWh/year	4160 hrs (12 hrs/day/5 days/wk for 52 wks)
Summer peak demand	0.035	kW	
Winter peak demand	0.031	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2003		
Life	15	years	
Savings Information:			
Electricity	75	kWh/year	
Summer peak demand	0.015	kW	
Winter peak demand	0.013	kW	
Gas/Fuel		MMBTU/year	
Percent savings	30%		
Feasible applications	13%		50% of lighting in classrooms, healthcare and office
2020 Savings potential	15,272	GWh	
2020 Savings potential	154	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$0.00	2003 $	Lamps cost roughly the same, but fewer fixtures required
Other cost/(savings)		$/year	
Cost of saved energy	$0.000	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	lighting designer education; IES acceptance, consumer preference		
Effect on utility	Less eye strain & glare for occupants		
Current promotion activity	Some case studies; articles published in trade journals		
Rating	3	(1-5)	
Rationale	Products are readily available; only need further education		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Manufacturer S/P labeling; education of lighting designers		
Sources:			
Savings	Berman 2003		
Peak demand	HMG 1999, PGE 2000		
Cost	Rubinstein 2003		
Feasible applications	Berman 2003; DOE 2002; Liebel 2003		
Measure life	Vorsatz et al 1997		
Other key sources	Leibel 2003		
Principal contacts	Francis Rubinstein 510-486-4096; Don Jewett (415) 289-7455		
Notes			

L16 AIR-TIGHT CFL DOWNLIGHTS

Description of Technology

Increasingly recessed downlights have become the lighting fixture of choice for residential construction. Because only a very small part of the fixture is visible, the fixtures can be made inexpensively without sacrificing aesthetics. It is estimated that 21.7 million were manufactured in 2001 alone with approximately 350 million currently installed (Gordon 2003). However, there are two energy-related problems associated with recessed downlights. First, they rely on low efficacy incandescent lamps, and second they add envelope leakage and potentially an insulation void to the area in which they are located. In sixty new California homes, Davis Energy Group found an average of 12 recessed lights per house, leaking 104 $cfm_{50,}$ or 6% of total measured house leakage (DEG 2002).

Current Status of Measure

To improve on current practice, manufacturers are now beginning to produce air-tight recessed downlight fixtures that use compact fluorescent lamps (CFLs). One problem discovered during extensive testing completed at Pacific Northwestern National Laboratories relates to problems with heat build-up in the remote ballast. Since the ballast is in the attic and surrounded by insulation, the heat being generated by the ballast is not adequately removed and thus the ballast overheats. Research completed by LBNL under the California Energy Commission's PIER program developed an advanced CFL downlight. LBNL, in a partnership with NRDC, CEC, SMUD, and Lithonia Lighting has installed these units in about fifty new homes in the Sacramento area.

Energy Savings and Costs

Replacing a 75 Watt incandescent bulb with a 28 Watt CFL will reduce lighting energy use by 63%. The configuration of the advanced CFL downlight is such that two cans share a single electronic ballast. With higher light output, six CFL downlights can replace eight standard downlights at an equivalent installed cost (Siminovitch 2004).

Key Assumptions Used in Analysis

It is assumed that the 28 Watt CFL will replace a standard recessed can with a 75 Watt bulb. Assuming 2.1 hours of use a day (HMG 1999), the 75 Watt bulb will consume 57 kWh/year and a 28 Watt CFL will consume 21 kWh/year, a 63% reduction. The configuration of the advanced CFL downlight is such that two cans share a single electronic ballast. With higher light output, six CFL downlights can replace eight standard downlights at an equivalent installed cost, for additional energy savings (Siminovitch 2004).

Recommended Next Steps

Successful results from the SMUD field trial and favorable builder reviews indicate a high potential for this product. Utility incentives and marketing support would help in promoting this product. Energy codes promoting fluorescent lighting would also be of assistance. With the current high demand for recessed can lighting in new homes, an improved low-cost product has high potential for success.

L16 Airtight Compact Fluorescent Downlights

Description	Flourescent downlight with remote ballast for easy installation.		
Market Information:			
Market sector	RES		
End-use(s)	LIGHT		
Energy types	ELEC		
Market segment	ROB, NEW		
Basecase Information:			
Description	8 Incandescent recessed downlight		
Efficiency	75	watts	
Electric use	460	kWh/year	Assumes 2.1 hrs lighting/day (kitchen)
Summer peak demand	0.30	kW	
Winter peak demand	0.45	kW	
Gas/fuel use	0		
New Measure Information:			
Description	6 Airtight recessed CFL downlights		
Efficiency	28		
Electric use	172	kWh/year	Assumes 2.1 hrs lighting/day (kitchen)
Summer peak demand	0.11	kW	
Winter peak demand	0.17	kW	
Gas/Fuel use	0		
Current status	FLDTEST		
Date of commercialization	2004		
Life	15	years	
Savings Information:			
Electricity	288	kWh/year	
Summer peak demand	0.19	kW	
Winter peak demand	0.28	kW	
Gas/Fuel	0	MMBTU/year	
Percent savings	63%		
Feasible applications	30%		fraction of new construction lighting that is downlights
2020 Savings potential	38,967	GWh	
2020 Savings potential	393	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0	2003 $	Replace 8 incandescent with 6 CFL
Other cost/(savings)	($5)	$/year	3 incandescent lamp replacements per year
Cost of saved energy	-$0.012	$/kWh	
Cost of saved energy	-$1.19	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Need for educating builder community		
Effect on utility	Less heat gain from fixture, reduced infiltration		
Current promotion activity			
Rating	4	(1-5)	
Rationale	Ballast problems fixable, marketable much like CFL's		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Market to builders & architects, utility incentives, promote thru green organizations		
Sources:			
Savings	DEG Estimate		
Peak demand	DEG Estimate		
Cost	Siminovitch LBNL (510-486-5863), McCullough PNNL, (503-445-4770)		
Feasible applications	DEG Estimate		
Measure life	McCullough 2003, DEG Estimate		
Other key sources	McCullough 2003, DEG 2003		
Principal contacts	Siminovitch LBNL (510-486-5863), McCullough PNNL, (503-445-4770)		
Notes	small additional savings due to reduced ceiling infiltration		

O1 NETWORKED COMPUTER POWER MANAGEMENT

Description of Technology

Computer networks consume a considerable and increasing amount of energy. Approximately 74 TWh of power is used by office equipment and networks (Roberson 2000). A large fraction of this energy is consumed while the user is not present, even though ENERGY STAR desktop computers with “sleep” capabilities have been available for years. In corporate, institutional, and government offices, the network software may not support use of low-power states when the computer is un-used for long periods of time. Conceptually and pragmatically, the problem has at least two dimensions, notably the monitor and the central processor unit (CPU). The potential power savings are about 30 to 50 Watts for CRT monitors and about half that for LCD screens. The Pentium 4 processors in current CPUs draw about 55 Watts while working and 2 Watts while in sleep mode.

Current Status of Measure

Control of networked CRT and LCD monitors is no longer considered an emerging technology, with tools incorporated in network management packages from vendors such as Computer Associates, CSC, and others. Many large organizations have implemented the feature on their own, and in addition, ENERGY STAR distributes monitor software (EZ Save) for free. Korn estimated that at least 30% of large networks have monitor controls now (Korn 2003). The current “frontier” is CPU power management. Commercial products are available from Verdiem (Surveyor) 1e (NightWatchman) and others, but their market penetration is considered low (Korn 2003). Surveyor software is readily available at this time and has been extensively tested in a number of different environments (Tatham 2003).

Energy Savings and Costs

The cost of installation is dependent upon the size of the network, but is approximately $15 per computer (Tatham 2003). Incremental savings for CPU management (beyond monitor management) are estimated at 100–400 kWh/year (Tatham 2003) and 200 kWh/year (Degans 2003).

Key Assumptions Used in Analysis

ENERGY STAR estimates annual savings of 200 kWh per computer, at a cost of $15 per seat (Korn, 2003, personal communication).

Recommended Next Steps

Both technical and human interface problems remain. The former is exemplified by “wake-on-LAN” features to allow software updates, security patches, and other network activities overnight; network administrators do not yet have confidence in these features, so rising concerns about system security, viruses, and worms lead IT staffs to disable features (Schroeder 2003). Users occasionally have trouble understanding the difference between “sleep” and “off,” and attempt to reboot their work stations in the mornings. They also fear that the new software might include “spyware.” The next recommended step is further dissemination of information to network administrators and end-users. It is recommended that the “wake on LAN” be implemented at test sites to verify its performance and acceptance.

O1 Networked Computer Power Management

Description	Allows network administrator to remotely reduce desktop computer power ("sleep").	
Market Information:		
Market sector	COM	
End-use(s)	OFFEQ	
Energy types	ELEC	
Market segment	RET, NEW	
Basecase Information:		
Description	PC with monitor	
Efficiency	NA	
Electric use	496	kWh/year
Summer peak demand	0.057	kW
Winter peak demand	0.057	kW
Gas/fuel use	NA	
New Measure Information:		
Description	Sleep mode operation	
Efficiency	NA	
Electric use	296	kWh/year
Summer peak demand	0.034	kW
Winter peak demand	0.034	kW
Gas/Fuel use	NA	
Current status	COMM	
Date of commercialization	2002	
Life	5	years
Savings Information:		
Electricity	200	kWh/year
Summer peak demand	0.023	kW
Winter peak demand	0.023	kW
Gas/Fuel	0	MMBTU/year
Percent savings	40%	
Feasible applications	75%	
2020 Savings potential	28,372	GWh
2020 Savings potential	286	TBtu (source)
Industrial savings > 25%	NO	
Cost Information:		
Projected Incre. Retail Cost	$15	2003 $
Other cost/(savings)	$0	$/year
Cost of saved energy	$0.02	$/kWh
Cost of saved energy	$1.72	$/MMBtu
Data quality assessment	C	(A-D)
Likelihood of Success:		
Major market barriers	Hassle factor for system administrators and network users	
Effect on utility	Users may object when computer "sleeps"	
Current promotion activity	EnergyStar and admin. Software vendors	
Rating	3	(1-5)
Rationale	Implementation issues	
Priority / Next Steps		
Priority	Medium	
Recommended next steps	Document savings, evaluate user issues	
Sources:		
Savings	Degans 2003, LBNL 2002	
Peak demand	LBNL 2002	
Cost	Tatham 2003	
Feasible applications	DEG estimate	
Measure life	DEG estimate	
Other key sources	Schroeder 2003	
Principal contacts		
Notes		

P1A RESIDENTIAL MICRO-CHP USING FUEL CELLS

Description of Measure

This profile examines residential combined heat and power (CHP) applications using fuel cells in to deliver both electricity and heat. Fuel cells produce electricity through electrochemical reactions, similar to a battery but different in that the fuel cell is continuously supplied with fuel and oxygen. The fuel cell technologies currently under development are distinguished by the electrolyte they use and their operating temperature. The different types of fuel cells include proton exchange membrane (PEM) fuel cells, solid oxide fuel cells (SOFC), direct methanol fuel cells (DMFC), molten carbonate fuel cells (MCFC), phosphoric acid fuel cells (PAFC), and alkaline fuel cells (AFC). PEM cells are currently the most advanced in this size class, though they are a low temperature technology so the quality of the heat is lower than for technologies such as MCFC and SOFC that could drive thermally activated cooling technologies. Natural gas is the most likely fuel for these systems in the near term (Shipley 2004). Fuel cells promise efficient, clean and quiet electricity generation. To achieve maximum efficiency, a significant portion of fuel cell waste heat must be captured and put to use to displace thermal loads in the house (e.g., space heating) or through thermally activated technologies such as desiccant or absorption cooling.

Current Status of Measure

North American fuel cell developers and manufacturers that have targeted the residential sector include Avista Labs, Ballard, H Power, Plug Power (now merged with H Power), and others. Most expect to have commercial products available in 2005 or 2006.

Energy Savings and Costs

Actual electric conversion efficiencies of PEM fuel cells being achieved in tests are about 25%. Installed costs in CHP mode today are over $6,000/kW. Once fully developed, however, PEM fuel cells operated on natural gas are expected to be about 30% efficient for power generation with an additional 38% of the fuel input recoverable as heat for an overall system efficiency of 68%. Installed CHP system costs using PEM fuel cells are projected to be about $5,500/kW.

Key Assumptions Used in Analysis

The analysis assumes an average 2,000 ft^2 house with an annual electricity consumption of 12,338 kWh/year and total space heating and DHW consumption of 89 MMBtu/year. In the analysis a 2 kW PEM fuel cell with heat recovery is used and meets the majority of the electric, space heating, and DHW loads, with the balance made up with purchased energy. Since the details and availability of net metering are uncertain, the systems are not sized to produce power for resale. Thermally activated cooling technologies were included only implicitly. If resale of power were an attractive option, the systems should be resized to achieve maximum economic benefit based on the specifics of the tariff. The analysis assumes an installed system cost of $11,000 for the fuel cell plus a maintenance and overhaul cost of 1.5cents/kWh. Manufacturers' goal is for a stack life of 40,000 hours with an estimated stack replacement cost equivalent to 60% of the original cost.

Recommended Next Steps

To support market uptake of residential CHP, and stationary fuel cells in general, governments and utilities need to deal with barriers pertaining to interconnection and integration with the distribution system. One critical issue is the structure of net-metering and time-based rates to connect the CHP systems to the grid. Standardized building and electrical codes are also necessary to make permitting easier and to boost end-user acceptance. Another critical step is continued aggressive R&D to reduce the cost and improve performance of the fuel cell technologies and address building integration issues. Development of small-scale thermally activated cooling technologies would expand the potential into cooling-dominated regions and afford greater electric demand reduction by shifting cooling load from the electric grid to the CHP system.

P1a Residential Micro-CHP Using Fuel Cells

Description	non-renewable, <10 kw CHP using Fuel Cells		
Market Information:			
Market sector	RES		
End-use(s)	OTH		
Energy types	GAS		
Market segment	RET, NEW		
Basecase Information:			
Description	2,000 sqft average new house		
Efficiency			
Electric use	12,338	kWh/year	avg EUI
Summer peak demand	2.8	kW	50% load factor
Winter peak demand	1.4	kW	base load
Gas/fuel use	89		avg EUI
New Measure Information:			
Description	2 kW PEM fuel cell with waste heat recovery with a 65% time availability		
Efficiency	68% overall	30% elec+ 38% heat recovery	
Electric use	950	kWh/year	net purchased household electricity
Summer peak demand	1.0	kW	90% availability on peak
Winter peak demand	-0.4	kW	90% availability on peak
Gas/Fuel use	113.4		Net gas consumption for power genration plus heating
Current status	FLDTEST		
Date of commercialization	2006		
Life	10	years	Reported 20 yrs likely high: overhaul needed at 40,000 hrs
Savings Information:			
Electricity	11,388	kWh/year	avoided purchased electricity
Summer peak demand	1.8	kW	
Winter peak demand	1.8	kW	
Gas/Fuel	-24	MMBTU/year	Increased gas purchases
Percent savings	42%		Savings in primary energy
Feasible applications	1.3%		2% of new construction and 1% of existing stock
2020 Savings potential	19,068	GWh	
2020 Savings potential	171	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$11,000	2003 $	$5500/kW
Other cost/(savings)	$199	$/year	maintenance and overhaul cost of 1.5 cents/kWh
Cost of saved energy	$0.18	$/kWh	
Cost of saved energy	$17.43	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	New way of doing business, incremental costs, reliability, dwindling natural gas suppleis		
Effect on utility	Increased equipment maintenance		
Current promotion activity	Demonstration projects		
Rating	2	(1-5)	
Rationale	Increased natural gas costs make economics less attractive		
Priority / Next Steps			
Priority	Not		Unless economics improve
Recommended next steps	Reduce product costs, new electrical rate structure to encourage residential co-generation		
Sources:			
Savings	Shipley 2004		
Peak demand	Brown & Koomey 2002		
Cost	Shipley 2004		
Feasible applications	Marbek estimate		
Measure life	Marbek estimate		
Other key sources	Hedman 2002		
Principal contacts			
Notes			

P1B RESIDENTIAL MICRO-COGENERATION USING STIRLING ENGINES

Description of Technology

Distributed power refers to small-scale generation connected to the electricity grid and to generation on the customer side of the meter. It promises low cost, reliable, and efficient power and heat. Stirling Engines are promising distributed power technologies for residential micro-cogeneration. They are heat engines driven by thermal expansion and contraction of a working gas, usually hydrogen. Stirling engines use an external heat source, which simplifies design, minimizes noise and vibration, and allows multi-fuel use. These features make the Stirling engine a promising alternative to the internal combustion engine. The Stirling engine concept originated in the 1800s; however, they were unsuccessful until recently due to the high precision manufacturing processes required. Two types of Stirling engines show potential for residential cogeneration—kinematic Stirling and free-piston Stirling. The free-piston Stirling does away with mechanical linkages, resulting in fewer moving parts, no need for a lubricant, low maintenance costs, and a longer life. Kinematic Stirling engines are typically larger than their free-piston counterparts. Electric capacities for kinematic Stirling units are between 5–500 kW, while the capacities for free-piston units are between 0.01 and 25 kW.

Current Status of Measure

Internationally, several developers and manufacturers have targeted the residential sector for Stirling engine applications, supported in part by government and utility programs. Commercialization is expected in the 2003–2006 period. The emphasis to date has been on engine capacities designed to meet all or a portion of the typical electricity and heating loads required of grid-connected single detached homes. Some European companies involved in Stirling engine research include Gasunie, Gastec, Zantingh, EnergieNed, and ENECO Energie. WhisperGen is a New Zealand company promoting a natural gas 850 W kinematic Stirling unit. In the United States, two firms, Stirling Thermal Motors (STM) and Stirling Technology Co. (STC), are developing Stirling technology onsite generators in sizes upwards of 1 kW. STC offers 5 sizes from 100W to 3kW. Sunpower has developed a prototype biomass-fired 1 kW free-piston Stirling engine and expects to have a commercial model ready by 2006.

Energy Savings and Costs

The Stirling engines are 15–30% efficient in converting heat energy to electricity, with many reporting a range of 25 to 30%. The goal is to increase the performance to the mid-30% range (Krepchin 2002). Early prototypes for the kinematic Stirling cost $10,000/kW, but are expected to reach a mature price of approximately $1,000/kW by 2006. Free-piston Stirling engines are currently more expensive (Sunpower's 1 kW prototype cost $35,000); however, the mature market price is expected to be between $500–1,000 per kW. Stirling engines are expected to run 50,000 hours between overhauls, and free-piston Stirling engines may last up to 100,000 hours (Krepchin 2002).

Key Assumptions Used in Analysis

This analysis assumes 25% electricity conversion efficiency and a 40% waste heat recovery efficiency for space heating and DHW. The analysis assumes an average 1,800 ft^2 house with an annual electricity consumption of 12,338 kWh/year and total space heating and DHW consumption of 89 MMBtu/year. This analysis also assumes a mature cost of $1,000/kW plus overhaul and maintenance costs of 3 cents/kWh.

Recommended Next Steps

Both technical and institutional issues need to be addressed for Stirling engines to be accepted in the residential market. Governments and utilities need to collaborate in dealing with barriers pertaining to connection and integration with the distribution system. Standardized building codes, permit procedures, and electrical interconnection standards are necessary to boost end-user acceptance. Technically, there is a need for continued support to help developers work to lower first costs through a combination of design refinements and material substitution.

P1b Residential Micro-CHP Using Stirling Engines

Description	non-renewable, <10 kw CHP using Stirling Engines		
Market Information:			
Market sector	RES		
End-use(s)	OTH		
Energy types	GAS		
Market segment	RET, NEW		
Basecase Information:			
Description	2,000 sqft average new house		
Efficiency			
Electric use	12,338	kWh/year	avg EUI
Summer peak demand	2.8	kW	50% load factor
Winter peak demand	1.4	kW	base load
Gas/fuel use	89		avg EUI
New Measure Information:			
Description	2 kW Stirling engine with waste heat recovery with a 60% time availability		
Efficiency	65%	overall; 25% elect. + 40% heat recovery	
Electric use	950	kWh/year	net purchased household electricity
Summer peak demand	1.0	kW	90% availability on peak
Winter peak demand	-0.4	kW	90% availability on peak
Gas/Fuel use	115.9		Net gas consumption for power genration plus heating
Current status	PROTO		
Date of commercialization	2006		
Life	10	years	
Savings Information:			
Electricity	13,288	kWh/year	avoided purchased electricity
Summer peak demand	1.5	kW	
Winter peak demand	1.5	kW	
Gas/Fuel	-27	MMBTU/year	Increased gas purchases
Percent savings	50%		Savings in primary energy
Feasible applications	1.3%		2% of new construction and 1% of existing stock
2020 Savings potential	22,249	GWh	
2020 Savings potential	201	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$3,000	2003 $	$1,500/kW
Other cost/(savings)	$266	$/year	maintenance and overhaul cost of 2 cents/kWh
Cost of saved energy	$0.06	$/kWh	
Cost of saved energy	$5.53	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	New way of doing business, incremental costs, reliability, dwindling natural gas suppleis		
Effect on utility	Increased equipment maintenance		
Current promotion activity	Initial field protype trials		
Rating	2	(1-5)	
Rationale	Increased natural gas costs make economics less attractive		
Priority / Next Steps			
Priority	Low		Unless economics improve
Recommended next steps	Reduce product costs, new electrical rate structure to encourage residential co-generation		
Sources:			
Savings	Reiss, Krepchin et al, 2002		
Peak demand	Brown & Koomey 2002		
Cost	Reiss, Krepchin et al, 2002		
Feasible applications	Marbek estimate		
Measure life	Marbek estimate		
Other key sources	Hedman 2002		
Principal contacts			
Notes			

P2 A&B Commercial Micro-CHP Using Fuel Cells and Microturbines

Description of Measure

Commercial combined heat and power refers to the use of reciprocating engines, microturbines, Stirling engines, and fuel cells to produce both electricity and thermal power at or near the building site. Recent advances in small-scale power generation technologies have begun to make CHP a reality, with the potential to both reduce building energy costs and increase power reliability and quality. One key is better thermal technologies for cooling with waste heat, such as absorption refrigeration and desiccant cooling. Reciprocating engine approaches lead today because of their efficiency, reliability, and low installed cost. Fuel cells and microturbines may compete with low emissions, higher thermal temperatures (in some cases), and quiet operation. Fuel cell technologies include proton exchange membrane (PEM), solid oxide (SOFC), direct methanol (DMFC), molten carbonate (MCFC), phosphoric acid (PAFC), and alkaline (AFC). Fuel cell technologies are scalable, allowing for the installation of multiple units to meet an application requirement. While PEM fuel cells are currently the most advanced, SOFC and MCFC are of particular interest for building CHP systems because their higher temperatures allow for use of thermally activated technologies (Shipley 2004). Microturbines (generally < 250 kW capacity) using technologies derived from aircraft engines have been developed by several companies. In the near term, microturbines promise lower cost, higher thermal energy temperatures, and better load following capability (Capstone 2003; Hedman 2002).

Current Status of Measure

A number of companies are currently involved in commercial-scale fuel cell development. They include Nuvera, Ballard, Plug Power, and Siemens Power Generation. The development efforts are being supported by a variety of government technology and innovation initiatives. Most of the companies expect to have products available between 2005 and 2006. There are currently five major manufacturers of microturbine generators. Capstone (30 kW and 60 kW electric capacity), Ingersoll-Rand (70 kW, 250 kW, and 2 MW), Bowman Power (U.K, 80 kW), Elliott, and Turbec (the latter a joint venture between Volvo and ABB in Sweden) produce 100 kW units. All of the manufacturers offer combined heat and power options. Natural gas is the most common fuel, but many of the units can burn other fuels.

Energy Savings and Costs

Once fully developed, SOFC and MCFC are expected to be between 40–50% efficient and cost between $1,000–1,500/kW. Alkaline fuel cells are expected to be 50–60% efficient, and prices should drop to $350–1,000/kW in mass production (E Source 2002). Most fuel cells assemblies for commercial use are being designed for natural gas with capacities in the 150–250 kW range. EIA's 2001 projections predicted that the cost of all types of fuel cells will remain above $4,000/kW in the next few years, only trickling down to $1,400/kW by 2020, though manufacturers are clearly more optimistic about the timing (DOE 2001c; Shipley 2004). Microturbine efficiency has been improving while the cost has been falling as the technology matures. We project that the electric efficiency of a microturbine in CHP configuration will increase to 25% while 40% of the input energy can be recovered as usable thermal energy for an overall operating system efficiency of 65%. The electric efficiency of CHP system turbines is lower than power-only turbines because of the need to raise the exhaust temperature for better thermal performance. The installed cost of microturbine CHP systems is projected to about $1,750/kW (Hedman 2002).

Key Assumptions Used in Analysis

We model a 100,000 commercial office building with energy intensity of 13.4 kWh/ft^2 for electricity and 28.6 kBtu/ft^2 for gas for DHW and space heating. A portion of these energy requirements are met using a building CHP system using either a fuel cell or microturbine. Since the details and availability of any power resale tariff is uncertain, the systems are sized to produce no excess power. Thermally activated cooling technologies were also not explicitly considered. If resale of power were attractive, the systems should be resized to achieve maximum economic benefit based on the specifics of the tariff. The fuel cell system uses 200kW of SOFC with an electricity conversion efficiency of 40% and further 35% of the input energy recovered for space heating or DHW, bringing the overall efficiency to 75%. The installed cost of the fuel cell CHP system is assumed to be

$3,500/kW. A maintenance cost of 1.5 cents/kWh and a stack life of 40,000 hours are assumed. The microturbine system uses 200kW of turbines with an electricity conversion efficiency of 25%, and 40% of the input energy recovered for space heating or thermally activated cooling, bringing the overall efficiency to 65%. The installed cost of the microturbine CHP system is assumed to be $1,750/kW. A maintenance cost of 2 cents/kWh and a 40,000 hours between rebuilds are assumed (Hedman 2002).

Recommended Next Steps

Both the fuel cell and microturbine technologies need further development to reduce cost, improve reliability and enhance operating performance. Additional research is needed to understand how best to integrate CHP systems into buildings to achieve maximum benefit. This includes the use of thermally activated cooling technologies that offer the promise of greater efficiency and load reduction benefits from displacing vapor-compression cooling. In addition, a better understanding of how distributed energy systems interact with the electric system is needed to support utility policies. On the policy front, a number of challenges exist with getting interconnection and tariff issues related to distributed energy systems, including interconnection standards, real time electricity pricing, and tariff structures that allow the sell-back of electricity at certain times.

P2a Commercial Micro-CHP Using Fuel Cells

Description	non-renewable, >10 kw (usually >100kw) CHP		
Market Information:			
Market sector	COM		
End-use(s)	OTH		
Energy types	GAS		
Market segment	RET, NEW		
Basecase Information:			
Description	100,000		sqft office building
Efficiency		National average energy instensity	
Electric use	1,338,998	kWh/year	13.4 kWh/ft²
Summer peak demand	278	kW	55% load factor
Winter peak demand	153	kW	base load only
Gas/fuel use	2860		28.6 kBtu/ft²
New Measure Information:			
Description	200 kW SOFC with heat recovery with 60% time availability		
Efficiency	70%	overall; 45% elect. + 25% heat recovery	
Electric use	200,198	kWh/year	net purchased building electricity
Summer peak demand	97.9	kW	90% availability on peak
Winter peak demand	-27.1	kW	90% availability on peak
Gas/Fuel use	3027.3		
Current status	FLDTEST		
Date of commercialization	2006		
Life	15	years	
Savings Information:			
Electricity	1,138,800	kWh/year	
Summer peak demand	180	kW	
Winter peak demand	180	kW	
Gas/Fuel	-167	MMBTU/year	
Percent savings	69%		
Feasible applications	5%		Marbek estimate
2020 Savings potential	77,226	GWh	
2020 Savings potential	767	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$700,000	2003 $	$3500/kW installed with heat recovery
Other cost/(savings)	$23,088	$/year	maintenance and overhaul cost of 1.5 cents/kWh
Cost of saved energy	$0.07	$/kWh	
Cost of saved energy	$7.36	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	New way of doing business, incremental costs, reliability, dwindling natural gas suppleis		
Effect on utility	Increased equipment maintenance		
Current promotion activity	Demonstration projects		
Rating	2	(1-5)	
Rationale	Increased natural gas costs make economics less attractive		
Priority / Next Steps			
Priority	Low		Unless economics improve
Recommended next steps	Recent natural gas cost increases make economics less attractive		
Sources:			
Savings	Shipley 2004		
Peak demand	Brown & Koomey 2002		
Cost	Shipley 2004		
Feasible applications	Marbek estimate		
Measure life	Shipley 2004		
Other key sources	Hedman 2002		
Principal contacts			
Notes			

P2b Commercial Micro-CHP Using Micro-Turbines

Description	non-renewable, >10 kw (usually >100kw) CHP		
Market Information:			
Market sector	COM		
End-use(s)	OTH		
Energy types	GAS		
Market segment	RET, NEW		
Basecase Information:			
Description	100,000		sqft office building
Efficiency		National average energy instensity	
Electric use	1,338,998	kWh/year	13.4 kWh/ft²
Summer peak demand	278	kW	55% load factor
Winter peak demand	153	kW	base load only
Gas/fuel use	2860		28.6 kBtu/ft²
New Measure Information:			
Description	200 kW microturbine with heat recovery with 65% time availability		
Efficiency	65% overall	25% elect. + 40% heat recovery	
Electric use	200,198	kWh/year	
Summer peak demand	97.9	kW	90% availability on peak
Winter peak demand	-27.1	kW	90% availability on peak
Gas/Fuel use	4037.1		
Current status	FLDTEST		
Date of commercialization	2006		
Life	15	years	
Savings Information:			
Electricity	1,138,800	kWh/year	
Summer peak demand	180	kW	
Winter peak demand	180	kW	
Gas/Fuel	-1,177	MMBTU/year	
Percent savings	63%		
Feasible applications	5%		Marbek estimate
2020 Savings potential	77,226	GWh	
2020 Savings potential	692	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$350,000	2003 $	$1750/kW installed with heat recovery
Other cost/(savings)	$30,784	$/year	maintenance and overhaul cost of 2 cents/kWh
Cost of saved energy	$0.05	$/kWh	
Cost of saved energy	$5.33	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	New way of doing business, incremental costs, reliability, dwindling natural gas suppleis		
Effect on utility	Increased equipment maintenance		
Current promotion activity	Demonstration projects		
Rating	2	(1-5)	
Rationale	Increased natural gas costs make economics less attractive		
Priority / Next Steps			
Priority	Low		Unless economics improve
Recommended next steps	Recent natural gas cost increases make economics less attractive		
Sources:			
Savings	Shipley 2004		
Peak demand	Brown & Koomey 2002		
Cost	Shipley 2004		
Feasible applications	Marbek estimate		
Measure life	Shipley 2004		
Other key sources	Hedman 2002		
Principal contacts			
Notes			

PR1 AUTOMATED BUILDING DIAGNOSTICS SOFTWARE (ABDS)

Description of Technology

Building Automation Systems (BAS) were introduced in the mid-1980s to optimize the operation of HVAC equipment through computerized monitoring and control of HVAC equipment in large commercial buildings. The technology has continuously evolved from the first systems that performed monitoring and simple control via bulky mini-computer based workstations to the latest distributed networks with powerful graphic workstations, wireless web-based components, and expanded self-tuning control algorithms. Despite the level of evolution, the performance of BAS, also referred to as Facility Management Systems (FMS), has been disappointing, falling short of the overall potential to improve comfort while reducing energy use (Krepchin 2001; Turner 2003). Most of the problems stem from the difficulties in operating the BAS once they have been installed and commissioned. Building owners and operators often do not have the necessary dedicated personnel who can solve BAS/FMS problems. There is a tendency to solve building comfort and operational problems through simple "triage" by disabling BAS/FMS control loops or disabling equipment schedules. The next generation of BAS/FMS software, Automated Building Diagnostic Software (ABDS), promises to solve these common problems through the use of more advanced self-tuning control algorithms and automatic data analysis to identify problems and suggest solutions using built-in "expert systems." ABDS is designed to automatically perform building commissioning on an ongoing basis, but without the time, disruption, and cost of a commissioning project. The capacity to provide continuous optimization through control, correction, and monitoring results in a greater certainty of meeting the performance potential.

Current Status of Measure

The ABDS systems are capable of optimizing the performance of both large commercial centralized systems and packaged HVAC equipment used in smaller buildings. ABDS is still in its infancy with the development of the systems being led by private and public research institutions and companies. Currently, there are four ABDS products that are either commercially available or under development. The most versatile and commercially available ABDS tool is the Performance and Continuous Recommissioning Analysis Tool (PACRAT) from Facility Dynamics Engineering. This tool is designed for large commercial buildings. The Whole Building Diagnostician (WBD)—being developed through collaboration among the Pacific Northwest National Laboratories, the California Energy Commission, and the Department of Energy—is a tool designed to provide diagnostics of air handling equipment. The Diagnostic Agent for Building Operators (DABO) system is being developed by the Energy Diversification Research Laboratory (CEDRL) of the Canadian Centre for Mineral and Energy Technology (CANMET). DABO's primary capabilities are to perform diagnosis of air handling units and VAV boxes through continuous monitoring of data and use of artificial intelligence models. A commercially available version is expected to be licensed to DELTA Controls and available in the fall of 2004. The ACRx Handtool, developed by Field Diagnostic Services Inc. and licensed in 2001 by Honeywell, is designed for diagnosis of compressors in packaged equipment and is used primarily in batch mode for troubleshooting during scheduled maintenance intervals (Krepchin 2001).

Energy Savings and Costs

The results from ABDS demonstrations to date indicate that energy savings are similar to what can be achieved through recommissioning with typical savings ranging from 5 to 20%. The demonstration costs for implementation and interface of an ABDS for a 250-point BAS can be up to $50,000. For a 100,000 ft^2 building this translates into a cost of $0.50/$ft^2$. The one-time cost of an ACRx Handtool plus software and sensors is approximately $2,500. There are additional charges during the inspection of equipment to access historical data, which cost another $500. Most of the costs for using an ACRx Handtool are for the technician's time during the inspection plus the required maintenance/repair costs (Krepchin 2001).

Key Assumptions Used in Analysis

For a new construction application, savings of 10% of the total whole building energy use intensity (EUI) are assumed in this analysis. This is equivalent to 2.8 ekWh/ft^2yr (electricity and heat) for an average commercial building, with a whole building EUI of 28 ekWh/ft²yr. Assuming some cost reduction for an eventual maturing of the technology, costs are assumed to be in the range of $0.20 to 0.50/ft².

Recommended Next Steps

The ABDS technology promises to achieve a greater certainty of achieving energy savings and comfort improvement in the commercial building market. However, the successful market penetration of the technology depends on the active support and participation of the major BAS/FMS industry players. The consensus by experts is that 50% or more of the current installed base of BAS/FMS systems do not operate as they are supposed to (Turner 2003). Since most of these systems are being maintained by the original control vendors, the necessary steps to troubleshoot and fix these systems will have to be undertaken by the same vendors. Owners would be unreceptive to the idea of a new software package from a new vendor that is separate from their existing BAS/FMS software. The preferred solution would be one seamless product that represents an upgrade to the existing BAS/FMS front end. It's expected that alliances will need to be formed in order to develop fully integrated products that merge ABDS and the BAS/FMS control software. It's also anticipated that the major control companies will consider in-house development of ABDS for their next-generation systems in order to address the large base of BAS/FMS systems that do not function properly. In 2001, Johnson Controls was the only reported controls company to be actively working on development of ABDS and was in the process of transitioning from a research phase to product development. However, in 2001 Honeywell licensed the ACRx Handtool from Field Diagnostic Services Inc. Program operators should encourage demonstrations of the new features to document savings.

PR1 Automated Building Diagnostics Software

Description	Second-generation BAS/FMS, self-tunning expert systems to optimize HVAC operation		
Market Information:			
Market sector	COM		
End-use(s)	HC, VENT		
Energy types	ALL		
Market segment	RET		
Basecase Information:			
Description	100,000		sq.ft. building with standard BAS/FMS
Efficiency		National average energy instensity	
Electric use	1,338,998	kWh/year	13.4 kWh/ft²
Summer peak demand	278	kW	55% load factor
Winter peak demand	153	kW	base load only
Gas/fuel use	2860		28.6 kBtu/ft²
New Measure Information:			
Description	ABDS optimizes the operation of BAS/FMS and HVAC equipment		
Efficiency	10%	reduction in whole building energy use	
Electric use	1,205,098	kWh/year	
Summer peak demand	250	kW	
Winter peak demand	138	kW	
Gas/Fuel use	2574		
Current status	COMM		
Date of commercialization	2001		
Life	10	years	BAS/FMS front ends are typically updated at 5 to 8 year intervals and sometimes more frequently.
Savings Information:			
Electricity	133,900	kWh/year	
Summer peak demand	28	kW	
Winter peak demand	15	kW	
Gas/Fuel	286	MMBTU/year	
Percent savings	10%		
Feasible applications	30%		applicable to large commercial only
2020 Savings potential	54,481	GWh	
2020 Savings potential	704	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$50,000	2003 $	$0.50/sqft
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$3.95	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Incremental cost, separate software to existing BAS, software from non-control vendors		
Effect on utility	Improved comfort and system reliability		
Current promotion activity	None		
Rating	3	(1-5)	
Rationale	Substantial barriers to overcome but likely to overcome in the long-term		
Priority / Next Steps			
Priority	High/Medium		
Recommended next steps	Control companies need to develop ABDS or form alianses with current vendors		
Sources:			
Savings	Krepchin 2001.		
Peak demand	Brown & Koomey 2002		
Cost	Krepchin 2001.		
Feasible applications	Marbek estimate		
Measure life	Marbek estimate		
Other key sources			
Principal contacts			
Notes			

PR2 ULTRA LOW ENERGY COMMERCIAL BUILDING DESIGNS (50% > CODES)

Description of Practice

The integrated design process (IDP) to produce highly energy efficient and comfortable commercial and institutional buildings has become visible in North America. The IDP Design Assistance Professional (DAP) contributes knowledge of energy-efficient technologies and applications using a variety of analytical tools. Several programs have shown high performance construction using IDP, including Pacific Gas and Electric Advanced Customer Technology Test (ACT^2), Bonneville Power Administration (BPA) Energy Edge, and Canada's C-2000 program. They showed 25–50% energy use reductions relative to the current code, at relatively low costs. A common element is the use of a displacement ventilation (DV) system with radiant cooling (McDonell 2003).

Current Status of Measure

Current initiatives designed to demonstrate the performance of ultra-low energy buildings include the Zero Energy Buildings in the United States, Europe's Zero Energy Developments (ZED), and the International Energy Agency (IEA) Annex 35 Hybrid Ventilation demonstration projects. In London, the new 450,000 ft^2, 40-story UK headquarters of Swiss Re is expected to set new standards for high rise office building construction. It uses a hybrid ventilation system with displacement ventilation that operates when weather conditions do not allow sufficient air exchange. The Swiss Re building designers used computational fluid dynamic (CFD) models to examine the natural ventilation air flow patterns. The CFD modeling showed that the building could rely on natural ventilation 40% of the time and automatically seal itself and go on either heating or cooling mode when weather conditions could not meet the comfort needs (Kitson 2003). Other energy efficiency features of the building include electrochromic glazing and 100% daylighting via light wells. The 8,000 ft^2 Zion National Park Visitor Centre in Utah is another leading-edge high performance building with hybrid ventilation. With the help of a photovoltaic design, the purchased energy use is 64% below that of a conventional design (Criscione 2002a).

Energy Savings and Costs

Energy savings of 50 to 70% over conventional construction can be achieved with the ultra-low energy designs, at zero or low incremental costs. Design optimization tends to reduce HVAC equipment sizes, resulting in lower equipment costs that help to offset the incremental design costs. Most of the IEA Annex 35 Hybrid Ventilation projects, for example, have demonstrated neutral costs. The Bang & Olufsen headquarters in Denmark has a hybrid ventilation design that resulted in an overall construction cost equal to that of a current practice, while the cost of HVAC equipment was 50% less than typical HVAC costs (Hendriksen 2002). Several buildings demonstrated in Canada's C-2000 program have also exhibited similar results (NRCan 2002c).

Key Assumptions Used in Analysis

This analysis is based on a commercial building with a whole building EUI of 28 kWh/ft^2yr (13 kWh/ft^2yr of electricity and 29 kBtu/ ft^2yr of natural gas) and assumes potential energy savings of 65% over current practice. This generates an energy saving of 18.2 kWh/ft^2 yr (equal hydro and heat reduction) and a peak demand reduction of 1.2 W/ft^2, which would not necessarily coincide with the utility peak. We assume an incremental cost of \$1/ft^2.

Recommended Next Steps

The key barriers preventing wider adoption of these design techniques are lack of awareness by owners and developers, and lack of familiarity with tools and techniques by designers. Efforts to accelerate the market take-up focus on three key areas: first, familiarize the design community with how to design displacement ventilation systems (McDonell 2003); second, educate the design community in the use of CFD software—the cost of the software learning curve represents a significant barrier; and third, multiple modeling platforms are required to model non-standard HVAC systems such as photovoltaics or transpired solar collectors (SolarWalls). Beyond the design community itself, there is the need to convey to the target market that the ultra-low energy design offers considerable non-energy benefits, including better health, comfort, and productivity of occupants and tenants. Technology demonstrations and case studies in North America would help; the European experience, while inspiring, often seems remote to building owners in the United States and Canada.

PR2 Ultra Low Energy Commercial Building Designs (50% > codes)

Description	Ultra-Low EE Designs that include use of hybrid/natural ventilation and renewables		
Market Information:			
Market sector	COM		
End-use(s)	ALL		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	100,000		sq. ft. office designed to current practice
Efficiency		National average energy instensity	
Electric use	1,338,998	kWh/year	13.4 kWh/ft²
Summer peak demand	278	kW	55% load factor
Winter peak demand	153	kW	base load only
Gas/fuel use	2860		28.6 kBtu/ft²
New Measure Information:			
Description	high performance design including hybrid ventilation and use of renewables		
Efficiency	65%	reduction in whole building energy use	
Electric use	468,649	kWh/year	
Summer peak demand	222	kW	80% reduction in peak
Winter peak demand	53	kW	
Gas/Fuel use	1001		
Current status	COMM		
Date of commercialization	1998		
Life	40	years	
Savings Information:			
Electricity	870,349	kWh/year	
Summer peak demand	56	kW	
Winter peak demand	99	kW	
Gas/Fuel	1,859	MMBTU/year	
Percent savings	65%		
Feasible applications	10%		Estimate applicable to 10% of new construction
2020 Savings potential	15,421	GWh	
2020 Savings potential	199	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$100,000	2003 $	$1/sqft
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.01	$/kWh	
Cost of saved energy	$0.55	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Negative incentive for design team, hybrid ventilation and design tool knowledge		
Effect on utility	Increased comfort, enhanced productivity		
Current promotion activity	DOE and NREL ZERO Energy Buildings, LEED		
Rating	2	(1-5)	
Rationale	Interest at the high end, but most builders want low first cost and re-use designs		
Priority / Next Steps			
Priority	Special		
Recommended next steps	Information dissemination with focus on high performance designs, designer training		
Sources:			
Savings	Marbek estimate		
Peak demand	Brown & Koomey 2002		
Cost	Criscione 2002; IEA 2002; NRCan 2002		
Feasible applications	Marbek estimate		
Measure life	Marbek estimate		
Other key sources			
Principal contacts			
Notes			

PR3 INTEGRATED COMMERCIAL BUILDING DESIGN (30% > CODE)

Description of Technology

Clients and designers increasingly seek ways to differentiate projects with "green" attributes and efficiency. One of the most important responses to have emerged is the energy performance requirement embodied in the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, which offers a pathway to accelerate market penetration of highly energy efficient buildings in North America. LEED includes points for high energy efficiency by design. Several programs and demonstrations show that LEED-accredited buildings readily achieve performance levels 30% beyond current code.

Current Status of Measure

LEED is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. In the U.S. and Canada, the Green Building Council, representing all segments of the building industry, has the lead role in developing LEED as a national standard for "green construction." The LEED rating includes evaluation of site selection, water efficiency, energy performance and atmospheric pollution, materials and resources, indoor environmental quality, and innovation in the design process. Municipalities and states with design guidelines include the Portland Green Building Initiative Guidelines and the State of Pennsylvania Guidelines for High Performance Buildings (Krepchin 2000). Following publication of the New Buildings Institute (NBI) "e-benchmark," ASHRAE committed to producing guidance documents for highly efficient buildings, too.

Energy Savings and Costs

Energy savings vary significantly. CBIP, BC Hydro, and Enbridge Consumers Gas have minimum targets of 25% better than Canada's Model National Energy Code for Buildings (MNECB). On average, CBIP buildings have shown a modeled performance that is approximately 30 to 35% better than an MNECB reference building (NRCan 2003). Initiatives by Southern California Edison (SCE) Savings by Design program, National Grid US (formerly (New England Electric System) Design 2000 Plus, and others show that 30% savings are readily achievable. Of course, costs vary with performance targets. The most cost-effective Energy Edge buildings (from a 1990s program operated in the Pacific Rim Northwest) had an incremental cost (adjusted to 1998 dollars) of $3/ft^2 (Suozzo and Nadel 1998). Buildings built under the Design 2000 Plus from National Grid were reported to have average incremental costs of $1.30/ft^2. BC Hydro's Design Assistance Program has seen, on average, no incremental cost over the base case design (Marbek Resource Consultants 2003) Canada's C-2000 program showed average costs of approximately 2% more than the base case design.

Key Assumptions Used in Analysis

We have assumed a 30% energy savings above ASHRAE 90.1–2001. This reduction is equivalent to 8.4 kWh/ft^{2}yr for an average commercial building with a whole building EUI of 28 kWh/ft^{2}yr (13 kWh/ft^{2}yr of electricity and 29 kBtu/ ft^{2}yr of natural gas). We also estimate a 0.7 W/ft^2 reduction in peak demand based on a reductions of 0.5 W/ft^2 in lighting and 0.2 W/ft^2 in cooling plant and auxiliaries. We have used incremental costs of $1/ft^2 in our analysis, and we have assumed that the technology applies to 75% of new construction.

Recommended Next Steps

A useful next step to help the design community adopt IDP for new construction is to redesign the fee structures to give bonuses for more efficient designs instead of the equipment cost (Hubbard and Eley 1997). Easy-to-use design tools will help the community and can be the basis for training programs. Dissemination of successful design results to them will give them confidence to adopt IDP and recommend it to clients. Utilities could use incentive programs to provide additional impetus to the market, but must coordinate their programs with existing initiatives sponsored by governments and other green building organizations. In the long term, building codes will need to be revised to reflect a new base level for energy efficiency.

PR3 Integrated Commercial Building Design (30% > Code)

Description	Design for energy efficiency 30% better than 90.1-2001, which is the base LEED level.		

Market Information:

Market sector	COM
End-use(s)	ALL
Energy types	ALL
Market segment	NEW

Basecase Information:

Description	100,000		sq. ft. office designed to current practice
Efficiency		National average energy instensity	
Electric use	1,338,998	kWh/year	13.4 kWh/ft²
Summer peak demand	278	kW	55% load factor
Winter peak demand	153	kW	base load only
Gas/fuel use	2860		28.6 kBtu/ft²

New Measure Information:

Description	Integrated Building Design (IBD) to achieve 30% energy savings over current construction	
Efficiency	30%	reduction in whole building energy use
Electric use	937,299	kWh/year
Summer peak demand	195	kW
Winter peak demand	107	kW
Gas/Fuel use	2002	
Current status	COMM	
Date of commercialization	1995	
Life	40	years

Savings Information:

Electricity	401,699	kWh/year	
Summer peak demand	83	kW	
Winter peak demand	46	kW	
Gas/Fuel	858	MMBTU/year	
Percent savings	30%		
Feasible applications	68%		applicable to 75% of new construction (buildings > 5000 sqft)
2020 Savings potential	48,043	GWh	
2020 Savings potential	620	TBtu (source)	
Industrial savings > 25%	NO		

Cost Information:

Projected Incre. Retail Cost	$100,000	2003 $	$1/sqft
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.01	$/kWh	
Cost of saved energy	$1.19	$/MMBtu	
Data quality assessment	B	(A-D)	

Likelihood of Success:

Major market barriers	Negative incentive for design team, long lead times, incremental costs	
Effect on utility	Increased comfort, enhanced productivity	
Current promotion activity	SCE Savings by Design, National Grid US Design 2000 Plus, LEED	
Rating	3	(1-5)
Rationale	Interest at the high end, but most builders want low first cost and re-use designs	

Priority / Next Steps

Priority	High
Recommended next steps	Change fee structure and bid process, information dissemination

Sources:

Savings	From definition of measure
Peak demand	Brown & Koomey 2002
Cost	Criscione 2002; IEA 2002; NRCan 2002
Feasible applications	Marbek Estimate
Measure life	Marbek Estimate
Other key sources	
Principal contacts	
Notes	

PR4 RETROCOMMISSIONING

Description of Technology

On start-up, many new commercial buildings do not perform as designed. Additionally, commercial building performance tends to degrade over time, unless there are active programs and knowledgeable personnel to operate and maintain equipment and controls. When buildings operate poorly, operators face rising equipment repair costs, rising utility bills, deteriorating indoor air quality, and tenant dissatisfaction. *Retrocommissioning* (RCx) involves a systematic step-by-step process of identifying and correcting problems and ensuring system functionality (Haasl and Sharp 1999). RCx focuses on steps for optimizing the building through O&M tune-up activities and diagnostic testing, though capital improvements may also be recommended. The best candidates for retrocommissioning are those buildings over 100,000 ft^2, with newer HVAC systems, and a functioning building control system. By conducting RCx, building managers can diagnose problems in mechanical systems, controls, and lighting, and improve the overall performance of the building. Improving the functionality of individual mechanical and electrical components, as well as their combined performance as a system, reduces energy consumption, operating costs, and occupant discomfort.

Current Status of Measure

RCx is not a widespread practice, though awareness about its benefits is starting to grow. A small number of utilities and other organizations have developed programs to promote RCx. Programs offer provider and building manager training, technical and financial assistance, and demonstration projects. For example, through its FlexTech and Technical Assistance Programs, the New York State Energy Research & Development Authority offers technical assistance and no-cost scoping studies by trained RCx providers. NYSERDA intends to demonstrate the benefits of RCx through several case studies. Nstar, Xcel, and PGE also have programs (Thorne and Nadel 2003b). There are also efforts to strengthen the commissioning industry. The Northwest Energy Efficiency Alliance initiated the Building Commissioning Association (BCA), which hosts conferences to promote the understanding of commissioning and provides training to professionals involved in the field. Other professional organizations such as The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Association of Energy Engineers (AEE) have also incorporated retrocommissioning into their activities.

Energy Savings and Costs

In 1996, a study conducted of 44 retrocommissioned buildings found that energy savings range from 5% to 15% or more (median of 19%) and energy cost savings range from 2% to 49% (Gregerson 1997). The buildings varied in size and type. RCx investment ranged from 3 to 43¢ per square foot (average of 19¢), with simple payback of two to four years. About half of the projects were conducted by staff and students at Texas A& M University. RCx conducted by professional providers would likely incur higher costs.

Key Assumptions Used in Analysis

For this analysis, we include the floor space of non-warehouse commercial buildings over 100,000 ft^2, plus half the 50,000 to 100,000 ft^2 stock. These are the best candidates for RCx. We also assume an average cost of 25¢/ft^2 and ongoing costs of 5¢/ft^{2}yr, to maintain savings. RCx would most feasible in large buildings that have HVAC systems less than 20 years old and with a functioning control system. These buildings account for about 5% of the number of commercial buildings in the U.S., but about 32% of the commercial building floor area (DOE 2003g Table 2.2.5).

Recommended Next Steps

Despite many demonstrated benefits, RCx faces some important barriers. Most important is simple lack of awareness of the benefits. A number of misperceptions, such as large costs and long-term paybacks, also persist. Therefore, educating building owners and operators on the energy and non-energy benefits and providing training to RCx providers are early critical steps. Assisting owners in conducting site studies and offering financial incentives have also proven to be effective in encouraging buildings owners. There is also need for further training of engineers on how to do RCx well and cost effectively.

PR4 Retrocommissioning

Description	Commissioning existing buildings		
Market Information:			
Market sector	COM		
End-use(s)	HC, VENT, LIGHT		
Energy types	ALL		
Market segment	NEW, RET		
Basecase Information:			
Description	100,000		square foot commercial building
Efficiency	average energy instensity		
Electric use	1,338,998	kWh/year	
Summer peak demand	278	kW	
Winter peak demand	153	kW	
Gas/fuel use	2860		
New Measure Information:			
Description	100,000		square foot retrocommissioned building
Efficiency	10%	reduction of energy consumption	
Electric use	1,205,098	kWh/year	
Summer peak demand	250	kW	
Winter peak demand	138	kW	
Gas/Fuel use	2574		
Current status	COMM		
Date of commercialization	1997		approximate
Life	7	years	
Savings Information:			
Electricity	133,900	kWh/year	
Summer peak demand	28	kW	
Winter peak demand	15	kW	
Gas/Fuel	286	MMBTU/year	
Percent savings	10%		Conservative value from literature reports
Feasible applications	54%		CBECS99 Table B2, buildings>100ksf + 1/2 of 50k
2020 Savings potential	33,506	GWh	
2020 Savings potential	443	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$25,000	2003 $	$.25 per sq. ft.
Other cost/(savings)		$/year	Some staff time to maintain savings and extend equip. life
Cost of saved energy	$0.03	$/kWh	
Cost of saved energy	$2.64	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Lack of awareness; misperception of cost & payback period		
Effect on utility	Decrease equipment maintenance; more comfortable spaces		
Current promotion activity	Demo projects, education/training, financial incentives		
Rating	3	(1-5)	
Rationale	Programs underway now, gradually catching on		
Priority / Next Steps			
Priority	High/Medium		
Recommended next steps	Increased education, incentives, no-cost site studies		
Sources:			
Savings	Thorne & Nadel 2003		
Peak demand			
Cost	Gregerson 1997		
Feasible applications	CBECS 1999		
Measure life	Thorne and Nadel, 2003		
Other key sources	Jennifer Thorne, ACEEE, 202-429-8873; www.peci.org		
Principal contacts			
Notes	Persistence not yet well established.		

PR5 ZERO (NET) ENERGY HOUSES, INCLUDING HOUSES WITH >50% ENERGY SAVINGS

Description of Technology

The goal of zero (net) energy house programs is commercial acceptance of houses that are so efficient that modest investments in onsite renewable energy (photovoltaics and solar thermal, primarily) lead them to use less purchased energy annually than they can sell back as surplus. This includes and builds on integrated design processes (IDP), a fully integrated approach to construction and equipment to maximize savings while minimizing costs. Canada's Residential 2000 (R-2000) program and Advanced House project, Pacific Gas & Electric's ACT^2, the Davis and Stanford Ranch houses, and others demonstrated energy savings of 50 to 60%, relative to current construction practice (Eley Associates 1996a; 1996b). To date, the market penetration of such homes has been low. However, the Zero Energy House (ZEH), a conceptual advance, combines IDP with annual energy self-sufficiency through onsite renewable energy.

Current Status of Measure

The DOE ZEH initiative aims to increase the market penetration of new homes that perform at least 50% more efficiently than those built to current minimum efficiency standards, while also increasing the number of new homes that can meet their own energy needs. DOE has funded "home building" teams consisting of energy efficiency experts and homebuilders to construct four demonstration houses across the U.S. To date, two ZEH homes have been constructed, in Livermore, California and Tucson, Arizona. Through its "Building America" initiative, DOE has also collaborated with the Tennessee Valley Authority (TVA) to build demonstration "Affordable Zero Energy Test Houses" for Habitat for Humanity; two such homes have been built so far.

Energy Savings and Costs

The ZEH demonstration homes built to date have aggressively reduced overall energy use. The 1998 Florida Solar Energy Center (FSEC) demonstration project achieved 82% electricity savings over standard construction. Performance results from two of the ZEH demonstrations shows that relative to code construction, overall energy savings were 51%, with electricity savings ranging from 60 to 82% and fossil fuel savings of 46% (Dakin 2003). The measures in the zero energy package included light colored exterior walls, tight construction and ducts, more insulation and the elimination of insulation defects, fluorescent lighting, and highly efficient appliances. The customer level peak demand reduction for both the FSEC and Livermore ZEH houses was estimated to be 2.4 kW. The incremental cost of constructing the ZEH homes has ranged from $21,000 to $38,000 with approximately half of the cost attributed to the PV system (Dakin 2003).

Key Assumptions Used in Analysis

We have assumed an overall 65% reduction in whole house energy use (85% electricity and 60% space heating and DHW). We have assumed a 2.5 kW peak demand at the customer level, equivalent to an average photovoltaic collector. We expect the incremental cost of a market-mature ZEH to decline significantly, particularly since the PV component is such a large portion of the incremental cost (DOE 2003h). We envision an overall reduction of 30 to 50% relative to the costs of the early demonstration projects. The analysis is based on an assumed average current incremental cost of $\$16/ft^2$ and an assumed mature incremental cost of $\$9/ft^2$.

Recommended Next Steps

The NREL Zero Energy Home (ZEH) program goal is a construction rate of 100,000 ZEH affordable houses by 2020. While the technology is still maturing, the principles are well understood, and true ZEH houses will probably be built within the next 12 to 24 months. The real challenges are those of communication and promotion in order to familiarize builders and home buyers with the design philosophy. The second challenge is to make ZEH cost effective. Current demonstration projects have significant incremental costs, which need to come down. Since a large portion of the cost is in the photovoltaic collectors, a reduction in the manufacturing cost of photovoltaic systems will make a significant contribution towards the reduction of the incremental costs. In the interim, efforts to promote homes with 50% + energy savings, but without the distributed generation, should be encouraged.

PR5 Zero (Net) Energy Houses, Including Houses with > 50% Energy Savings

Description	Residential designs that combine EE construction, efficient appliances and renewables		
Market Information:			
Market sector	RES		
End-use(s)	ALL		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	2,000 sqft average new house		
Efficiency			
Electric use	12,338	kWh/year	avg US EUI per EIA RECS
Summer peak demand	2.8	kW	50% load factor
Winter peak demand	1.4	kW	base load
Gas/fuel use	89		avg EUI
New Measure Information:			
Description	High efficiency package of measures plus photovoltaic system		
Efficiency	65% overall		
Electric use	1,851	kWh/year	85% savings
Summer peak demand	0.3	kW	2.5 kW PV
Winter peak demand	0	kW	
Gas/Fuel use	35.6		60% savings
Current status	FLDTEST		
Date of commercialization	2006		
Life	40	years	
Savings Information:			
Electricity	10,487	kWh/year	
Summer peak demand	2.5	kW	
Winter peak demand	1.4	kW	
Gas/Fuel	53	MMBTU/year	
Percent savings	75%		Savings in primary energy
Feasible applications	8%		Approx. 1.5 million homes by 2020
2020 Savings potential	15,629	GWh	
2020 Savings potential	199	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$18,000	2003 $	$9 per sq. ft.
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.07	$/kWh	
Cost of saved energy	$6.59	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	New way of doing business, incremental costs, reliability, dwindling natural gas suppleis		
Effect on utility	Increased equipment maintenance		
Current promotion activity	Demonstration projects		
Rating	2	(1-5)	
Rationale	relatively low progress in rationalizing construction and integrating components		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Reduce product costs, new electrical rate structure to encourage residential co-generation		
Sources:			
Savings	Dakin 2003		
Peak demand			
Cost	Dakin 2003		
Feasible applications	ACEEE Estimate		
Measure life	Marbek Estimate		
Other key sources			
Principal contacts			
Notes			

PR6 BETTER, EASIER TO USE RESIDENTIAL HVAC SIZING METHODS

Description of Technology

Empirically, furnaces, boilers, and central air conditioners are generally oversized enough to reduce performance. For air conditioners, oversizing causes short-cycling, which reduces efficiency and latent heat capability. For non-condensing furnaces and boilers, short cycling increases off-cycle losses. Oversizing is the norm. For example, James et al. (1997) found that one-half of 400 houses had central air conditioning systems oversized by 20 to 60%, compared to "ACCA Manual J," the most widely used actual load calculation approach. Manual J has been implemented in computer versions by several groups. For retrofits, Manual J requires measurements of window, wall, foundation, and other relevant elements, and estimates of insulation levels and similar parameters for each. This is generally time-consuming, so there is need for trustworthy practices that will save time and convert the information to a form that helps contractors sell equipment and services better.

Current Status of Measure

Market transformation programs in New Jersey, California, and Florida require contractors to complete and submit ACCA Manual J load calculations for incentives, with flexibility on what implementations are used for the analysis. The cost of these computations is presumably borne by the consumer. Available programs take about an hour for all inputs and calculations, less for an operator very experienced with a particular house type. No PDA or simplified programs have been found other than for room air conditioners.

Energy Savings and Costs

ACCA Manual J yields sizes that are generous by 15% (James et al. 1997). In that study, oversizing led to 13% greater air conditioning peak demand (0.3 kW), 4% greater cooling energy use, and 5% greater heating energy (primarily due to short-cycling). These losses could be essentially eliminated with proper sizing. Easier-to-use methods probably would include graphic interfaces, pre-loaded "templates" for most common house types (including defaults for insulation levels), weather data for specific metropolitan areas, and fast ways to estimate wall and floor areas accurately enough. For example, photometric system software integrated into a PDA could size windows and walls and determine house area from exterior photographs (Sachs 2003). Sensitivity analyses and related research are required to help contractors understand how much precision is required for each measured or estimated parameter. Counting amortization of software and time required for a proper analysis, we estimate cost at $75 and potential savings of $40 relative to standard sizing techniques.

Recommended Next Steps

The key barriers to proper sizing are (a) contractors' resistance to changing methods that they believe minimize callbacks, (b) time required to do proper analyses relative to perceived value to customers, and (c) difficulty of doing proper analyses, particularly since some parameters are under owner control (e.g., use of window shading). Funding is required to develop simplified methods, carry out pilot studies, and do the training and related activities required to integrate proper sizing into conventional practice.

PR6 Better, Easier to Use, Residential HVAC Sizing Methods

Description	"Mechanization" of sizing methods to improve accuracy and decrease time		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	ALL		
Market segment	NEW, ROB		
Basecase Information:			
Description	20% oversizing of furnace and CAC		
Efficiency	12, 80	SEER, AFUE	
Electric use	2,123	kWh/year	avg central AC
Summer peak demand	3.24	kW	10 EER, .9 load factor
Winter peak demand	N/A	kW	
Gas/fuel use	65		avg gas heat
New Measure Information:			
Description	Proper sizing		
Efficiency	SEER 12, AFUE 80		
Electric use	2,038	kWh/year	
Summer peak demand	2.8	kW	
Winter peak demand	N/A	kW	
Gas/Fuel use	61.8		
Current status	RES		
Date of commercialization	2005		
Life	18	years	no change
Savings Information:			
Electricity	85	kWh/year	
Summer peak demand	0.42	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	3.25	MMBTU/year	
Percent savings	5%		
Feasible applications	70%		Assume: 20% do Manual J now, and 50% more would if easier
2020 Savings potential	3,055	GWh	
2020 Savings potential	113	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$35	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.007	$/kWh	no credit taken for decreased peak demand
Cost of saved energy	$0.73	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	no product yet, contractor resistance in most states		
Effect on utility	better sizing --> less cycling --> greater comfort & better latent control		
Current promotion activity	none found		
Rating	2	(1-5)	2
Rationale	Good contractors will like better methods, most contractors aren't this savvy		
Priority / Next Steps			
Priority	Low		
Recommended next steps	develop prototype and specifications for commercialization		
Sources:			
Savings	Vieira and others, undated		
Peak demand	Vieira and others, undated		
Cost	Sachs estimate from time savings relative to Manual J calculation		
Feasible applications	ACEEE est., Assume 20% do Manual J now, 50 would if it were much faster and easier		
Measure life	DOE, 2001. Life of CAC unit that would be installed with this sizing method		
Other key sources			
Principal contacts	Vieira (321-638-1404) and Shirey (321-638-1451) at FSEC		
Notes	5% heating savings by Sachs, estimating savings from less short-cycling.		

PR7 BULLS-EYE COMMISSIONING

Description of Technology

"Bulls-eye commissioning" is a technique to spot the most cost-effective areas to address in retrocommissioning (see Practice PR4) by analysis of 15-minute interval billing data. Its premise is that most benefits (80%) can be found with relatively little effort (20% of full RCx) if the right data are analyzed. In this case, the basic tool is graphic display of daily to annual time series of electricity consumption (kW) per 15-minute intervals, data available at low cost with automated meter reading (AMR) meters.

Current Status of Measure

Bulls-eye commissioning was introduced recently and is currently in use by one municipal utility, Eugene (OR) Water and Electric Board (EWEB). This commissioning is specifically designed to find and fix the most severe problems as quickly and inexpensively as possible, rather than carry out comprehensive analyses. It uses the 80:20 label as an indicator of its approach.

Energy Savings and Costs

In the only published study, Price and Hart (2002) suggested that the bulls-eye diagnostic methods added 15% to energy savings in one non-commissioned building whose savings after retrofit were "disappointing." When interval data are analyzed by knowledgeable staff, bulls-eye commissioning is likely to efficiently find control problems including inappropriate equipment schedules. We estimate that the cost is likely to be about $1,950 (AMR purchase and installation, software, and a day of professional time for analysis.)

Key Assumptions Used in Analysis

We assume that bulls-eye effort is done as a form of (retro)commissioning, so that problems will be fixed by a mechanical contractor, and the owner (or program operator) is only exposed to bulls-eye commissioning costs. For other retrocommissioning, repair costs are included. The feasible stock is taken as non-warehouse commercial buildings between 5,000 and 50,000 ft^2. Larger buildings generally need more comprehensive retrocommissioning. We assume a shorter life than for retrocommissioning, because bulls-eye does not include a training component.

Recommended Next Steps

One barrier noted by Price and Hart is that customers often do not accept that their costly computer-controlled HVAC systems are not working optimally. In addition, bulls-eye commissioning, although relatively inexpensive, still has a perceived first cost barrier for the smallest commercial buildings, as the cost of instrumentation and analysis will be about $1,400. We recommend additional field demonstrations in other regions for verification.

PR7 Bulls-Eye Commissioning

Description	Rapid graphic analysis of demand data to find greatest performance anomalies.		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	RET, ROB		
Basecase Information:			
Description	10,000 sq. ft. Commercial building, contractor installed retrofits, no "retrocommissioning."		
Efficiency		Information not in source document	
Electric use		kWh/year	Information not in source document
Summer peak demand	400	kW	
Winter peak demand	N/A	kW	Information not in source document
Gas/fuel use	N/A		Information not in source document
New Measure Information:			
Description			
Efficiency		Information not in source document	
Electric use		kWh/year	Information not in source document
Summer peak demand	340	kW	
Winter peak demand	NA	kW	Information not in source document
Gas/Fuel use	N/A		Information not in source document
Current status	FLDTEST		
Date of commercialization	2002		
Life	5	years	
Savings Information:			
Electricity	73,000	kWh/year	10,000 sq. ft building
Summer peak demand	60	kW	N/A
Winter peak demand		kW	
Gas/Fuel		MMBTU/year	
Percent savings	7.5%		15% savings in good applications, but avg. will be half this
Feasible applications	45%		From CBECS 1999, Table B6, bldgs 5001 to 50,000 s.f.
2020 Savings potential	4,623	GWh	cooling only
2020 Savings potential	47	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,948	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.006	$/kWh	
Cost of saved energy	$0.61	$/MMBtu	
Data quality assessment	D	(A-D)	
Likelihood of Success:			
Major market barriers	Very immature: few examples, one citation, one group		
Effect on utility	more comfortable building		
Current promotion activity	Promotion by Eugene Water & Electric Board		
Rating	3	(1-5)	
Rationale	Will "look" like "RCx-lite" and be an easier sell, since lower perceived risk		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Field Demonstrations and evaluations in other regions		
Sources:			
Savings	Price & Hart, 2002		
Peak demand	Price & Hart, 2002		
Cost	Price & Hart, 2002		
Feasible applications	CBECS, 1999, Table B6 on size distribution of commercial buildings		
Measure life	Estimated.		
Other key sources	None.		
Principal contacts	Price, Hart, Eugene Water & Electric Board, 541-484-2411		
Notes	There is only one literature citation for this practice		

R1 SOLID STATE REFRIGERATION (COOL CHIPS™)

Description of Technology

Cool Chips™ are thin, efficient, and small thermoelectric cooling devices. Thermoelectric cooling uses an electric current to move high-energy electrons (and their associated heat) across a junction between two semi-conductors. Conventional thermoelectric cooling efficiencies are limited to about 10%. Cool Chips use nanotechnology manufacturing to replace the electron transfer junction with a 2 to 10 nanometer gap. This gap enables the electrons to move in one direction only through electron tunneling, thereby preventing heat migration back to the heat source. The result is a cooling coefficient of performance (COP) that is twice that of conventional mechanical cooling systems. Cool Chips also offer reduced operation and maintenance costs (no moving parts), improved environmental performance (no refrigerants and less material), quieter operation, and lower space requirements (as an example, a one-square-inch Cool Chip panel could satisfy the requirements of an average refrigerator [Criscione 2002b]).

Current Status of Measure

The Cool Chips technology is being developed by Cool Chips PLC. Lab-scale production of Cool Chips prototypes is currently underway. The Cool Chips goal is greater efficiency than conventional compressors, with simpler processes that yield competitive products. In December 2002, Cool Chips announced a research agreement with SRI International for prototype characterization and fabrication. The goal of this research is to help develop a manufacturing process for production devices (Cool Chips PLC 2003). Boeing's Phantom Works conducted an independent evaluation and determined that the operating principles of the technology are sound and that the measured physical data comply with the theory (Boeing 2001).

Energy Savings and Costs

There is no prototype demonstration experience from which to obtain measure cost estimates and, consequently, performance assumptions are based on observations emerging from lab scale work. Laboratory results show efficiencies of 50–55% of the theoretical maximum Carnot efficiency, but the developers project that this will ultimately rise to 70 to 80%, approximately 50% better than conventional refrigeration devices now in use (Cool Chips PLC 2003). The company claimed that product costs would be lower compared to conventional compressor technology used in residential refrigerators, saving $20–30 per refrigerator (Cool Chips 2003).

Key Assumptions Used in Analysis

We conservatively assumed savings of 40% relative to conventional refrigerators and air conditioners. We have assumed zero incremental costs. It is too early in the product development cycle for refrigerator manufacturers to speculate on the likely success and production cost of products made with Cool Chips. If the product performs as predicted by the developer, it would ultimately replace mechanical refrigeration throughout the residential market.

Recommended Next Steps

This is a high-risk technology with significant potential if it succeeds. Government's role at this stage is likely limited to providing funds for basic research. The technology is likely to be developed initially for niche applications, such as aerospace. At that point, governments will become the major customers for the technology.

R1 Solid State Refrigeration (Cool Chips™)

Description	Solid-state Thermoelectric cooling system. No moving parts or refrigerants		
Market Information:			
Market sector	R&C		
End-use(s)	REF		
Energy types	ELEC		
Market segment	ROB, NEW		
Basecase Information:			
Description	New refrigerator meeting 2001 standard		
Efficiency	N/A		
Electric use	496	kWh/year	
Summer peak demand	0.07	kW	85% load factor
Winter peak demand	0.07	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	Cool Chip compressor that uses a thermoelectric cooling principle		
Efficiency	40%	improvement in EER	
Electric use	298	kWh/year	
Summer peak demand	0.04	kW	
Winter peak demand	0.04	kW	
Gas/Fuel use	N/A		
Current status	RES		
Date of commercialization	2006		
Life	19	years	same as std refigerator
Savings Information:			
Electricity	198	kWh/year	
Summer peak demand	0.027	kW	
Winter peak demand	0.027	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	40%		
Feasible applications	90%		
2020 Savings potential	16,892	GWh	
2020 Savings potential	171	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.00	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	C	(A-D)	Can the potential improvement in COP be achieved?
Likelihood of Success:			
Major market barriers	Manufacturing hurdles, capital for commercialization		
Effect on utility	More compact, allowing other smaller units or more internal space		
Current promotion activity	On-going R&D		
Rating	3	(1-5)	
Rationale	Economics and non-energy benefits very favorable but technology still immature		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Continue R&D to refine manufacturing process, financing [financing for what?]		
Sources:			
Savings	Criscione 2002.		
Peak demand	Brown & Koomey 2002		
Cost	Cool Chips 2003		
Feasible applications	Marbek estimate		
Measure life	DOE 1995b		
Other key sources			
Principal contacts	Cool Chips PLC, Gibraltar, +350.59995 or +350.586.99000		
Notes			

R2 MODULATING COMPRESSORS FOR PACKAGED REFRIGERATION

Description of Technology

Packaged refrigeration equipment is estimated to account for more than half of the electricity used by refrigeration systems in the commercial sector. Reach-in/display cases consume approximately half of the energy use in packaged refrigeration equipment. The rest is consumed by vending machines, ice-makers, and other equipment (Easton Consultants 1993). Efficient commercial refrigerators and freezers that achieve savings of 25 to +40% (falling under the CEE Tier 1 and Tier 2 categories) are currently available in the North American market. In the U.S., the ENERGY STAR-labeled commercial refrigerators and freezers are the same as CEE Tier 1 equipment. These savings are achieved with improved single-speed compressors and improved insulation, gaskets, and controls. Additional energy can be saved by using modulating compressors and scroll compressors.

Current Status of Measure

Hermetic reciprocating compressors are the most common type of compressor in commercial packaged refrigeration. Energy use of these compressors can be reduced through compressor speed modulation, which can be attained with an electronically commutated motor (ECM). These motors, more commonly referred to as variable speed motors, provide capacity control to more accurately match the refrigeration load (TIAX 2002) and may reduce noise levels, too. Unfortunately, these compressors are not common in North America: Electrolux offers a full range in Europe, but only one model for the U.S. market (Electrolux 2003). Scroll compressors also offer superior performance, reliability, and longevity. New models also have capacity control and so are well suited to capacity modulation with ECMs. Fully modulating scroll compressors, more commonly referred to as variable speed scroll compressors, are available in sizes above 2 hp (Copeland 2003b).

Energy Savings and Costs

Replacement of hermetic reciprocating compressors with variable speed hermetic compressors would reduce energy use ranging 15 to 40%. For example, the Electrolux Americold model shows an EER that is 30% greater than the value of a comparable fixed speed compressor used in a typical two-door commercial reach-in refrigerator. Energy savings of 25 to 50% can be achieved with variable speed scroll compressors based on measured savings for larger 3 hp condensing units. The estimated cost premium of a variable speed compressor ranges from $100 to 150 for a typical 48 cu.ft. two-door, reach-in commercial refrigerator (TIAX 2002).

Key Assumptions Used in Analysis

In this analysis, variable speed compressors are conservatively estimated to save 20% of energy relative to conventional hermetic reciprocating compressor technology. The application comprises the variable speed compressor, ECM, and controls. This would save 640 kWh/year for a typical 48 cu.ft. two-door reach-in commercial refrigerator with an annual consumption of 3,200 kWh/year. The baseline cost of the compressor is assumed to be approximately $500; the incremental cost to include modulation is approximately $150 (or 30%).

Recommended Next Steps

Cost appears to be the main barrier to the manufacture of variable speed scroll compressors in the fractional hp sizes suitable for the commercial packaged refrigeration market. Technical development and demonstration is required to prove performance. In turn, this will support the necessary educational efforts targeted to manufacturers (to consider better compressors and capacity modulation) and to consumers on the benefits of these compressors, which will stimulate demand for this high performance equipment. (TIAX 2002).

R2 Modulating Compressor for Packaged Refrigeration

Description			
Market Information:			
Market sector	COM		
End-use(s)	REF		
Energy types	ELEC		
Market segment	ROB, NEW		
Basecase Information:			
Description	Typical 48 cu.ft. two-door reach-in commercial refrigerator		
Efficiency	N/A		
Electric use	3,200	kWh/year	
Summer peak demand	0.42	kW	87% load factor, provided by Leo Rainer
Winter peak demand	0.42	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	Variable speed compressors with capacity modulation		
Efficiency		20% compressor energy; 18% compressor demand reductions	
Electric use	2,560	kWh/year	
Summer peak demand	0.34	kW	
Winter peak demand	0.34	kW	
Gas/Fuel use	N/A		
Current status	RES		
Date of commercialization	2008		Components are available, but not built into products yet
Life	15	years	
Savings Information:			
Electricity	640	kWh/year	
Summer peak demand	0.08	kW	
Winter peak demand	0.08	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	20%		
Feasible applications	50%		50% of comm refr should be attainable
2020 Savings potential	4,440	GWh	
2020 Savings potential	45	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$150	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.02	$/kWh	
Cost of saved energy	$2.24	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Appliance manufacturers slow to adopt; requires additional design changes; incremental product cost		
Effect on utility	Better temperature control		
Current promotion activity	Energy Star labelled commercial refrigerators, CEE efficiency tiers		
Rating	4	(1-5)	
Rationale	Maturing technology; costs will decline as manufacturing volumes increase		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Demonstration of performance; develop fractional HP scroll compressors		
Sources:			
Savings	Marbek estimate and TIAX 2002		
Peak demand	TIAX 2002		
Cost	Marbek estimate and TIAX 2002		
Feasible applications	Marbek estimate		
Measure life	BPA research 1994; TIAX 2002		
Other key sources			
Principal contacts			
Notes			

R3 EFFICIENT FAN MOTOR OPTIONS FOR COMMERCIAL REFRIGERATION

Description of Technology

Packaged refrigeration equipment is estimated to account for more than half of the electricity used by refrigeration systems in the commercial sector. In the U.S., the ENERGY STAR-labeled commercial refrigerators and freezers are generally at least 25% more efficient than some products in the market. However, the existing stock of packaged refrigeration equipment is considered very inefficient due to the focus by most purchasers on first cost and the lack of effort from manufacturers to differentiate equipment on the basis of energy efficiency (Nadel 2002). Fan and fan motors used in the condensers and evaporators account for 20% of the annual energy use and operate at overall efficiencies as low as 7 to 15%. These low efficiencies are due to both inefficient fans and low cost shaded pole (SP) motors with low efficiencies (TIAX 2002). New axial fan designs enable improved fan performance and advanced electric motors such as brushless DC or electronically commutated motors (ECM) offer motor performance solutions.

Current Status of Measure

Better evaporator and condenser fan-motor combinations are available in the North American marketplace, but their use has been mostly in premium residential refrigerator products. The emergence of these technologies in commercial refrigeration is being affected by voluntary efficiency programs in the U.S. and Canada. The specifications from all these agencies establish acceptable levels of energy consumption. Higher efficiency fan-motor combinations are a part of the manufacturers' strategy for meeting these efficiency levels. The Canadian Standards Association (CSA) issued Energy Performance Standards both for Food Service Refrigerators and Freezers and for Automatic Ice-Makers and Ice Storage Bins in 1998. As of 2000, over 80% of available models of ice-makers met the ice-maker performance standard. In 2001, the U.S. EPA circulated a draft ENERGY STAR specification for reach-in refrigerators and freezers. The Consortium for Energy Efficiency's Tier 2 efficiency specifications for reach-in refrigerators and freezers and also for ice-makers will drive better fan motors.

Energy Savings and Costs

It appears that the majority of currently installed evaporator and condenser fan-motor sets can be replaced with advanced units that can achieve energy savings as high as 70% of the fan-motor energy. The input fan power of an evaporator and condenser in a typical 48 cu.ft. two-door reach-in commercial refrigerator can be reduced from 70W (35W per component) to 20W (10W per component) with use of the energy-efficient fans and motors (TIAX 2002). Incremental costs range from a low of approximately $20 for a better fan with a brushless DC motor to $50 for an ECM motor. The total incremental cost for a commercial fridge would be in the range of $40 to 100 (Nadel 2002; TIAX 2002).

Key Assumptions Used in Analysis

In this analysis, savings of 70% are assumed with replacement of evaporator and condenser fans that draw a total of 35 W each with ECM-equipped evaporator and condenser fan motors that draw 10 W each. This is equivalent to electricity savings of 448 kWh for a typical 48 cu.ft. two-door, reach-in commercial refrigerator with an annual consumption of 3,200 kWh/year.

Recommended Next Steps

Educational material for equipment purchasers on the benefits and economics of energy-efficient commercial refrigeration equipment is highly desirable (Nadel 2002). In turn, this will help purchasers start to demand efficiency and prompt manufacturers to use the more efficient components. The two-tier efficiency standards will also drive the market towards these efficiency fan-motor combinations. The minimum standards should be reset periodically to continue to move the bottom end of the market. The upper tier of products, those rated high efficiency, should ideally be identified using a recognized brand such as ENERGY STAR. Since the current market share for ENERGY STAR commercial refrigerators is around 50% (Smith et al. 2003), EPA should consider revising the ENERGY STAR specification, perhaps to the CEE Tier 2 level. Unfortunately, the total energy consumption of this equipment is small (2,841 GWh in 2020), so it is a low priority.

R3 Efficient Fan Motor Options for Commercial Refrigeration

Description	Efficient fan and ECM motors to reduce evaporator and condenser energy use		
Market Information:			
Market sector	COM		
End-use(s)	REF		
Energy types	ELEC		
Market segment	ROB, NEW		
Basecase Information:			
Description	Typical 48 cu.ft. two-door reach-in commercial refrigerator		
Efficiency	7 - 15%	Overall fan/motor efficiencies	
Electric use	640	kWh/year	
Summer peak demand	0.08	kW	87% load factor
Winter peak demand	0.07	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	Better fans plus brushless DC or ECM motors		
Efficiency	23 - 50%		
Electric use	192	kWh/year	
Summer peak demand	0.03	kW	
Winter peak demand	0.02	kW	
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	2003		Components are available, but only in high-end products
Life	9	years	
Savings Information:			
Electricity	448	kWh/year	
Summer peak demand	0.06	kW	
Winter peak demand	0.05	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	70%		
Feasible applications	40%		Walk-in and reach-in refrigerator and freezers
2020 Savings potential	2,841	GWh	fans are 20% of refrigeration load
2020 Savings potential	29	TBtu (source)	
Industrial savings > 25%	YES		
Cost Information:			
Projected Incre. Retail Cost	$50	2003 $	Range of $40 to $100 - use $50 for mature market cost
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.02	$/kWh	
Cost of saved energy	$1.56	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Appliance manufacturers slow to adopt; incremental product cost		
Effect on utility	None		
Current promotion activity	Energy Star labelled commercial refrigerators		
Rating	4	(1-5)	
Rationale	Maturing technology; costs will decline as manufacturing volumes increase		
Priority / Next Steps			
Priority	Medium		Savings are modest
Recommended next steps	Upgrade Energy Star incentives for CEE Tier 2 units		
Sources:			
Savings	TIAX 2002		
Peak demand	Brown & Koomey 2002		
Cost	ACEEE 2002, TIAX 2002		
Feasible applications	ACEEE estimate		
Measure life	BPA research 1994; TIAX 2002		
Other key sources			
Principal contacts			
Notes			

S1 HIGH PERFORMANCE WINDOWS (U<0.25)

Description of Technology

In most homes, windows are the weak link in terms of energy efficiency and comfort (NRCan 2002) and can account for as much as 25% of the heat loss of homes built to current code. Over the past 10 to 15 years or so, new windows has improved significantly by adopting low emissivity glazing, inert gas fills, insulating spacers, and better design of window frames. Indeed, the small incremental cost of low-e coatings and gas fill have made double pane, low-e gas filled windows commonplace both for new construction and the replacement market, with Canadian Energy Ratings (ERs) ranging from -11 to +15 (NRCan 1994). ER accounts for solar gain and infiltration losses, as well as the transmission losses. Canada's R-2000 standard requires minimum ER in Toronto of -13 (NRCan 2002). To qualify for ENERGY STAR in the U.S, a window must have a U-value no higher than 0.35 Btu/hr-ft^2-°F (that is, an R-value no lower than 2.86 hr-ft^2-°F/Btu). High insulation technology (HIT) windows, also known as "superwindows," are now available in the market offering energy and comfort performance improvements that exceed these requirements.

Current Status of Measure

HIT windows embody incremental design and performance improvements beyond today's energy-efficient windows. For example, using low-e films suspended between 2 panes of glass to create two or more spaces (interpane air space) can achieve performance superior to triple pane windows. These multi-air space windows have the same weight as a double pane window. Alternative HIT window strategies include vacuum windows and aerogels. Due to their high cost, HIT windows are currently best for heating-dominated climates above 5,500 heating degree days/year. HIT window sales currently amount to less than 1% of the North American market. Nevertheless, there are a significant number of HIT products available with a thermal performance greater than R-4 (Arasteh 2003). The National Fenestration Rating Council May 2003 Certified Products Directory (NFRC 2003) lists approximately 360 manufacturers that offer roughly 3,800 window products rated at greater than R-4 and some 80 products beyond R-6. The HIT window products include fixed and operable windows with wood, fiberglass, plastic, and vinyl frames (no aluminum windows). They are available in two- to four-pane units as well as a few double pane units with interpane air spaces. In general, HIT windows rated at R-4 and beyond can replace double pane, low-e, aluminum, thermally broken frame (R-2) windows for both new construction and replacement applications.

Energy Savings and Costs

While energy savings vary by climate, there are performance results from demonstrations and studies in many areas of North America. A 2000 study by LBNL and NFRC showed modeled seasonal heating energy savings of 14 to 16% and fuel cost savings of $50 to 100/year for a typical 2,000 ft² house located in a northern state (Arasteh 2003). Costs of HIT windows are dropping continuously thanks to increased demand and improved technology (Reilly 2001).

Key Assumptions Used in Analysis

The analysis is based on a typical new 2,000 ft² cold climate house with 300 ft² of window area located in Chicago, Illinois with an annual space heating energy use of 84,400 MJ/year (80 MMBtu/year). Space heating energy savings of 15% are assumed, resulting in savings of 12,700 MJ/year (12 MMBtu/year). A cost increment of 20%, or $3.0/ft², of window is estimated, based on a mature market. Current cost differential is approximately $5/ ft² (Thwaites 2003) but this can be expected to narrow with time.

Recommended Next Steps

Energy benefits alone may not convince homeowners and builders to upgrade to HIT windows. Currently, the combination of high incremental first cost and poor awareness of the benefits mean that the cost of the windows will not be fully reflected in the potential sale price of the home. Collaboration with window manufacturers to reduce the incremental cost of HIT windows as was done in the mid-1990s between Viking and BPA would help increase the HIT windows market share. There is also a need for improved promotion of HIT windows by utilities, to encourage their use to help reduce peak cooling loads. Designers and builders should be targeted with promotional campaigns that will raise their awareness of the benefits of the new window designs.

S1 High Performance Windows (U<0.25)

Description	Windows using multiple layers, gas fills, low-e coatings and low conductance frames		
Market Information:			
Market sector	RES		
End-use(s)	HEAT		
Energy types	ALL		
Market segment	NEW, ROB		
Basecase Information:			
Description	2000 sqft. House with 300 sqft of window area		
Efficiency	ıdows with overall U<0.48		
Electric use	2,123	kWh/year	AC use
Summer peak demand	3.24	kW	conventional AC load
Winter peak demand	N/A	kW	
Gas/fuel use	80		>5500 HDD
New Measure Information:			
Description	Triple glazing, low-e gas fill low conductance frame		
Efficiency	<0.25	Overall U-value	
Electric use	1,698	kWh/year	Reduction assumed similar to heating reduction
Summer peak demand	2.59	kW	Reduction assumed similar to heating reduction
Winter peak demand		kW	
Gas/Fuel use	64		
Current status	COMM		
Date of commercialization	1993		
Life	35	years	
Savings Information:			
Electricity	425	kWh/year	
Summer peak demand	1	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	16	MMBTU/year	
Percent savings	20%		
Feasible applications	35%		Homes over 5500 DD
2020 Savings potential	4,534	GWh	
2020 Savings potential	144	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$900	2003 $	
Other cost/(savings)		$/year	
Cost of saved energy	$0.03	$/kWh	
Cost of saved energy	$2.71	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	High first cost,		
Effect on utility	Higher comfort, lower condensation, lower noise		
Current promotion activity	These are currently available and promoted by manufacturers		
Rating	3	(1-5)	
Rationale	Cost effective products can be manufactured as demonstrated by BPA in 1993		
Priority / Next Steps			
Priority	Medium		Savings are modest
Recommended next steps	Utility/manufacturer collaboration to lower first cost and promote awareness		
Sources:			
Savings	LBNL 2003		
Peak demand	Marbek Estimate		
Cost	Thwaites 2003		
Feasible applications	Marbek Estimate		
Measure life	Marbek Estimate		
Other key sources			
Principal contacts	D. Arasteh, LBNL 510-486-6844; S. Thwaites, Thermotech 613-225-1101		
Notes			

S2 ACTIVE WINDOW INSULATION

Description of Technology

The use of an active window insulation (automated venetian blind) system as a daylighting strategy offers potential savings in both lighting and cooling-related energy use. As part of a "smart" integrated window/lighting/cooling system, automated blinds can provide dynamic control of daylight exposure vis-à-vis lighting/cooling requirements and current operating conditions.

Current Status of Measure

Automated venetian blinds are currently in a pre-market status, being produced in very limited quantities with field tests underway (LaFrance 2003; Lee 2003).

Energy Savings and Costs

Testing by Lawrence Berkeley National Labs of an automated venetian blind system in a southeast-facing private office in Oakland, California (over the course of a year) identified a daily lighting energy use reduction of 1–22%, daily cooling load reduction of 13–28%, and peak cooling loads reduction of 13–28%. Incremental cost at the Oakland test bed site was determined to be approximately \$7–8/ft^2-glass (or \$3–4/ft^2-floor), including balance of system (power source, motor, drive electronics, microprocessor, software, photodetectors, dimmable ballasts, remote control, wiring, installation, commissioning, and maintenance). Simple payback of the integrated system was estimated at 10 years at \$0.09/kWh (Lee et al. 1998).

Key Assumptions Used in Analysis

DOE-2 building energy simulations have predicted annual energy savings from an integrated venetian blind/lighting system in a Los Angeles commercial building at 16–26% and annual peak demand reductions at 17–24% (with any exposure except north) over a baseline advanced spectrally selective window system (Lee and Selkowitz 1998).

Results of the DOE-2 energy simulations have been used in the analysis for commercial buildings, with residential benefits assumed at half the level of commercial benefits. Incremental cost estimates of \$7.50/ft^2-glass have been assumed, based on the LBNL analysis. The residential building assumed in this analysis has 2,000 ft^2 of floor space and 300 ft^2 of window; commercial building is assumed at 25,000 ft^2 of floor space and 2,000 ft^2 of window.

Recommended Next Steps

Cost is still a predominant issue with active window insulation, and additional sales would likely improve economies of scale. Additional research may bring further cost reductions, although research is currently focused on alternative technologies, such as electrochromic glazings, that achieve similar function without obstructing views.

S2a Active Window Insulation

Description	Automated venetian blinds for residential		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ALL		
Market segment	NEW, RET		
Basecase Information:			
Description	2000 sqft. House with 300 sqft of window area		
Efficiency			
Electric use	2,123	kWh/year	Avg AC use
Summer peak demand	3.24	kW	conventional AC load
Winter peak demand	N/A	kW	
Gas/fuel use			
New Measure Information:			
Description	Exterior window application		
Efficiency			
Electric use	1,900	kWh/year	Res. elec savings assumed at 50% of comm. level = 10.5%
Summer peak demand	2.9	kW	Res pk dmd reduc assumed at 50% of comm. level = 10.25%
Winter peak demand	N/A	kW	
Gas/Fuel use	N/A		
Current status	FLDTEST		
Date of commercialization	2006		estimate
Life	15	years	Midpoint of 10-20 range estimated by LaFrance
Savings Information:			
Electricity	223	kWh/year	
Summer peak demand	0.3	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	11%		
Feasible applications	20%		Competing with drapes in residential retrofit market
2020 Savings potential	4,011	GWh	
2020 Savings potential	41	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,688	2003 $	Assumed $7.50/sqft, 3/4ths of all windows
Other cost/(savings)		$/year	
Cost of saved energy	$0.73	$/kWh	
Cost of saved energy	$72.23	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Cost; competition with conventional products		
Effect on utility	Decreased glare, better light control, but some maintenance likely		
Current promotion activity	Premature, not in production yet		
Rating	1	(1-5)	
Rationale	Cost issues		
Priority / Next Steps			
Priority	Not		
Recommended next steps	None		
Sources:			
Savings	Lee and Selkowitz 1998; 2001 RECS		
Peak demand	Lee and Selkowitz 1998; Nadel & Sachs		
Cost	Lee et al. 1998		
Feasible applications			
Measure life	LaFrance 2003		
Other key sources			
Principal contacts	Eleanor Lee, LBL		
Notes			

S2b Active Window Insulation (Automated), commercial

Description	Automated venetian blinds for commercial		
Market Information:			
Market sector	COM		
End-use(s)	COOL, LIGHT		
Energy types	ALL		
Market segment	NEW, RET		
Basecase Information:			
Description	25K sqft commercial building		assumed 2000 sqft window
Efficiency			
Electric use	372,500	kWh/year	1999 CBECS, Table C10, p.172
Summer peak demand	66.7	kW	500 sqft/ton = 50 tons; EER 9
Winter peak demand	N/A	kW	
Gas/fuel use			
New Measure Information:			
Description	Exterior window application		
Efficiency			
Electric use	294,275	kWh/year	21% ann energy sav (midpoint of LBL 1998 claim: 16-26%)
Summer peak demand	53	kW	20.5% pk dmd reduc (midpoint of LBL 1998 claim: 17-24%)
Winter peak demand	N/A	kW	
Gas/Fuel use	N/A		
Current status	FLDTEST		
Date of commercialization	2006		estimate
Life	15	years	Midpoint of 10-20 ranged estimated by LaFrance
Savings Information:			
Electricity	78,225	kWh/year	
Summer peak demand	12	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	21%		
Feasible applications	32%		Estimate of apps. with right "demographics" (40%) and lighting needs (80%)
2020 Savings potential	9,205	GWh	
2020 Savings potential	93	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$15,000	2003 $	Assumed $7.50/sqft, all windows
Other cost/(savings)		$/year	
Cost of saved energy	$0.02	$/kWh	
Cost of saved energy	$1.83	$/MMBtu	
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Cost; competition with conventional products		
Effect on utility	Decreased glare, better light control, but some maintenance likely		
Current promotion activity	Premature, not in production yet		
Rating	2	(1-5)	
Rationale	Cost issues		
Priority / Next Steps			
Priority	Special		
Recommended next steps	None		
Sources:			
Savings	Lee and Selkowitz 1998; 1999 CBECS		
Peak demand	Lee and Selkowitz 1998; Nadel & Sachs		
Cost	Lee et al. 1998		
Feasible applications			
Measure life			
Other key sources			
Principal contacts	Eleanor Lee, LBL		
Notes			

S3 ELECTROCHROMIC GLAZING (ACTIVE GLAZING)

Description of Technology

Electrochromic glazing permits dynamic changes of a window's thermal, solar, and visible transmittances by applying small amounts of electric current to an electrochromic film affixed to the glass. Designs can incorporate manual or automatic actuation through devices such as rheostats, thermostats, photocells, etc. Several electrochromic technologies are under study, including a design using electrically conductive layers of film that exchange ions when a voltage (or negative voltage) is applied (Lee and DiBartolomeo 2000).

Current Status of Measure

Electrochromic glazing is a research, development, and demonstration area today.

Electrochromics are currently being produced in pilot-scale quantities and undergoing limited field tests. Commercially, they may first be seen in residential sector skylights, where smaller glazing size and defects are of less concern. Later, promising markets include commercial buildings, where both cooling costs and peak shaving opportunities are high, especially where both cooling and heating benefits can be achieved.

Energy Savings and Costs

Electrochromic glazing offers savings through cooling, lighting, and peak load reduction. Electrochromic glazing has the potential to reduce peak cooling loads by 10% (Scruton 2003) to 20–30% (Lee, DiBartolomeo, and Selkowitz 2000) in perimeter zones of commercial buildings. At more than $\$100/ft^2$, electrochromic glazing is currently cost-prohibitive, although extensive research continues in this area. With an incremental cost target of $\$25/ft^2$ by 2007 (which may be optimistic), according to Scruton (2003) and $\$5/ft^2$ by 2020, electrochromics continue to receive a few million dollars per year in research support, as seen in the recent DOE grants awarded to Sage Electrochromics and Rockwell (DOE 2003c; LaFrance 2003).

Key Assumptions Used in Analysis

Recent presentations show electrochromic glazings yielding cooling energy savings up to 28% and heating energy savings up to 31% (Sage Electrochromics 2003). Because these numbers represent best-case performance, we assume half of those savings in commercial buildings and heating residential buildings; cooling in residential buildings is assumed to be one-quarter of the best-case savings specified above.

Recommended Next Steps

Price is the major barrier; little else will matter until costs fall to a tenth or less of their present levels. It should be noted that reductions achieved through electrochromic glazings are accompanied by a significant reduction in visible transmittance. Thus, cooling load reductions provided by the glazings are likely to be offset by some degree of lighting use increase. Further research is necessary to improve material performance and reduce costs. Until electrochromic glazings can become more competitive in the marketplace, they are likely to remain a niche product.

S3a Electrochromic Glazing - residential

Description	Smart windows that lighten or darken in response to the outdoor environment		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	2000 sqft. House with 300 sqft of window area		
Efficiency			
Electric use	2,123	kWh/year	Avg AC use
Summer peak demand	3.24	kW	conventional AC load
Winter peak demand	N/A	kW	
Gas/fuel use	65		Avg gas space heat
New Measure Information:			
Description	Electrochromic use in exterior windows		
Efficiency			
Electric use	1974	kWh/year	Res. elec savings assumed at 50% of comm. level = 7%
Summer peak demand	3.1	kW	Res pk dmd reduc assumed at 50% of comm. level = 5.75%
Winter peak demand	N/A	kW	Winter pk dmd reduc assumed at 100% of comm. level = 11.5%
Gas/Fuel use	54.9		Gas/Fuel savings assumed at 100% of comm. level = 15.5% sav.
Current status	FLDTEST		
Date of commercialization	2008		
Life	20	years	
Savings Information:			
Electricity	149	kWh/year	
Summer peak demand	0.2	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	10	MMBTU/year	
Percent savings	13%		
Feasible applications	5%		Cost prohibitive; used for aesthetics over energy savings
2020 Savings potential	55	GWh	
2020 Savings potential	3	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$1,125	2003 $	Assumed $5/sqft long-term, 3/4ths of all windows
Other cost/(savings)		$/year	
Cost of saved energy	$0.08	$/kWh	
Cost of saved energy	$7.80	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Cost, durability, performance		
Effect on utility	Improved thermal and visual comfort		
Current promotion activity	DOE supported research		
Rating	2	(1-5)	
Rationale	Technical and economic barriers		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Continued product development		
Sources:			
Savings	Sage 2003; 2001 RECS; Nadel 2003		
Peak demand	Sage 2003; Nadel 2003		
Cost	LaFrance 2003		
Feasible applications	LaFrance 2003; Lee and DiBarolomeo 2000; Lee et al. 2000		
Measure life	Pitts 2003; LaFrance 2003; Lee and DiBartolomeo 2000; Lee et al. 2000		
Other key sources			
Principal contacts			
Notes			

S3b Electrochromic glazing - commercial

Description	Smart windows that lighten or darken in response to the outdoor environment		
Market Information:			
Market sector	COM		
End-use(s)	HC		
Energy types	ELEC		
Market segment	NEW		
Basecase Information:			
Description	25000		sqft commercial building with 2000 sqft window
Efficiency			
Electric use	43,950	kWh/year	Based on national average EUIs for cooling and heating
Summer peak demand	22.8	kW	22% load factor
Winter peak demand	N/A	kW	
Gas/fuel use	715		Based on national average EUIs for cooling and heating
New Measure Information:			
Description	Electrochromic use in exterior windows		Using specs of SageGlass 2003, cut in half
Efficiency			
Electric use	37,797	kWh/year	Cooling energy savings up to 28%
Summer peak demand	20.2	kW	Peak demand energy savings up to 23%
Winter peak demand	N/A	kW	
Gas/Fuel use	604.2		Heating energy savings up to 31%
Current status	FLDTEST		
Date of commercialization	2008		
Life	20	years	
Savings Information:			
Electricity	6,153	kWh/year	
Summer peak demand	2.6	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	111	MMBTU/year	
Percent savings	15%		
Feasible applications	5%		Cost prohibitive; used for aesthetics over energy savings
2020 Savings potential	110	GWh	
2020 Savings potential	3	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$10,000	2003 $	Assumed $5/sqft long-term, all windows
Other cost/(savings)		$/year	
Cost of saved energy	$0.05	$/kWh	
Cost of saved energy	$4.64	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Cost, durability, performance		
Effect on utility	Improved thermal and visual comfort		
Current promotion activity	DOE supported research		
Rating	3	(1-5)	
Rationale	Technical and economic barriers		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Continued product development		
Sources:			
Savings	Sage 2003; 1999 CBECS; Nadel 2003		
Peak demand	Sage 2003; Nadel 2003		
Cost	LaFrance 2003		
Feasible applications	LaFrance 2003; Lee and DiBartolomeo 2000; Lee et al. 2000		
Measure life	Pitts 2003; LaFrance 2003; Lee and DiBartolomeo 2000; Lee et al. 2000		
Other key sources			
Principal contacts			
Notes			

S4 ATTIC FOIL THERMAL ENVELOPE (RESIDENTIAL)

Description of Technology

Typical residential construction separates the upper weather barrier from the upper thermal barrier: a pitched roof protects from rain and snow, while an insulated ceiling is supposed to isolate the attic thermally from the living area, controlling both exfiltration and conductive/radiative heat transfer. Unfortunately, in the world of real buildings, the situation is more complex. Radiant barriers such as reinforced aluminum foil can mitigate the transfer of heat from the very hot roof to the cooler insulation top side, thus decreasing the flow of heat to the occupied space during the cooling season. By definition, radiant barrier materials must have high reflectivity (usually 0.9, or 90%, or more) and low emissivity (usually 0.1 or less) and must face an open air space to perform properly (DOE 1991).

Current Status of Measure

Radiant barriers are commercially available, but with low market penetration. For example, in Florida, where benefits would be nearly maximum and where the product has been promoted and tested for years, current market share is about 1.8% (Parker, Sherwin, and Anello 2001). From this we infer that national and even regional shares are substantially less than 2%.

Energy Savings and Costs

From DOE (1991) we take the unit cost of radiant barriers as half the unit cost of R-19 insulation, or 30¢/ ft^2. Both Medina (2000) and DOE (1991) noted that savings are inverse to the level of attic insulation in place, ranging from 42% of ceiling heat transfer with R-11 insulation down to 25% with R-30 insulation. DOE (1991) noted that ceiling heat flow is only 15–25% of total heat gain, so the range of gains is only 4 to 10% in the total cooling bill.

Key Assumptions Used in Analysis

We assume 9% cooling energy savings and 16% unit reduction in peak demand (3.6 kWh/day and 0.42 kW, respectively, per Parker, Sherwin, and Anello (2001), and also applicability in humid regions, that is, 25% of houses. We assume national shipment-weighted average central air conditioners (SEER 11.1, EER 9). We assume a 20-year life for downward-facing foil radiant barriers installed under attic roofs; there seems little evidence of degradation over time of the downward-facing surface from dust, etc, so the remaining dangers would be mechanical damage (Yarbrough 2003).

Recommended Next Steps

Roofers are not enthusiastic, since radiant barriers marginally raise roof temperatures (ca. 3ºF) and could thereby shorten roof assembly life. The product has suffered also from "hyping" by vendors claiming savings of 30% or more. Radiant barriers mounted on attic floors instead of being hung from rafters or attached to sheathing may lose some effectiveness as dust accumulates and reduces reflectance/increases emissivity. From examination of the tables in DOE (1991), the best applications will be hot climate retrofits where additional attic insulation would be even harder to install and where the attic is adequately ventilated. No large-scale steps are recommended nationally: regional/state promotion may be appropriate in hot climates, particularly with capacity constraints (measure appears to reduce peak demand more than energy use).

S4 Attic Foil Thermal Envelope (Residential)

Description	Foil to decrease heat transfer from roof to attic insulation		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	R-19 ceiling insulation		
Efficiency			
Electric use	2,123	kWh/year	Avg AC use
Summer peak demand	3.24	kW	conventional AC load
Winter peak demand	N/A	kW	
Gas/fuel use	N/A		
New Measure Information:			
Description	R-19 ceiling insulation + radiant barrier		
Efficiency			
Electric use	1,932	kWh/year	9% savings
Summer peak demand	2.72	kW	16% demand savings
Winter peak demand	N/A	kW	
Gas/Fuel use	N/A		
Current status	COMM		
Date of commercialization	1975 (est).		
Life	20	years	Estimate for against-rafter (2-surface) installation.
Savings Information:			
Electricity	191	kWh/year	
Summer peak demand	0.52	kW	Parker et al, adj. for smaller houses (420 w. saved v. 640)
Winter peak demand	N/A	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	9%		
Feasible applications	30%		Hot climate, attic HVAC
2020 Savings potential	2,699	GWh	
2020 Savings potential	27	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$390	2003 $	From DOE 1991, Sachs adjustments
Other cost/(savings)		$/year	
Cost of saved energy	$0.16	$/kWh	
Cost of saved energy	$16.22	$/MMBtu	Not Cost-effective
Data quality assessment	C	(A-D)	
Likelihood of Success:			
Major market barriers	Poor payback, Homeowners & contractors unfamiliar, skeptical.		
Effect on utility	Cools living space top floor, ca. 2 degrees (Parker and others)		
Current promotion activity	Many commercial sources advertise		
Rating	2	(1-5)	
Rationale	Benefits hard to articulate properly, much confusion in literature and on web.		
Priority / Next Steps			
Priority	Not		
Recommended next steps	Educate builders and consumers on realistic savings potential.		
Sources:			
Savings	Parker and others, 2001		
Peak demand	Parker and others, 2001		
Cost	DOE, 1991, ACEEE modified		
Feasible applications	ACEEE, quarter of country with max. ac intensity (ca. 1500 hr/yr or more)		
Measure life	No data found; degradation by tearing or dust-buildup. Estimate 20 yr. functional		
Other key sources	DOE, 1991		
Principal contacts	Reflective Insulation Manufacturers Association, www.rima.net, 480-513-4749		
Notes			

S5 RESIDENTIAL COOL COLOR ROOFING

Description of Technology

Light color roofing material has been used widely in cooling-dominated climates to reduce the summer contribution of solar-driven roof gains. Typically these lighter colored roofing materials are used on commercial or industrial buildings with flat roofs not visible from the ground. These reflective surfaces haven't found popularity in the residential sector due primarily to aesthetic issues associated with having a shiny white roof surface. New "cool" color technology research has developed products that reflect heat regardless of color. These products came from military research in the early 1980s where the goal was to find pigments that would confuse infrared sensors. The cool colors achieve high infrared reflectance (~65%) by adding metallic elements to get a product with a traditional appearance that has an improvement in total solar reflectance (TSR) of 150 to 500%.

Current Status of Measure

Although cool colors have only had limited success in the residential market (less than 1% market share), significant research is being completed at national laboratories and major roofing manufacturers. Much work is being done to incorporate the technology into darker roofing materials since this combination promises the greatest benefit. The status of these technologies varies from development to commercialized. Metal roof manufacturers currently offer cool roofs using these pigments and work with the color manufacturers to incorporate the new, more efficient products when they become available. The Cool Metal Roofing Coalition is a consortium of manufacturers that has been encouraging the use of cool colors in the building industry (CMRC 2003). Clay tile cool roofs are in the prototype phase, and the asphalt shingles and cedar shakes are also under development. Oak Ridge National Laboratory is currently working with the California Energy Commission and the Sacramento Municipal Utility District on a demonstration program for two products. Four houses will be built in Sacramento, California, two with metal roofs and two with tile roofs. Each pair of houses will consist of one base case and one cool roof.

Energy Savings and Costs

The current ENERGY STAR Cool Roof simulation model available online at the ORNL website estimates 60% roof cooling load reduction using cool color roofing (ORNL 2003). Savings will vary depending on the product, the climate, house insulation characteristics, and amount of cooling energy use. Reduction in cooling peak demand and improved duct efficiencies (for attic-ducted systems) are also significant in cooling dominated climates. Depending on the product, the climate, and the house insulation characteristics, the savings and paybacks can vary widely—indeed, there will be no cost differential for some categories (Scruton 2003). Peak demand benefits and improved duct efficiencies are also significant in cooling-dominated climates where attic ducts are common.

Key Assumptions Used in Analysis

With residential roofs contributing approximately 11% to annual residential cooling energy consumption (DOE 2003g), savings of 6.6% are projected based on the estimated 60% roof cooling load savings. Estimated cost is assumed to be 10¢/ft^2 of roof area. Estimated life for asphalt roofing is 20 years and 40 years for metal and tile roofs.

Recommended Next Steps

The most important issue identified by manufacturers and ORNL is education of the public and builders as to the potential savings these products offer. Upon completion of the Sacramento study, data will be available for development of a case study. Additional regional studies would further document Cool Roof performance. Cost-benefit evaluations could then be completed with results disseminated to builders, architects, and policy makers. Utility incentives and building codes that recognize the benefit of cool colors would be appropriate.

S5 Residential Cool Color Roofing

Description	Dark colored pigments which have high reflectance		
Market Information:			
Market sector	RES		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	Standard house with dark asphalt shingles		
Efficiency	20%	Total solar reflectance	
Electric use	2,123	kWh/year	Energy Databook, national average cooling
Summer peak demand	3.24	kW	
Winter peak demand	NA	kW	
Gas/fuel use			
New Measure Information:			
Description	asphalt shingles with cool color		
Efficiency	34%	Total solar reflectance	
Electric use	1,690	kWh/year	60% savings from roof and duct load
Summer peak demand	3.03	kW	
Winter peak demand	NA	kW	
Gas/Fuel use			
Current status	COMM		
Date of commercialization	2004		
Life	20	years	depends on product
Savings Information:			
Electricity	433	kWh/year	
Summer peak demand	0.21	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	N/A	MMBTU/year	
Percent savings	20%		
Feasible applications	70%		70% of national market
2020 Savings potential	14,276	GWh	
2020 Savings potential	144	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$200	2003 $	$.10/sqft
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.04	$/kWh	
Cost of saved energy	$3.67	$/MMBtu	
Data quality assessment	B	(A-D)	Good data for metal roof, but other technologies need R&D
Likelihood of Success:			
Major market barriers	Cost, consumer education, need product for asphalt shingle market		
Effect on utility	Improved comfort		
Current promotion activity	Limited		
Rating	3	(1-5)	
Rationale	Metal roof barriers can be overcome, other technologies require development		
Priority / Next Steps			
Priority	Medium		
Recommended next steps	Educate builders and consumers, about metal now and other techs when available.		
Sources:			
Savings	Desjarlais 2003, Reid 2003, Nixon 2003b		
Peak demand	Desjarlais 2003, Parker et al. 2000		
Cost	Desjarlais 2003		
Feasible applications	DEG estimate		
Measure life	Various manufacturers		
Other key sources	Nixon 2003a		
Principal contacts	Nixon, Shepherd (513-874-0714), Desjarlais, ORNL (865-574-0022)		
Notes			

S8 HIGH QUALITY ENVELOPE INSULATION

Description of Technology

Current industry standard construction practice focuses on rapid installation of wall insulation with little attention to detail. Although standard width wall cavities with no obstructions (such as wiring, piping, electrical outlets, etc.) are often adequately insulated, many non-standard cavities are poorly insulated. Insulation is crammed into these narrow cavities, batts are compressed, and voids are common in areas where added labor is necessary for proper installation. Field measurements performed at ten California production homes (DEG 2002) led to the adoption of California Title 24 energy standards that degrade typical cavity insulation R-value to 69% of nominal, while providing a credit for third-party verified "quality" insulation installation. Two alternatives exist for improving the installed performance of wall insulation. The first requires improved training and compensation for insulation contractors to provide them the knowledge and time to properly insulate a home. The second is use of spray-applied insulation, which if installed properly results in a void-free wall cavity.

Current Status of Measure

A number of fiberglass insulation contractors offer a "premium" service to install zero defect wall insulation. Much of this attention has been driven by construction quality programs such as MASCO's Environments for Living (EFL) program. Spray-applied cellulose is a competing product providing performance equal to or exceeding "zero defect" batts. To date, it has not achieved significant penetration in the production home market. As more and more builders enter quality construction programs, they quickly realize the benefits of proper insulation installation and will hopefully adopt it as standard practice in all their homes.

Energy Savings and Costs

For a typical sized home, the added cost for proper batt insulation is about $250 (Stover 2001) and for spray-applied cellulose is about $300–400 (Lea 2003). DOE's Energy Databook estimated that on a national basis, 15% of heating loads and 8% of cooling loads are due to energy transfers through walls. Savings will vary with climate and indoor thermostat setpoints.

Key Assumptions Used in Analysis

Wall assembly U-values were calculated for a nominal 2x4 wall (16 inches on center) with standard R-13 batt insulation and zero defect installation. The overall wall average R-value improved from 8.2 to 9.7, after accounting for framing factor effects. An incremental cost of $250 was assumed.

Recommended Next Steps

The construction industry is slow to adopt new construction practices that don't directly translate into increased marketability or reduction in cost. With the advent of quality construction programs such as EFL, builders are starting to realize the benefits of a wide range of measures including improved wall insulation. Improved indoor comfort translates into happier homeowners resulting in a positive impact on a builder's bottom line. Energy codes and utility incentives should recognize (and credit) improved wall insulation practices to help promote its acceptance.

S8 High Quality Envelope Insulation

Description	Properly installed batts or spray cellulose wall insulation		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	2x4 R-13 framed wall		26% framing factor
Efficiency	R-8.2 effective R-value	includes framing factor and insulation defects	
Electric use	2,123	kWh/year	Energy Databook, national average cooling
Summer peak demand	3.24	kW	
Winter peak demand	NA	kW	
Gas/fuel use	65		Energy Databook, national average gas heating
New Measure Information:			
Description	High quality wall insulation with spray cellulose or "zero defect" batt		
Efficiency	R-9.7 effective R-value	includes framing factor	
Electric use	2,097	kWh/year	save 15.3% of wall's 8% cooling contribution
Summer peak demand	3.20	kW	save 15.3% of wall's 8% cooling contribution
Winter peak demand	N/A	kW	
Gas/Fuel use	63.5		save 15.3% of wall's 15% heating contribution
Current status	COMM		
Date of commercialization	1970's		
Life	50	years	
Savings Information:			
Electricity	26	kWh/year	
Summer peak demand	0.04	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	1.5	MMBTU/year	
Percent savings	2%		
Feasible applications	90%		of new homes
2020 Savings potential	349	GWh	
2020 Savings potential	15	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$250	2003 $	
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.08	$/kWh	
Cost of saved energy	$7.81	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Education of consumers, education of builders/insulation contractors		
Effect on utility	Potential equipment sizing benefit, improved comfort, reduced builder liability		
Current promotion activity	Quality construction programs (e.g. Environments For Living), CA 2005 Energy code		
Rating	2	(1-5)	Due to marginal economics
Rationale	Market is starting to expand as builders see benefit, could become standard practice		
Priority / Next Steps			
Priority	Low		
Recommended next steps	Educate builders and insulation contractors, promote through codes		
Sources:			
Savings	DEG 2002		
Peak demand	DEG Estimate		
Cost	Lea 2003, Stover 2001		
Feasible applications	DEG Estimate		
Measure life	Lea 2003		
Other key sources	www.energy.ca.gov/2005_standards/documents/2002-04-23_workshop/2002-04-23_WORKSHOP_REPORT.PDF		
Principal contacts	Lea 2003		
Notes			

S9 ENGINEERED WALL FRAMING

Description of Technology

Engineered wall framing (EWF) is a subset of optimum value engineering (OVE), which was first introduced through a HUD project named "Operation BREAKTHROUGH" in 1977. Rising lumber costs at that time motivated a study of ways to reduce costs by more efficiently using resources and reducing jobsite waste. Typical residential construction practices do not focus on framing either in the design phase (e.g., laying out roof trusses over wall studs) or in the field where framers add considerably more wood than is needed for structural integrity. These traditional construction practices produce excessive scrap and many redundant structural members, resulting in a much higher percentage of wood in the wall cavity than needed. The thermal performance of the wall is degraded since R-1 per inch wood replaces R-3 (or more) insulation in the wall cavity. EWF practices promote improved thermal performance and reduced wood use by implementing the following techniques:

- 24" on center wall framing
- Align wall framing with trusses and use a single top plate
- Design headers for loading conditions and use insulated headers
- Align door/window openings with stud spacing where possible
- Eliminate unnecessary framing at intersections and corners

The EWF construction practice requires upfront engineering to determine if the wider stud and floor joist spacing is sufficient for the specific design and location. Also, the framing crew must be trained in the alternative window and door framing techniques that reduce redundant support members while providing sufficient support.

Current Status of Measure

Most of the Building America teams are currently using some form of OVE as part of their stick-built projects and have had good success. The Natural Resources Defense Council (NRDC 1998) and the National Association of Home Builders Research Center (NAHB 1977) have both published manuals detailing construction techniques. There is currently a joint effort underway between NAHB and HUD known as the "Program for Research and Optimum Value Engineering" (PROVE). This program is in its seventh year of operation and is dedicated to research and education of OVE techniques. As the program progresses and the education campaign proceeds, we can expect to see more of these optimized building practices in the future.

Energy Savings and Costs

Spray cellulose and premium batt insulation can improve the cavity R-value by about 30%. In analyzing the cases, the improved insulation walls were modeled with an R-13 cavity R-value, and the base case assumed a cavity R-value of 9, consistent with the 2005 CEC Standards. The R-values were calculated for an 8' by 20' wall with the two framing factors, and the corresponding energy uses calculated using these R-values.

Key Assumptions Used in Analysis

Projected savings are based on framing factor calculations of walls with 26.1% framing factor and optimal 12% framing factor. Annual savings were calculated based on the improved wall thermal performance and nationwide estimates of walls on residential heating and cooling energy consumption of 15 and 8% respectively.

Recommended Next Steps

The principal barrier is probably the low visibility of improvement to consumers. Promotion efforts by green building groups and other environmental organizations will help promote the resource benefits of technology. Codes can assist in helping builders achieve energy credits associated with EWF. As the industry is transformed, the cost of training will be eliminated and the economic incentive for the builder will increase. Effort is needed in communicating the energy and non-energy benefits of EWF to the building community

S9 Engineered Wall Framing

Description	Wall framing system to reduce wood content in walls		
Market Information:			
Market sector	RES		
End-use(s)	HC		
Energy types	ALL		
Market segment	NEW		
Basecase Information:			
Description	2x4 R-13 framed wall		26% framing factor
Efficiency	R-8.2 effective R-value	includes framing factor and insulation defects	
Electric use	2,123	kWh/year	Energy Databook, national average cooling
Summer peak demand	3.24	kW	
Winter peak demand	NA	kW	
Gas/fuel use	65		Energy Databook, national average gas heating
New Measure Information:			
Description	Engineered wall system		24" on center, 12% framing factor
Efficiency	R-9.3 effective R-value	includes insulation defects	
Electric use	2,103	kWh/year	save 12% of wall's 8% cooling contribution
Summer peak demand	3.21	kW	save 12% of wall's 8% cooling contribution
Winter peak demand	N/A	kW	
Gas/Fuel use	63.8		save 12% of wall's 15% heating contribution
Current status	COMM		
Date of commercialization	1970's		OVE first presented in 1977
Life	50	years	
Savings Information:			
Electricity	20	kWh/year	
Summer peak demand	0.03	kW	
Winter peak demand	N/A	kW	
Gas/Fuel	1.2	MMBTU/year	
Percent savings	2%		
Feasible applications	90%		of new homes
2020 Savings potential	274	GWh	
2020 Savings potential	12	TBtu (source)	
Industrial savings > 25%	NO		
Cost Information:			
Projected Incre. Retail Cost	$0	2003 $	design and training costs = material savings
Other cost/(savings)	$0	$/year	
Cost of saved energy	$0.00	$/kWh	
Cost of saved energy	$0.00	$/MMBtu	
Data quality assessment	B	(A-D)	
Likelihood of Success:			
Major market barriers	Education of consumers, builders, framing contractors		
Effect on utility	Reduction in construction waste, significant non-energy environmental benefits		
Current promotion activity	PROVE study, SWA promotion at Seminars		
Rating	3	(1-5)	
Rationale	As consumers and builders become more knowledgeable, demand will go up.		
Priority / Next Steps			
Priority	Special/Not		
Recommended next steps	Promote through energy codes, document economics, coordinate w. green organizations		
Sources:			
Savings	DEG estimate		
Peak demand	DEG estimate		
Cost	NRDC 1998, DEG estimate		
Feasible applications	DEG estimate		
Measure life	DEG estimate		life of house
Other key sources	NAHB 1977		
Principal contacts			
Notes			

BIBLIOGRAPHY

(Note: additional references for Appendix B are located at the end of that appendix.)

[ABTP] Advanced Buildings Technologies & Practices. 2003. "HID Electronic Ballasts & Lamps." http://www.advancebuildings.org/main_t_lighting_hid.htm. Ontario, Canada: Advanced Buildings Technologies & Practices.

[ADL] Arthur D. Little, Inc. 1999. *Opportunities for Energy Savings in the Residential and Commercial Sectors with High-Efficiency Electric Motors.* Report 35495-14. Cambridge, Mass.: Arthur D. Little, Inc.

———. 2002. *Application of Best Industry Practices to the Design of Commercial Refrigerators.* http://www.cee1.org/com/com-ref/doe-rep02.pdf. Cambridge, Mass.: Arthur D. Little, Inc.

Amrane, K. G. Hourahan, and G. Potts. 2003. "Latent Performance of Unitary Equipment." *ASHRAE Journal*, vol. 45, no. 1, p. 28-31.

Anderson, J. (Ambien Climate Technologies). 2003. Personal communication with Steve Brennan. September 11.

Andrews, John. 2002. "Laboratory Evaluation of the Delta Q Test for Duct Leakage." In *Proceedings of the 2002 ACEEE Summer Study in Buildings,* 1.15–1.28. Washington, D.C.: American Council for an Energy-Efficient Economy.

ANSI/ARI. 2001. *Rating Air-To-Air Heat Exchangers for Energy Recovery Ventilation Equipment.* Standard 1060-2001. Arlington, Va.: Air-Conditioning and Refrigeration Institute.

Appliance Magazine. 2003. "LG to Mass Produce 'Green' Fridge.'" http://www.ammagazine.com. *Appliance Magazine,* September.

Arasteh, D. (Lawrence Berkeley National Laboratories). 2003. E-mail correspondence to G. Todesco. July.

Architectural Energy Corporation. 2001. "Background Research Summary: Integrated Energy Systems Productivity and Building Science." Prepared for California Energy Commission PIER office under contract 400-99-013. Architectural Energy Corporation.

[ARI] Air Conditioning and Refrigeration Institute. (in preparation). *Guideline V-2003: Calculating the Efficiency of Energy Recovery Ventilation and its Effect on Efficiency and Sizing of Building HVAC Systems.* Arlington, Va.: Air Conditioning and Refrigeration Institute.

———. 2000. *Directory of Certified Unitary Equipment Standards 210/240, 270.* Arlington, Va.: Air Conditioning and Refrigeration Institute.

[ASHRAE] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1991. *Methods of Testing for Rating Combination Space-Heating and Water-Heating Appliances.* ANSI/ASHRAE 124-1991. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

———. 1998. *Operating Experiences with Commercial Ground-Source Heat Pump Systems.* Special Publication. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

———. 2003. *Handbook, Applications.* Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

[AWHC] American Water Heater Company. 2003a. "Polaris High-Efficiency Residential Gas Water Heater." Product Brochure No. L-PG-10.0a. American Water Heater Company.

———. 2003b. "Polaris High-Efficiency Commercial Gas Water Heater." Product Brochure No. L-PG-10.0a. American Water Heater Company.

Babyak, R. 2000. "Tweaking Transfer." http://www.ammagazine.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2606,4100,00.html. *Appliance Manufacturer.*

———. 2001. "Linear Launch." http://www.ammagazine.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2606,27010,00.html. *Appliance Manufacturer.*

———. 2003. "Technology Update: Air Conditioning & Refrigeration 'Gas Cooling Breakthrough'." *Appliance Manufacturer* 51 (6): 20–23.

Bardhi, P. (National Grid). 2003. Personal communication with Marycel Tuazon. July.

Bauman, F. 2003. *Underfloor Air Distribution Design Guide.* Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Berman, Sam. 2000. "The Coming Revolution in Lighting Practice." *Energy User News,* October, 25 (10). http://www.energyusernews.com/eun/cda/articleinformation/features/bnp__features__item/0,,14423,00+en-uss_01dbc.htm.

Bierman, A. (Lighting Research Center). 2003. Personal communication with Marycel Tuazon.

Bisbee, D. (SMUD). 2003. Personal communication with Hugh Dwiggins. August 14.

Bockley, E. (Sylvania). 2003. Personal communication with Marycel Tuazon. July.

Boeing. 2001. "Boeing Completes Evaluation of Borealis Cool Chips™ Technology." http://www.boeing.com/news/releases/2001/q4/nr_011130a.html. Seal Beach, Calif.: Boeing.

Bourassa, N., P. Haves, and J. Huang. 2002. "A Computer Simulation Appraisal of Non-Residential Low Energy Cooling Systems in California." In *Proceedings of the ACEEE 2002 Summer Study on Energy Efficient Buildings,* 3:41–53. Washington, D.C.: American Council for an Energy-Efficient Economy.

Bourne, D. and J. Stein. 1999. *Aeroseal: Sealing Ducts from the Inside Out.* Report ER-99-16. Boulder, Colo.: E Source.

[BPA] Bonneville Power Administration. 2003. *High Performance T8 Fluorescent Lighting Systems.* http://www.bpa.gov/energy/n/projects/conserve_augmentation/eso/high_per_fluor_faq.pdf. Portland, Oreg.: Bonneville Power Administration.

Brodrick, J. (U.S. Department of Energy). 2004. Personal communication.

Brons, J. (Lighting Research Center, RPI). 2003. Personal communication with Marycel Tuazon. September.

Brotnov, M. (Lennox). 2003. Personal communication with Hugh Dwiggins. September 23.

Bulbs.com. 2003. http://www.bulbs.com. Worcester, Mass.: Bulbs.com.

Bullough, J. 2003. "LED Lighting Systems." http://www.lrc.rpi.edu/programs/NLPIP/publicationdetails.asp?id=885&type=2. Troy, N.Y.: Lighting Research Center.

[CEC] California Energy Commission. 1999. "Residential Manual for Compliance with California 1998 Energy Efficiency Standards." Publication 400-98-002. Sacramento, Calif.: California Energy Commission.

———. 2002. "Measure Analysis and Life-Cycle Cost Report." Publication 400-02-011. Sacramento, Calif.: California Energy Commission.

———. 2003. *California Energy Demand 2003–2013.* Sacramento, Calif.: California Energy Commission.

Calwell, C., C. Granda, L. Gordon, and M. Ton. 1999a. *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets, Volume 1: Strategies and Recommendations.* http://www.cee1.org/resid/rs-lt/rs-lt-pubs/ltwy_vol1.pdf. Washington, D.C.: Natural Resource Defense Council.

———. 1999b. *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets, Volume 2: Background and Reference.* http://www.cee1.org/resid/rs-lt/rs-lt-pubs/ltwy_vol2.pdf. Washington, D.C.: Natural Resource Defense Council.

Calwell, C. and T. Reeder. 2002. *Power Supplies: A Hidden Opportunity for Energy Savings*. San Francisco, Calif.: Natural Resources Defense Council.

Campbell, Steve. 2002. "Saving Energy with High-Tech Lighting Systems." http://www.edcmag.com/edc/cda/articleinformation/features/bnp__features__item/0,,77293,00+en-uss_01dbc.html. *Environmental Design + Construction,* May 8.

[CBECS] Commercial Buildings Energy Consumption Survey. 1999. "1999 Detailed Tables, Table B6: Building Size, Number of Buildings." http://www.eia.doe.gov/emeu/cbecs/set3.html. Washington, D.C.: U.S. Department of Energy, Energy Information Agency.

———. 2002. "1999 Commercial Buildings Energy Consumption Survey (CBECS) Detailed Tables." http://www.eia.doe.gov/emeu/cbecs/detailed_tables_1999.html. Washington, D.C.: U.S. Department of Energy, Energy Information Agency.

[CEE] Consortium for Energy Efficiency. 2001. *A Market Assessment for Condensing Boilers in Commercial Heating Applications.* http://www.cee1.org/gas/gs-blrs/Boiler_assess.pdf. Boston, Mass.: Consortium for Energy Efficiency.

[Census] U.S. Census Bureau. 1999a*. Natural Gas Consumption and Conditional Energy Intensity by Building Size, 1999.* http://www.eia.doe.gov/emeu/cbecs/tables/consumption.html. Washington, D.C.: U.S. Bureau of Census.

———. 1999b. *Census Region and Division, Floorspace, 1999.* http://www.eia.doe.gov/emeu/cbecs/pdf/b5.pdf. Washington, D.C.: U.S. Bureau of the Census.

Chen, D. (Reth). 2003. Personal communication with Hugh Dwiggins.

CMRC Cool Metal Roofing: http://www.coolmetalroofing.org.

Cool Chips PLC. 2003. "Cool Chips PLC Business Plan." Gibraltar: Cool Chips PLC.

Constantino, S. (EnerKon Corporation). 2003. Personal communication with Marc Hoeschele. November 25.

[Copeland] Copeland Corporation. 2003a. "Product Solutions Digital Scroll." Copeland Corporation.

———. 2003b. "Product Solutions Scroll Compressors." Copeland Corporation.

———. 2003c. "Take the Lead - Discover a New Horizon." Copeland Corporation.

Craford, M.G. 2002. *Visible LEDs: The Trend toward High Power Emitters and Remaining Challenges for Solid State Lighting.* http://ncem.lbl.gov/team/presentations/Craford/sld001.htm. Presented to Lawrence Berkeley Laboratory. San Jose, Calif.: Lumileds Lighting LLC.

Craford, M.G., N. Holanyak, Jr., and F. Kish, Jr. 2001. "In Pursuit of the Ultimate Lamp." *Scientific American,* February, 63–67.

Crawford, J. (Sunpower). 2003. Personal communication with Marycel Tuazon. October.

Criscione, P. 2002a. "A Change in the Wind for Natural and Hybrid Ventilation." *ET Currents*, August.

———. 2002b. "A New Reality for Refrigeration?" *ET Currents,* 19: 6–7.

Crowe, Joan. P. (undated, accessed 11/2003). "Radiant Barriers: Essentials." http://www.professionalroofing.net/article.aspx?A_ID=290. *Professional Roofing.*

Crumley, Doug (Trane). 2003. Personal communication to Hugh Dwiggins. September.

Dakin, B. (Davis Energy Group Inc.). 2003. E-mail correspondence to G. Todesco. July.

David, S. (Technical Consumer Products, Inc.). 2003. Personal communication with Marycel Tuazon. August.

[DEG] Davis Energy Group. 2000. *Evaluation of the GeoExchange Heat Pump System—Fairfield Inn, Tracy*." Davis, Calif.: Davis Energy Group.

———. 2002a. *Residential Construction Quality Assessment Project: Phase II Final Report.* CEC 400-98-004. Davis, Calif.: Davis Energy Group, Inc.

———. 2002b. SMUD/Truckee Donner Geothermal Heat Pump Project 2001/2002 Monitoring Report.. Davis, CA. Davis Energy Group, Inc.

———. 2003. *Analysis of Standards Options for Residential Pool Pumps, Motors, and Controls.* Prepared for Pacific Gas and Electric Company. Davis, Calif.: Davis Energy Group.

Degens, P. (NEEA). 2003. Personal communication with Hugh Dwiggins. September 25.

Desjarlais, A. (Oak Ridge National Laboratory). 2003. Personal communication with Steve Brennan. August 21.

DiLouie, C. 2004. Lighting Controls: Today and Tomorrow. *Energy User News,* April, 12, 14.

[DOE] U.S. Department of Energy. 1991. "Attic Radiant Barrier Fact Sheet." DOE/CE-0335P. http://www.ornl.gov/sci/roofs+walls/radiant/rb_01.html. Washington, D.C.: U.S. Department of Energy.

———. 2001a. *Technical Support Document for Energy Efficiency Standards for Residential Central Air Conditioners.* Washington, D.C.: U.S. Department of Energy.

———. 2001b. "Energy Conservation Program for Consumer Products: Energy Conservation Standards for Water Heaters, Final Rule." *Federal Register,* Wednesday, January 17, 66 (11) 4,474–4,497.

———. 2001c. "Annual Energy Outlook"

———. 2002a. "Fluorescent Lamp Ballast Technical Support Document." http://www.eere.energy.gov/buildings/appliance_standards/residential/gs_fluorescent_0100_r.html. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy.

———. 2002b. *U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate*. September. Prepared by Navigant Consulting. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Program.

———. 2002c. *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps, Including Regulatory Impact Analysis.* http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/title_page.pdf. Washington, D.C.: U.S. Department of Energy.

———. 2002d. *Water Heater Rating Method.* 10 CFR Ch. II (1–1–02 Edition) Pt. 430, Subpt. B, App. E.

———. 2002e *In Hot Water, a Newsletter*, 2 (2): 1. U.S. Department of Energy.

———.2003a. "Clothes Washer Technical Support Document." Appendix B. http://www.eere.energy.gov/buildings/appliance_standards/residential/clwash_0900_r.html. Washington, D.C.: U.S. Department of Energy.

———. 2003b. "Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamps." http://www.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/hid_draft_report.pdf. Washington, D.C.: U.S. Department of Energy, Building Technologies Program, Office of Energy Efficiency and Renewable Energy.

———. 2003c. "Energy Department Awards $20.4 Million for Projects That Will Save Energy in Homes and Commercial Buildings." Press Release. October 15. http://www.energy.gov/engine/content.do?PUBLIC_ID=14302&BT_CODE=PR_PRESSRELEASES&TT_CODE=PRESSRELEASE. Washington, D.C.: U.S. Department of Energy.

———.2003d. *ENERGY STAR® Labeling Potential for Water Heaters.* http://www.energystar.gov/ia/partners/gen_res/prod_development/new_specs/downloads/water_heaters/WH_Paper.pdf. Washington, D.C.: U.S. Department of Energy.

———. 2003e. *High-Intensity Discharge Lamps.* http://www.eere.energy.gov/buildings/components/lighting/lamps/highintensity.cfm. Washington, D.C.: U.S. Department of Energy, DOE Building Technologies Program.

———. 2003f. *In Hot Water…A Newsletter about Heat Pump Water Heaters and Efficient Domestic Water Heating*. June, 2 (2).

———. 2003g. *2003 Building Energy Data Book*. http://buildingsdatabook.eren.doe.gov/.

———. 2003h. http://www.eia.doe.gov/oiaf/aeo/assumption/tbl12.html

———. 1997 A Final Rule, Energy Conservation Program for Consumer Products: Energy Conservation Standards for Refrigerators, Refrigerator-Freezers and Freezers. 10 CFR Part 430. Federal Register v. 62, #81, pp. 23101-23116.

———. 2004. Potential ENERGY STAR Water Heater Criteria. http://www.energystar.gov/index.cfm?c=new_specs.water_heaters. Washington, D.C.: U.S. Department of Energy.

[DSIRE] Database of State Incentives for Renewable Energy. 2003. Web site: www.dsireusa.org Raleigh, NC: North Carolina Solar Center. Accessed October 2003.

E Source. 1996. *Technology Atlas Series, Volume III: Space Heating.* Boulder, Colo.: E Source, Inc.

———. 1997. *Technology Atlas Series Volume II: Cooling.* Boulder, Colo.: E Source, Inc.

———. 2002. *Emerging Fuel Cell Technology.* Boulder, Colo.: E Source, Inc.

———. 2003. "DimALL from MaxLite." *ET Currents,* July (28), 2–3.

Easton Consultants, Inc. 1993. *Commercial Baseline Refrigeration Study.* Stamford, Conn.: Easton Consultants, Inc.

ECR International. (undated, accessed 11/2003). "Watter$aver. http://www.enviromaster.com/watter_saver. Rome, N.Y.: Enviromaster International LLC, an ECR International company.

[EIA] Energy Information Agency. 1997. *Nonresidential Buildings Energy Consumption Survey: Characteristics of Commercial Buildings 1995.* DOE/EIA-0246(95). Washington, D.C.: Energy Information Agency.

———. 2003a. "Table 3: Energy Prices by Sector and Source." *Annual Energy Outlook 2003.* Washington, D.C.: Energy Information Agency.

———. 2003b. "Household Energy Consumption and Expenditures Tables." *2001 Residential Energy Consumption Survey*. www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html. Washington, D.C.: Energy Information Agency.

———.2003c. "Table CE1-4c.Total Energy Consumption in U.S. Households by Type of Housing Unit, 2001—Preliminary Data." *2001 Residential Energy Consumption Survey*. ftp://ftp.eia.doe.gov/pub/consumption/residential/2001ce_tables/enduse_consump.pdf. Washington, D.C.: Energy Information Agency.

———. 2003d. "Table CE3-1c: 2001 Consumption and Expenditures Tables: Electric Air-Conditioning Consumption Tables." *2001 Residential Energy Consumption Survey*. Washington, D.C.: Energy Information Agency.

———. 2003e. *Annual Energy Outlook 2004 with Projections to 2025*. http://www.eia.doe.gov/oiaf/aeo/index.html Washington, D.C.: Energy Information Agency.

———. 2004a. http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_nus_a_d.htm . Natural Gas Navigator. Washington, D.C.: Energy Information Agency.

———. 2004b. "Electric Sales and Revenue 2002 Spreadsheets: Data Tables, Table 1d." http://www.eia.doe.gov/cneaf/electricity/esr/esr_tabs.html. Washington, D.C.: Energy Information Agency.

Eley Associates. 1996a. *ACT² Davis Residential Site Impact Evaluation Report.* Draft Report. Prepared for Pacific Gas and Electric Company, Research and Development Department. San Ramon, Calif.: Eley Associates.

———. 1996b. *ACT² Stanford Ranch Residential Site Impact Evaluation Report*. Draft Report. Prepared for Pacific Gas and Electric Company, Research and Development Department. San Ramon, Calif.: Eley Associates.

ENERGYGuide. 2002. "ENERGY STAR Lights®." Fall product catalog. Wellesley Hills, Mass.: ENERGYGuide.

———. 2003. "ENERGY STAR Lights®." Spring product catalog. Wellesley Hills, Mass.: ENERGYGuide.

ENERGY STAR. 2002. *Lighting the Way to a Brighter Future.* Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

———. 2003a. *Commercial Solid Door Refrigerators & Freezers.* Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

———. 2003b. *Lighting the Way to a Brighter Future.* http://www.lightingfortomorrow.com/pdf/ESNewsltrJune2003.pdf. Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

———. 2004. EZ Save Monitor Power Management Tool. http://www.energystar.gov/index.cfm?c=power_mgt.pr_pm_large_org

EnerKon. Cold Climate Heat Pump. http://www.enerkoncorp.com/showart.asp?contentID=15408

Enermodal Engineering. Framing Factors for Low-Rise Residential Building Envelopes in California. 2001. Kitchener, Ontario.

[EPA] U.S. Environmental Protection Agency. 1993. *Multiple Pathways to Super-Efficient Refrigerators.* Washington, D.C.: U.S. Environmental Protection Agency, Office of Atmospheric and Indoor Air Programs

[EPA] U.S. Environmental Protection Agency. 1997. "Heat Pipe Effectiveness Study". http://www.epa.gov/greeningepa/energy/hpipe.htm. Washington, D.C. Accessed September 2003.

[EPA] U.S. Environmental Protection Agency, ENERGY STAR Program. 2003a. "The ENERGY STAR Residential Light Fixture Advancement Project." Invitation to Participate. March 15.

http://energystar.gov/ia/partners/manuf_res/The_Energy_Star_RLF_Ad_Invitation.pdf. Washington, D.C.: U.S. Environment Protection Agency, ENERGY STAR Program.

———. 2003b. "ENERGY STAR Central Air Conditioner Calculator." http://www.energystar.gov/ia/business/bulk_purchasing/bpsavings_calc/Calc_CAC.xls. Washington, D.C.: U.S. Environmental Protection Agency, ENERGY STAR Program.

[EPRI] Electric Power Research Institute. 2002. *Technology Innovation in Electricity Use: A Cornerstone of Economic Progress.* December 13 draft. Palo Alto, Calif.: Electric Power Research Institute.

———. 2003. "Demonstrations and Case Studies of Applications of UVGI for Chiller Coils in Commercial Buildings." http://www.epriweb.com/public/2004_P017.pdf. Palo Alto, Calif.: Electric Power Research Institute.

eWaterheaters. 2004. http://www.ewaterheaters.net. Chicago, Ill.: eWaterheaters.

FEMP. 1995. "Residential Heat Pump Water Heaters: Energy-Saving Alternative for Home Hot Water." *Federal Technology Alert.* http://www.eere.energy.gov/femp/prodtech/pdfs/FTA_res_heat_pump.pdf. Washington, D.C.: Federal Energy Management Program.

———. "Unitary Air Conditioner Procurement." http://www.pnl.gov/uac. Washington, D.C.: Federal Energy Management Program.

Foster, R. (Consortium for Energy Efficiency). 2003. Personal communication with Marycel Tuazon. July.

Foster, S. (Ecos Consulting). 2003. Personal communication with Marycel Tuazon. August.

Frankenfield, Guy (Global Energy Group). 2003. Personal communication. October 30.

[FSEC] Florida Solar Energy Center. 2000. "EnergyGauge USA: Code Compliance and Home Energy Rating Software." http://energygauge.com/USARes/default.htp. Cocoa, Fla.: Florida Solar Energy Center.

[GAMA] Gas Appliance Manufacturers Association. 2003. *Consumers' Directory of Certified Efficiency Ratings for Heating and Water Heating Equipment*. April. http://www.gamanet.org/consumer/certification/certdir.htm. Arlington, Va.: Gas Appliance Manufacturers Association.

———. undated. *Statistical Highlights Ten Year Summary.* http://www.gamanet.org/member/statistics/TYS1992-2001.pdf Arlington, Va.: Gas Appliance Manufacturers Association.

Gautheir, Julia (Xcel Energy). 2002. Personal communication with Steven Nadel. October.

[GE] General Electric. 2003. "Halogen Lamps." Product Catalog. http://www.gelighting.com.

Glouchkow, James. (ēKOCOMFORT). 2003. Personal communication with Marycel Tuazon. October.

Gough, A. (Electric Power Research Institute). 2003. Personal communication with Marycel Tuazon. July.

Gordon KL, and JJ McCullough. 2003. "Recessed Lighting in the Limelight." Home Energy 21(1):12-13.

Gregerson, J. 1997. "Commissioning Existing Buildings." *Tech Update*, TU-97-3.

[GRI] Gas Research Institute. 1991. *Assessment of Technology for Improving the Efficiency of Residential Gas Water Heaters.* Topical Report GRI-91/0298. Chicago, Ill.: Gas Research Institute.

Groll, E.A. (Purdue University). 2003. Personal communication with Hugh Dwiggins. November 20.

[GSA] General Services Administration. 2003. http://hydra.gsa.gov/pbs/p100/CHAPTER5.PDF. Washington, D.C.: General Services Administration.

Gucciardo, April (HRAI). 2003. Personal communication with Marycel Tuazon. October.

Haasl, T. and T. Sharp. 1999. *A Practical Guide for Commissioning Existing Buildings*. Prepared for the U.S. Department of Energy, Office of Building Technology, State and Community Programs. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Hagspiel, A. (National Grid). 2003. Personal communication with Marycel Tuazon. July.

Haitz, R., F. Kish, J. Tsao, and J. Nelson. 2000. "The Case for a National Research Program on Semiconductor Lighting." White Paper. http://www.sandia.gov/lighting/lightingdocs/hpsnl_long.pdf. Albuquerque, N.M.: Sandia National Laboratories.

Hallford, Art (Trane). 2003. Personal communication.

[HBI] Healthy Buildings International. 2001. Web site: www.healthybuildings.com/s2/thermal%20Displacement%20Ventilation%20CFD%20Modeling.pdf. Fairfax, VA: Healthy Buildings International. Accessed October 2003.

Hedman, Bruce. 2002. *Gas-Fired Distributed Generation Technology Characterizations.* Golden, Colo.: National Renewable Energy Laboratory.

Hendriksen, O.J. et al. 2002. Pilot Study Report: Bang & Olufsen Head Quarter. Paris, France: International Energy Agency.

Hensen, J. and M. Hamelinck 1995. Energy Simulation of Displacement Ventilation in Offices Building Services Engineering Research and Technology 16 (2): 77-81

Higgins, C., ed. 2003. *Integrated Energy Systems: Productivity & Building Science.* P500-03-082. Sacramento, Calif.: California Energy Commission.

[HMG] Heschong Mahone Group. 1999a. *Lighting Efficiency Technology Report, Volume I: California Baseline.* Prepared for the California Energy Commission. http://www.energy.ca.gov/efficiency/lighting/lighting_reports.html. Fair Oaks, Calif.: Heschong Mahone Group.

———. 1999b. *Lighting Efficiency Technology Report, Volume III: Market Barriers Report*. Prepared for the California Energy Commission. http://www.energy.ca.gov/efficiency/lighting/lighting_reports.html. Fair Oaks, Calif.: Heschong Mahone Group.

———. 2003. *Modular Skylight Wells: Design Guidelines for Skylights with Suspended Ceilings.* http://www.energy.ca.gov/reports/2003-11-17_500-03-082_A-13.PDF Prepared for the New Buildings Institute on behalf of the California Energy Commission's PIER Program. Fair Oaks, Calif.: Heschong Mahone Group, Inc.

Hollick, J. (Conserval Engineering Inc.). 2003. Personal communication with Steve Brennan. September 18.

Hollingsworth, D. (LGE). 2003. Personal communication with Harvey Sachs. October.

Home Depot, The. 2003. http://www.homedepot.com. Atlanta, Ga.: The Home Depot.

Hourahan, Glen (Air Conditioning Contractors of America). 2003. Personal communication.

Hoye, M. (ICF Consulting). 2003. Personal communication with Marycel Tuazon. July.

Hubbard, G. and C. Eley. 1997. "Green Fees: Getting Paid for Getting It Right—Performance Based Fee Contracts for New Construction." see http://www.mccoppin.com/lectures.htm. Energy Efficient Building Association Conference, Minneapolis, MN.

[IEA] International Energy Agency. 2002. "Hybrid Ventilation in New and Retrofitted Buildings." *Principles of Hybrid Ventilation.* IEA-ECBCS Annex 35.

[IESNA] The Illuminating Engineering Society of North America. 2000. *The IESNA Lighting Handbook: Reference & Application.* Ninth Edition. New York, N.Y.: The Illuminating Engineering Society of North America.

Interlight. 2003. http://www.interlight.biz. Hammond, Ind.: Interlight International Lighting Corporation.

James, P., J.E. Cummings, J. Sonne, R. Vieira, and J. Klongerbo. 1997. "The Effect of Residential Equipment Capacity on Energy Use, Demand, and Run-Time." *ASHRAE Transactions*, 103 (2). Atlanta, Ga.: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Jennings, J.D., F. Rubinstein, and D. DiBartolemeo. 2000. *Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed*. LBNL-43096. http://eande.lbl.gov/btp/450GG/papers/43096.pdf. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Jewett, Don. (2003. Personal communication with Marycel Tuazon. October.

Johnson, Russ (Johnson Research, LLC). 2003. Personal communication with Harvey Sachs. July.

Jump, D., A. Rosillo, J. Flanagan, and J. Cavalli. 2003. "Retro-Commissioning Buildings with Public Goods Funds—Learning Lessons in Oakland." In *Proceedings of the 11th National Conference on Building Commissioning,* Session 28. Portland, Oreg.: Portland Energy Conservation, Inc.

Jump, D., I.S. Walker, and M.P. Modera. 1996. "Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems." In *Proceedings of the 1996 ACEEE Summer Study on Energy Efficiency in Buildings,* 1.147–1.156. Washington, D.C.: American Council for an Energy-Efficient Economy.

Kallett, R., E. Hamzawi, C. Sherman, and J. Erickson. 2000. "SMUD's New Residential Duct-Improvement Program Using an Aerosol-Based Duct Sealant." In *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings,* 2.163–2.174. Washington, D.C.: American Council for an Energy-Efficient Economy.

Kang, S. (MaxLite). 2003. Personal communication with Marycel Tuazon. August.

Kendall, M. and M. Scholand. 2001. *Energy Savings Potential of Solid State Lighting in General Lighting Applications.* Final Report. Prepared for U.S. Department of Energy, Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy. http://www.eere.energy.gov/buildings/documents/pdfs/ssl_final_report3.pdf. Arlington, Va.: Arthur D. Little, Inc.

Kesting, O. (Pacific Gas & Electric). 2003. Personal communication with Marycel Tuazon. July.

Kinney, L. 2002. "Stirling Set to Make a Big Stir." *ET Currents,* January.

Kitson, M. 2003. "Swiss Re Headquarters: Inside & Out." *Fluent News*, 12 (1): S2.

Kolderup, E. (Eley Associates). 2003a. Personal communication with Marc Hoeschele. December 1.

Kolderup, E. 2003b. http://www.energycodes.gov/news/2001_workshop/pdfs/kolderup_wiig.pdf. San Ramon, Calif.: Eley Associates.

Komonowsky, J. (Pacific Gas & Electric). 2003. Personal communication with Marycel Tuazon. August.

Korn, D. (The Cadmus Group). 2003. Personal communication with Harvey Sachs.

Krepchin, Ira. 2000. *Integrated Building Design: Can Teamwork Lead to High-Performance, Cost-Effective Buildings?* E Source Report ER-00-15. Boulder, Colo.: E Source, Inc.

———. 2001. *Automated Building Diagnostics: Improving Energy Performance and Occupant Comfort.* E Source Report ER-01-18. Boulder, Colo.: E Source, Inc.

———. 2002. "Stirling Technology II: Free-Piston Devices." *ET Currents,* March.

Krepchin, I. and J. Stein. 2000. *New Dimming Controls: Taking It Personally.* Boulder, Colo.: E Source, Inc.

Kubo, Toru, Harvey Sachs, and Steven Nadel. 2001. *Opportunities for New Appliance and Equipment Efficiency Standards: Energy and Economic Savings Beyond Current Standards Programs.* Washington, D.C.: American Council for an Energy-Efficient Economy.

LaFrance, M. (U.S. Department of Energy). 2003. Personal communication.

[LBNL] Lawrence Berkeley National Laboratory. 2000. "Electrochromic Window Tests in U.S. Office Show Promise." http://eetd.lbl.gov/newsletter/nl5/electro_window.html. *Environment Energy Technologies Division News,* Spring.

———. 2001. *Windows and Daylighting: Residential Performance: Annual Energy Databases & Modeling Assumptions.* http://windows.lbl.gov/AEP/database.htm. Berkeley, Calif.: Lawrence Berkley National Laboratory, Environmental Energy Technologies Division, Buildings Technology Department.

———. 2003. *Average Values: Manufacturer Price, Customer Equipment Price, Installation Cost, and Total Installed Cost.* Presentation slide. Berkeley, Calif.: Lawrence Berkley National Laboratory, Environmental Energy Technologies.

Lea, D. (Cellulose Insulation Manufacturers Association). 2003. Personal communication with Steve Brennan. August.

Lee, E.S. (Lawrence Berkeley National Laboratory). 2003. Personal communication.

Lee, E.S. and D.L. DiBartolomeo. 2000. "Application Issues for Large-Area Electrochromic Windows in Commercial Buildings." *Solar Energy Materials and Solar Cells.* LBNL-45841.

Lee, E.S., D.L. DiBartolomeo, and S.E. Selkowitz. 2000. "Electrochromic Windows for Commercial Buildings: Monitored Results from a Full-Scale Testbed." In *Proceedings of the 2000 ACEEE Summer Study on Energy Efficiency in Buildings.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Lee, E.S., L.D. DiBartolomeo, E. L. Vine, and S. E. Selkowitz. 1998. "Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office." In *Proceedings of the ASHRAE/DOE/BTECC Conference, Thermal Performance of the Exterior Envelopes of Buildings VII,* Clearwater Beach, Fla., December 7–11.

Lee, E.S. and S.E. Selkowitz. 1998. "Integrated Envelope and Lighting Systems for Commercial Buildings: A Retrospective." In *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy.

[LEED] Leadership in Energy and Environmental Design. 2003. *Green Building Rating System for New Construction & Major Renovations (LEED-NC).* Version 2.1 (revised). Washington, D.C.: U.S. Green Building Council.

Leslie, Russell P. (Lighting Research Center). 2003. Personal communication with Guiliano Todesco. April.

[LGE] 2003. http://www.lge.com/

Lighting for Tomorrow. 2003. "Finalists." http://www.lightingfortomorrow.com/finalist.shtml. National Lighting Fixture Design Competition.

Loftness, V., R. Brahme, M. Mondazzi, E. Vineyard, and M. McDonald. 2002. *Energy Savings Potential of Flexible and Adaptive HVAC Distribution Systems for Office Buildings.* http://www.arti-21cr.org/. Arlington, Va.: Air-Conditioning and Refrigeration Technology Institute.

Lauria, J. 1998. Getting More for Less: How Demand Controlled Ventilation Increases Air Quality and Reduces Costs. Farmington, CT. Carrier Corporation.

1e Corporation. NightWatchman software package. http://www.1e.com/SoftwareProducts/NightWatchman/Index.aspx

[LRC] Lighting Research Center – National Lighting Product Information Program. 1999. Dimming Electronic Ballasts. Specifier Reports. Volume 7 Number 3. Available at http://www.lrc.rpi.edu/. Accessed August 2003. Troy, NY.: Lighting Research Center.

———. 2003a. *Draft Technology Transfer Plan for Project 3.2: Energy Efficient Load Shedding Technology.* Prepared for the California Energy Commission, PIER Lighting Research Program. Troy, NY.: Lighting Research Center.

———. 2003b. "Integrated Skylight Luminaire." *DELTA Field Test Report (*1).

———. 2004. *Self-Commissioning Photosensor* http://www.lrc.rpi.edu/programs/lightingTransformation/improvedPhotosensors/pdf/selfCommisioningPhotosensor.pdf.

Lloyd, J.D. and P. Sood. (undated). *Motor Technology for Major Household Appliances.* SR Drives, Ltd. web site, http://www.srdrives.com/. (no longer there, 8/04)

Lstiburek, J. 2002. "Residential Ventilation and Latent Loads." *ASHRAE Journal,* 44, 18–22.

LumiLeds. 2003. "Lumileds to Ship Warm White, Incandescent-Equivalent LED in August." Press release. http://www.lumileds.com. San Jose, Calif.: Lumileds.

Magdych, J. (Cool Chips PLC). 2003. Personal communication with Steve Brennan. July.

Mahone, D. 2004. *Residential HVAC for Hot, Dry Climates.* Final Report. N. Horowitz, ed. San Francisco, Calif.: Natural Resources Defense Council.

Marbek Resource Consultants. 2003. *BC Hydro Conservation Potential Review 2002: Commercial Sector.* Prepared for BC Hydro. Vancouver, B.C., Canada: Marbek Resource Consultants.

Martinez, V. (LumiLeds). 2003. Personal communication with Marycel Tuazon. August.

Massachusetts Joint Utility End Use Monitoring Project. 1989.

MaxLite. 2003. http://www.maxlite.com. Pinebrook, N.J.: MaxLite

McConnell, P. (Residential Products Manager, Therma-Stor). 2003. Personal communication to Marc Hoeschele. September 23.

McCullough, J. (PNNL). 2003. Personal communication with Hugh Dwiggins. August 14.

McDonell, G. 2003. "Underfloor and Displacement: Why They Are Not the Same." *ASHRAE Journal,* July, 18–24.

McHugh, J. 2003. Personal communication with Marycel Tuazon. September.

McMaster-Carr. 2003. http://www.mcmaster.com. Atlanta, Ga.: McMaster-Carr.

Medina, Mario. 2000. "Radiant Barriers: Performance Revealed." *Home Energy*, Sept./Oct., 30–33.

Meier, Alan. 2002. Presentation at the California Energy Commission Public Interest Energy Research Workshop on Standby Power, Berkeley, Calif., August 26.

Meyers, C. (Senior Engineer, Heat Pipe Technologies). 2003. Personal communication to Marc Hoeschele. September 9.

Modera, M., D. Dickerhoff, O. Nilssen, H. Duquette, and J. Geyselaers. 1996. "Residential Field Testing of an Aerosol-Based Technology for Sealing Ductwork." In *Proceedings of the 1996 ACEEE Summer Study on Energy-Efficiency in Buildings,* 1.169–1.176. Washington, D.C.: American Council for an Energy-Efficient Economy.

Muhs, J. 2003a. "Hybrid Solar Lighting: Shedding New Light on Solar Energy…Bringing Sunlight Inside." Presented at the American Council for an Energy-Efficient Economy Market Transformation Conference, Washington, D.C., May.

———. 2003b. (Oak Ridge National Laboratory). Personal communication with Marycel Tuazon. August.

Muhs, J. and D.D. Earl. 2001. "Preliminary Results on Luminaire Designs for Hybrid Solar Lighting Systems." *Proceedings of Forum 2001: Solar Energy: The Power to Choose,* 21-25. Washington D.C.

Nadel, S. 2002. *Packaged Commercial Refrigeration Equipment: A Briefing Report for Program Planners and Implementers.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Nadel, S., D. Bourne, M. Shepard, L. Rainer, and L. Smith. 1993. *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Nadel, S., R.N. Elliott, M. Shepard, S. Greenberg, G. Katz, and A.T. de Almeida. 2002. *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities, 2nd Edition.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Nadel, S., L. Rainer, M. Shepard, M. Suozzo, and J. Thorne. 1998. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector*. Washington, D.C.: American Council for an Energy-Efficient Economy.

[NAHB] National Association of Home Builders. 1977. Reducing Home Building Costs with OVE Design and Construction. HUD-Guideline5. Upper Marlboro, MD: National Association of Home Builders.

[NBI] New Buildings Institute. 2001. *Advance Lighting Guidelines.* 2001 Edition. White Salmon, Wash.: New Buildings Institute.

Neal, C. Leon. 1998. "Field Adjusted SEER [SEERFA]." In *Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings,* 1.197 – 1.209. Washington, D.C.: American Council for an Energy-Efficient Economy.

Neme, C., S. Nadel, and J. Proctor. 1999. *Energy Savings Potential from Addressing Residential Air Conditioner and Heat Pump Installation Problems.* Washington, D.C.: American Council for an Energy-Efficient Economy.

[NEPSC] New England Power Service Company. 1987. *Load Research Report*. Westborough, Mass.: New England Power Service Company.

[NFRC] National Fenestration Rating Council. 2002. "We Are Changing the Way America Shops for Windows, Doors and Skylights." http://www.nfrc.org. Silver Spring, Md.: National Fenestration Rating Council.

———. 2003. “NFRC Certified Products Directory.” http://www.nfrc.org/nfrcpd.html Silver Spring, Md.: National Fenestration Rating Council.

[Ngrid] National Grid. “Design 2000 Plus 2003 Energy-Efficient Lighting Systems.” http://www.masselectric.com/filelib/pdf/d2wk1-02.pdf. Northborough, Mass.: National Grid.

NHSaves. 2003. “NHSaves.” Product catalog. Spring. Westborough, Mass.: NHSaves.

Nixon, J.D. 2003a. “The Chemistry Behind ‘Cool Roofs.’” *Eco-Structure,* Summer: 63–65.

———. (Shepherd Color Company). 2003b. Personal Communication with Steve Brennan. August 13.

[NLPIP] National Lighting Product Information Program. 2000. “Electronic Ballasts.” *Specifier Reports*, 8 (1). Troy, N.Y.: Rensselaer Polytechnic Institute, Lighting Research Center.

———. 2003. “Mid-Wattage Metal Halide Lamps.” *Lighting Answers,* January, (7): 1.

[NRCan] Natural Resources Canada. 1994. *Consumer’s Guide to Buying Energy Efficient Windows and Doors.* Ottawa, Ontario: Natural Resources Canada.

———. 2002a. http://oee.nrcan.gc.ca/equipment/english/page50.cfm?PrintView=N&Text=N. Ottawa, Ontario: Natural Resources Canada, Office of Energy Efficiency.

———. 2002b. “Standards for Window Energy Performance.” Ottawa, Ontario: Natural Resources Canada, Office of Energy Efficiency.

———. 2002c. http://greenbuilding.ca/C2000/abc-2kcr.htm. Ottawa, Ontario: Natural Resources Canada, Buildings Group.

———. 2003. http://oee.nrcan.gc.ca/neud/dpa/data_e/Parliament/Chapter_5.cfm. Ottawa, Ontario: Natural Resources Canada, Office of Energy Efficiency.

[NRDC] National Resources Defense Council. 1998. *Efficient Wood Use in Residential Construction.* New York, N.Y.: Natural Resources Defense Council.

[ORNL] Oak Ridge National Laboratory. 2003a. “Advanced Refrigerator/Freezer Technology.” http://www.ornl.gov/ORNL/BTC/adv-rf-tech.htm. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

———. 2003b. *Hybrid Solar Lighting Summit.* Preliminary notice. Oak Ridge, Tenn.: Oak Ridge National Laboratory.

Page, E. et al. 1997. *Lighting Energy Savings Opportunities in Hotel Guestrooms.* Lawrence Berkeley National Laboratories. Berkeley, CA. LBNL-L-217.

Page, E. and M. Siminovitch. 2000. “Lighting Energy Savings Opportunities in Hotel Guestrooms.” In *Proceedings of the 2000 ACEEE Summer Study on Energy-Efficiency in Buildings*, 3.265-3.273. Washington, D.C.: American Council for an Energy-Efficient Economy.

Parker, D.S., J.K. Sonne, J.R. Sherwin, and N. Moyer. 2000. *Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand.* Contract report FSEC-CR-1220-00. Cocoa, Fla:. Florida Solar Energy Center.

Parker, D.S., J. R. Sherwin, and M. T. Anello. 2001. *FPC Residential Monitoring Project: New Technology Development—Radiant Barrier Pilot Project.* Contract Report FSEC-CR-1231-01. http://www.fsec.ucf.edu/bldg/pubs/rbs/index.htm. Cocoa, Fla.: Florida Solar Energy Center.

Perry, T. 2003. “Red Hot.” *ICEEE Spectrum,* June: 27–29.

[PG&E] Pacific Gas & Electric. 1997? Annual Summary Report on DSM Programs in 1995 and 1996. San Francisco, Calif.: Pacific Gas & Electric.

———. 2000. “Pacific Gas and Electric Company 2001 Energy Efficiency Programs Application.” Attachment K, Workpapers, K-110–K-111. San Francisco, Calif.: Pacific Gas & Electric.

[PIER] PIER Lighting Research Program. 2003. “Project 3.2: Energy Efficient Load Shedding Technology Goals and Objectives.” http://www.archenergy.com/lrp/demandresp_lighting/project_3_2.htm.

Pigg, S. 2003. *Electricity Use by New Furnaces: A Wisconsin Field Study*. www.ecw.org. Madison, Wisc.: Energy Center of Wisconsin.

Pitts, Roland (National Renewable Energy Laboratory). Personal communication .

Plasski, M. (Applied Proactive Technologies, Inc.). 2003. Personal communication with Marycel Tuazon. July.

[PNNL] Pacific Northwest National Laboratories. 2003. http://www.pnl.gov/cfldownlights/index.html. August.

Porter, J. (Architectural Energy Corp.). 2003. Personal communication with Marycel Tuazon and Harvey Sachs. July.

Portland General Electric. 2003. "Lighting Rebates – Existing Buildings." http://www.portlandgeneral.com/business/energy_efficiency/programs/pdfs/existlight.pdf. Portland, Oreg.: Portland General Electric.

Price, W. and R. Hart. 2002. "Bulls-Eye Commissioning: Using Interval Data as a Diagnostic Tool." In *Proceedings of the ACEEE 2002 Summer Study on Buildings,* p. 3.295. Washington, D.C.: American Council for an Energy-Efficient Economy.

Proctor, John. 1993. *Performance of Residential High SEER Air Conditioning Units at High Ambient Temperature*. Prepared for the Pacific Gas & Electric. San Rafael, Calif.: Proctor Engineering Group.

——. 1998. "Performance of a Reduced Peak kW Air Conditioner at High Temperatures and Typical Field Conditions." In *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* 1.265–1.274. Washington, D.C.: American Council for an Energy-Efficient Economy.

——— (Proctor Engineering Group). 2003. Personal communication to Marc Hoeschele. October 30.

Proctor, John and Danny Parker. 2000. "Hidden Power Drains: Residential Heating and Cooling Fan Power Demand." In *Proceedings of the ACEEE 2000 Summer Study on Buildings,* 1.225–1.234. Washington, D.C.: American Council for an Energy-Efficient Economy.

Prolighting.com. 2003. http://www.prolighting.com. Howell, Mich.: Prolighting.com.

Pureland Supply. 2003. http://www.purelandsupply.com. Bridgeport, N.J.: Pureland Supply.

Regents of the University of Minnesota. 2003a. "Benefits." http://www.efficientwindows.org/benefits.cfm. Twin Cities, Minn.: Efficient Windows Collaborative.

———. 2003b. "Comparison of Window Performance in New Versus Existing Construction." Twin Cities, Minn.: Efficient Windows Collaborative.

Reid, A. (Duraloc Systems). 2003. Personal communication with Steve Brennan. August 18.

Reilly, S. 2001. *High Performance Glazing in Commercial Buildings.* E Source Report ER-01-16. Boulder, Colo.: E Source, Inc.

[RER] Regional Economic Research, Inc. 2000. *Residential Energy-Efficient Lighting Consumer Research.* Report #00-051. Prepared for Northwest Energy Efficiency Alliance. http://www.nwalliance.org/resources/reports/00051.pdf. San Diego, Calif.: Regional Economic Research, Inc.

Roberson, J. et al. 2002. *Energy Use and Power Levels in New Monitors and Personal Computers.* LBNL-48581. Berkeley, Calif.: Lawrence Berkeley National Laboratories.

Roney, R. (Roney Marketing, Inc., which represents GE lighting products in Ontario). 2003. Personal communication. October 20.

Ross, J.P. and Alan Meier. 2000. "Whole-House Measurements of Standby Power Consumption." Paper presented at the Second International Conference on Energy Efficiency in Household Appliances, Naples, Italy, September.

Rubinstein, Francis (Lawrence Berkeley National Laboratory). 2003. Personal communication with Marycel Tuazon. July and October.

Ryan, W. 2002. "New Developments in Gas Cooling." *ASHRAE Journal* 44 (4): 23–26.

Sachs, Harvey M. 2002. *Toward Market Transformation: Commercial Heat Pump Water Heaters for the New York Energy $mart*^{SM} *Program.* Washington, D.C.: American Council for an Energy-Efficient Economy.

———. 2003a. *Prospectus for Program Development: The Sales Engineer: Key to Residential HVAC Efficiency.* Washington, D.C.: American Council for an Energy-Efficient Economy.

———. 2003b. *Sustained High Performance Central Air Conditioners and Heat Pumps: Delivering Energy Efficiency in Use.* PreProspectus. Washington, D.C.: American Council for an Energy-Efficient Economy.

Sachs, Harvey M. and Sandy Smith. 2003. *Saving Energy with Efficient Residential Furnace Handlers: A Status Report and Program Recommendations.* Washington, D.C.: American Council for an Energy-Efficient Economy.

———. 2004. "How Much Energy Could Residential Furnace Air Handlers Save?" *ASHRAE Transactions*, 110 (1).

Sage Electrochromics, Inc. 2003. Untitled. Presentation at DOE's Windows R&D Roadmap Implementation Meeting, AAMA Fall Meeting.

Sanchez M.C. et al. 1998. *Miscellaneous Electricity Use in the U.S. Residential Sector.* LBNL-40295, Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Sand, J. R. (affiliation???). 2003. Personal communication.

———. 2003. "Trane Active Cromer Cycle Development and Performance Testing." Fact sheet for DOE management. Oct. 6.

Sandia National Laboratories. 2003. http://www.sandia.gov/lighting/index.html. Albuquerque, N.M.: Sandia National Laboratories.

Sardinsky, R. and J. Benya 2003. *Super T8s: Super Lamps, Super Ballasts.* Report ER-03-16. Boulder, Colo.: Platt's Research and Consulting.

Sauer, Harry J., Jr. and Ranald H. Howell. 1983. Heat Pump Systems. New York, NY. John Wiley & Sons.

Savings by Design. " Savings by Design 2003 Participant Handbook: Policies and Procedures for Participation in the Statewide Savings by Design Program." http://www.savingsbydesign.com/pdfs/2003SBDParticipantHandbook.pdf. San Francisco, Calif.: Savings by Design.

Schell, M., S. Turner, and O. Shim 1998. "Application of CO_2-Based Demand Controlled Ventilation Using ASHRAE Standard 62: Optimizing Energy Use and Ventilation." In *Proceedings of the ASHRAE Transactions Symposia,* Toronto, 1213-1225.

Schroeder, C. (MTSAC). 2003. Personal communication with Hugh Dwiggins. August 14.

Scruton, C. 2003. Personal communication with E. Stubee.

Shaw, J. (Carrier Corporation). 2003. Personal communication with Steve Brennan. September 18.

Shepard, M. (General Electric). 2003. Personal communication with Marycel Tuazon. July.

Shiller, D. (U.S. Environmental Protection Agency). 2003. Personal communication with Marycel Tuazon. July.

Shipley, A.M. and R.N. Elliott. 2004. *Stationary Fuel Cells: Future Promise, Current Hype.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Shirey, D. (Researcher, Florida Solar Energy Center). 2003. Personal communication with Marc Hoeschele. August 28.

Siminovitch, M. (Lawrence Berkeley National Laboratory). 2004. Personal communication with Marc Hoeschele. January 22.

Simmons, J. (Sandia National Laboratory). 2003. Personal communication with Marycel Tuazon. August.

Smith, S., M. Tuazon, and S. Nadel. 2003. *New York Energy $mart^{sm} Cool It! Baseline Market Research Report*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Sood, P., R. Furmanek, J. Lloyd, P. Riola, S. Randall. (undated). *Switched Reluctance Motor-Drive System for Washing Machines.* From SR Drives, Ltd. web site, http://www.srdrives.com/. 8/04)

Spartz, Philip (California Energy Commission). 2004. Personal communication.

Stephens, C. (Oregon State Energy Office). 2004. Personal communication with Hugh Dwiggins. January 22.

Stover, M. (Pulte Homes). 2001. Personal communication with Marc Hoeschele.

Stubee, Eric (SAIC). 2004. Comments in review of draft document.

Sunpower. 2003. "Linear Compressors for Refrigeration." http://www.sunpower.com/technology/line_comp.html. Athens, Ohio: Sunpower.

Suozzo, M. and S. Nadel. 1998. *Selecting Targets for Market Transformation Programs: A National Analysis.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Talbot, D. 2003. "LEDs vs. the Lightbulb." *Technology Review: MIT's Magazine of Innovation,* 106 (4): 30–36.

Tarricone, P. 2003. "The Oak Ridge Boys." *Lighting Design + Application,* July, 42–44.

Tatham, C. (Verdiem). 2003. Personal communication with Hugh Dwiggins. August 21.

[TCP] Technical Consumer Products, Inc. 2003. "GALAXe LED Desk Lamp." Specification sheet. http://www.tcpi.com//pdf/Galaxe%20spec%20sheet.pdf. Aurora, Ohio: Technical Consumer Products, Inc.

Thorne, Jennifer. 1998. *Integrated Space Conditioning and Water Heating Systems: One System Is Often Better than Two.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Thorne J., Toru Kubo, and Steven Nadel. 2000. *Opportunity Knocks: Capturing Pollution Reductions and Consumer Savings from Updated Appliance Efficiency Standards.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Thorne, J. and S. Nadel. 2003a. *Commercial Lighting Retrofits: A Briefing Paper for Program Implementers*. Washington, DC: American Council for an Energy-Efficient Economy.

———. 2003b. *Retrocommissioning: Program Strategies to Capture Energy Savings in Existing Buildings.* Washington, D.C.: American Council for an Energy-Efficient Economy.

Thwaites, S. (Thermotech Windows). 2003. Telephone conversation with D. Shipley. December 8.

[TIAX] Technology and Innovation Business Unit LLC (formerly A.D. Little, Inc.). 2002. *Application of Best Industry Practices to the Design of Commercial Refrigerators: Development of a High Efficiency Reach-In Refrigerator.* Prepared for the U.S. Department of Energy, National Energy Technology Laboratory. Cambridge, Mass.: Technology and Innovation Business Unit LLC.

Ton, M., S. Foster, and C. Calwell. 2003. *LED Lighting Technologies and Potential for Near-Term Applications.* Market Research Report #E03-114. Prepared for the Northwest Energy Efficiency Alliance. http://www.nwalliance.org/resources/reports/114ES.pdf. Portland, Oreg.: Ecos Consulting.

Tsao, J.Y. ed. 2002. *Light Emitting Diodes (LEDs) for General Illumination: An OIDA Technology Roadmap, Update 2002.* http://lighting.sandia.gov/lightingdocs/OIDA_SSL_Roadmap_Tutorial.pdf. Washington, D.C.: Optoelectronics Industry Development Association.

Turner, W. 2003. "Know Our Systems Better—Or Utilize Higher Technology?" *Strategic Planning for Energy and the Environment*, 23 (1). Lilburn, Georgia.

Unger, Reuven. 1999. "Development and Testing of a Linear Compressor Sized for the European Market." http://www.sunpower.com/pdf/Doc0074.pdf. Athens, Ohio: Sunpower.

Vieira, Robin K., Danny S. Parker, Jon F. Klongerbo, Jeffrey K. Sonne, and Jo Ellen Cummings. "How Contractors Really Size Air Conditioning Systems." http://www.fsec.ucf.edu/Bldg/pubs/ACsize.

Vineyard, Edward A. and James R. Sand. 1997. "Experimental and Cost Analyses of a One Kilowatt-Hour/Day Domestic Refrigerator-Freezer." *ASHRAE Transactions,* Symposia 103, Paper BN-97-7-2, 621–629.

Vorsatz, D., L. Shown, J. Koomey, M. Moezzi, A. Denver, and B. Atkinson. 1997. *Lighting Market Sourcebook for the U.S.* LBNL-39102. Berkeley, Calif.: Lawrence Berkeley National Laboratory.

Walerczyk, S. (Lighting consultant). 2003. Personal communication with Jennifer Thorne. August.

Walker, I., M. Mingee, and D. Brenner. 2003. *Improving Air Handler Efficiency in Residential HVAC Applications.* LBNL 53506. Berkeley, Calif.: Lawrence Berkeley Laboratory Publication.

Walker I., M. Sherman, M. Modera, and J. Siegel. 1998. *Leakage Diagnostics, Sealant Longevity, Sizing and Technology Transfer in Residential Thermal Distribution Systems.* LBL LBL-41118. Berkeley, Calif.: Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division, Energy Performance of Buildings Group.

Westphalen, D. and S. Koszalinski. 1999. *Energy Consumption Characteristics of Commercial Building HVAC Systems. Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation.* Arthur D. Little, Inc. Reference No. 33745-00. Published for the U.S. Department of Energy. Contract No.: DE-AC01-96CE23798. Cambridge, Mass.: Arthur D. Little, Inc.

———. 2001. *Energy Consumption Characteristics of Commercial Building HVAC Systems, Vol. 1: Chillers, Refrigerant Compressors, and Heating Systems*. NTIS PB2001-104340. Cambridge, Mass.: Arthur D. Little, Inc.

Wolpert, J.S. 1992. "Simulation, Monitoring, and the Design Assistance Professional." *Energy Engineering,* 89 (5): 6–21.

Xcel Energy. 2002. "Building Recommissioning." http://www.xcelenergy.com/ProductsServices/BuildingrecommissioningMN.asp. Minneapolis, Minn.: Xcel Energy.

———. 2003. "Xcel Energy New Construction Lighting Rebate Application." http://www.xcelenergy.com/docs/retail/busmrkts/BusinessLightingNewConstructionRebateMN.pdf. Minneapolis, Minn.: Xcel Energy.

Yarbrough, David (Consultant recommended by industry association, RIMA, on life expectancy). 2003 Personal communication.

Bibliography from the World Wide Web

http://www.fptechinc.com/Links/UVGItechSum.pdf: FPTech

http://www.nyletherm.com/waterheating.htm: Nyle Specialties

http://www.laars.com/: Laars Heating Systems.

http://cetc-varennes.nrcan.gc.ca/eng/publication/r2000-93e.html: DABO

http://greenbuilding.ca/GBIC.htm: Green Building Information Centre

http://oee.nrcan.gc.ca/newbuildings/cbip.cfm: Natural Resources Canada's Commercial Building Incentive Program

http://www.messerschmitt.com/en/ftp/INCOS_e.pdf: Messerschmidt

http://www.acrx.com/: ACRx Solutions

http://www.avistalabs.com/: ReliOn, Inc.

http://www.ballard.com/: Ballard

http://www.buildingsgroup.nrcan.gc.ca/projects/adv_houses_e.html: Natural Resources Canada

http://www.buildingsgroup.nrcan.gc.ca/projects/windows_ep_detail_e.html: Natural Resources Canada

http://www.buildingsystemsprogram.pnl.gov: DOE, whole building diagnostician

http://www.capstoneturbine.com: Capstone

http://www.cee1.org/com/com-main.php3: CEE

http://www.cee1.org/com/com-ref/com-ref-main.php3: CEE, refrigerators and freezers

http://www.cee1.org/com/com-ref/ice-main.php3: CEE, commercial ice makers

http://www.coolchips.com: Cool Chips PLC

http://www.copeland-corp.com/cp_rf/prod_sol/cp_rf_products_scroll.htm: Copeland Corporation, modulating (variable speed) scroll compressors

http://www.ecopeland.com/Literature/eCopeland/en_Broch_Cope_Horizontal.pdf: Copeland Corporation, horizontal refrigeration scrolls

http://www.eere.energy.gov/buildings/zeroenergy: DOE/EERE, Zero Energy Homes

http://www.eere.energy.gov/femp/technologies/eep_ice_makers.cfm DOE/EERE, commercial ice machines

http://www.efficientwindows.org/conditions.cfm: Efficient Windows Collaborative

http://www.eia.doe.gov/oiaf/aeo/assumption/tbl12.html: EIA, *Annual Energy Outlook*—Assumptions

http://www.ekocomfort.com: ēKOCOMFORT

http://www.electroluxcompressors.com/ECC/WebObjects/Electrolux.woa/wa/Nav/serieSpecMain?s=ESDACC Compressors

http://www.enerkoncorp.com/default.asp: EnerKon

http://www.energy.ca.gov/distgen/equipment/stirling_engines/stirling_engines.html Distributed Energy Resources Guide: Stirling Engines

http://www.energystar.gov/index.cfm?c=commer_refrig.pr_commercial_refrigerators: ENERGY STAR

http://www.esv.or.at/aktuelles/energyglobe/globe02/bbedzed_e.htm: BedZED: the Zero Energy Urban Village

http://www.facilitydynamics.com/pacrat.html: Performance and Continuous Re-commissioning Analysis Tool (PACRAT)

http://www.fosterandpartners.com/internetsite/html/Project.asp?JobNo=1004: Swiss Re Headquarters

http://www.fluent.com/about/news/newsletters/03v12i2/s1.htm: Swiss Re Headquarters Inside & Out article

http://www.fuelcelltoday.com: Fuel Cell Today

http://www.medistechnologies.com: Medis Technologies Fuel Cells http://www.nbnnews.com/NBN/issues/2004-02-09/Research/: Livermore ZEH house article

http://www.nuvera.com: Nuvera Fuel Cells

http://www.pge.com/003_save_energy/003c_edu_train/pec/info_resource/act2_proj.shtml: Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency

http://www.plugpower.com: PlugPower, fuel cells

http://www.stirlingtech.com: Stirling Technologies Company, Stirling engines

http://www.stmpower.com: Stirling Thermal Motors Power, Stirling engines

http://www.sunpower.com: Sunpower, Stirling engines

http://www.usgbc.org: U.S. Green Building Council

http://www.usgbc.org/LEED/LEED_main.asp: Leadership in Energy and Environmental Design

http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf: Leadership in Energy and Environmental Design, green building rating system

http://www.utcfuelcells.com: United Technologies

http://www.whispergen.com: WhisperGen, Stirling engines

http://www.verdiem.com: Verdiem, Surveyor Network Energy Manager

Appendix A. Low Priorities from Emerging Technologies Initial Screening

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Appliances, Cooking								
Halogen cooktop elements	low use and low savings relative to baseline, Nadel et al. 1998	ETR (1993); E Source (1996), DOE TSD		very low	RES	COOK	ELEC	
DHW + Laundry								
Res. microwave, heat pump, and advanced gas dryers		Laura Goldberg McNaughton, Residential Energy Efficiency Programs	high (Nadel et al. 1998)		RES	LAUN-DRY	ELEC	NEW
Residential electric water heating demand response and control equipment	not an energy saving measure; may reduce peak, not emerging	Laura Goldberg McNaughton, Residential Energy Efficiency Programs			RES	DHW	G&O	RET NEW ROB
GFX technology	heat recovery on graywater; limited applicability: needs at least 5' waste line drop, CSE <2c/kWh claim	Kevin James (ASE)		34% claimed	R&C	DHW	ALL	RET NEW
Ultra-high efficiency direct contact water heater	very limited applications (laundries, other process-like installations); OK for potable water (hotels?)	CADDET			C&I	DHW	G&O	RET NEW
Combined refrigerator & water heater	low potential with conventional refrigerators, which throw off only 10–20% of the heat needed for DHW	ETCC			RES	DHW, REF	ELEC	RET NEW
Metlund® Hot Water D'MAND® System	to be watched for next study	?			RES	HEAT	GAS	NEW

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
HVAC								
Cool duct coatings	replaces standard galvanized coatings of ducts that are moderately reflective (40%) and have low emittance (25%)	Jon McHugh, Heschong Mahone Group Inc.			C&I	Envelope	ELEC	NEW OEM RET
Cool duct coatings (continued)	high reflectance, high emissivity material on duct surface to minimize heat gain in attic ducts; the extent to which additional emissivity/reflectance of surface material will decrease heat gain is uncertain		unknown	unknown	RES	Envelope	ELEC	NEW OEM RET
Low pressure residential air distribution system (redesigned return)	short-run supply ducts reduces fan energy use; little savings data yet available but high potential	Skip Hayden			RES	VENT	G&O	NEW
Anti-microbial coatings as alternative to UV air treatment	UV itself has low penetration, so low energy impact. Technologies will compete with each other.	Harvey Sachs	~ 3c/kWh		ALL	OTH	ALL	RET NEW OEM
Modified blower door subtraction test	hard to assign savings to the diagnostic method	ACEEE Summer Study Proceeding			RES	HEAT	G&O	RET NEW
Nulling test for testing duct leakage	hard to assign savings to the diagnostic method	ACEEE Summer Study Proceeding			COM	HEAT	G&O	RET
Add-a-hole duct leakage test	hard to assign savings to the diagnostic method	ACEEE Summer Study Proceeding			RES	HEAT	G&O	RET NEW
Delta-Q test for testing duct leakage	hard to assign savings to the diagnostic method	Andrews 2002			COM	HEAT	G&O	RET

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Shaded "corrals" for roof-top equipment	physically shading roof-top equipment that is too high or space constrained for tree and vine growth to be useful	>2% market share ??			RES	OTH	ELEC	RET NEW OEM
Advanced controls, including better TXV-like liquid controllers for evaporators	not much saved over TXV	Harvey Sachs			R&C	CONTROL	ALL	RET NEW OEM
Wireless thermostat	described in Appendix B	Peter Douglas, NYSERDA			R&C	CONTROL	ALL	RET NEW
Evaporative condensers	$1500 for 10 ton unit, West only; may be attractive for peak savings	Harvey Sachs	~15c/kWh	0.06%	C&I	COOL	ELEC	RET NEW
Triple effect absorption chillers	no energy savings compared to good electric chiller (1.4 COP vs. 0.5kW/ton); fuel shifter	ETCC		0.00%	COM	COOL	GAS	RET NEW
Adsorption heat pump	no commercial activity found	ETR (1993)			R&C	HEAT	GAS	NEW
Spot coolers	portable A/Cs; increase energy use by enabling A/C when none before	Harvey Sachs			COM	COOL	ELEC	NEW
ēKOCOMFORT with desiccant cooling	low-energy cooling system for air conditioning and dehumidification trade-off: desiccant gives higher temp, lower humidity than mechanical refrigeration	Skip Hayden		<.25%	RES	COOL	G&O	RET NEW
Kelix Air Conditioner	uses centrifugal force instead of compressor to compress refrigerant; no reliable info found	DEG			RES	COOL	ELEC	RET NEW ROB

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Heat Recovery Ventilator (HRV/ERV)	bears watching, in part for peak impact		High CSE ~8c/kWh now.	0.14%	RES	VENT	ALL	NEW
Thermosiphon ventilation (residential)	not commercialized: hard to protect intellectual property, serious doubts about condensation and (regional) radon	Ned Ford, FUSE			COM	VENT	ELEC	RET NEW OEM
Nightbreeze	described in CA study	DEG		0.01%	RES	COOL	ELEC	NEW
High volume, low speed ceiling fans	ENERGY STAR program now in place; lighting also addressed	ETCC			COM	COOL	ELEC	RET NEW
Combined high efficiency/air purifying with ultraviolet residential HVAC	low static pressure, advanced air cleaner—electronic, UV, carbon? represents new application, but done efficiently	Laura Goldberg McNaughton, Residential Energy Efficiency Programs			RES	HC	G&O	RET NEW
Air filters with high efficiency for both air cleaning and electricity use (fan power)	may make new application more efficient, hard to estimate savings when use not well established	Harvey Sachs		0.24%	R&C	VENT	ALL	RET NEW OEM
Outdoor reset controls with condensing boilers	>2% market share	Matthew Dugan, Residential Energy Efficiency Programs		0.40%	R&C	HEAT	G&O	RET NEW ROB OEM
Residential hydronic radiant slab cooling	pre-cooling a slab with circulated chilled water can reduce kW hrs by 50%; DRY climate, new construction only; will meet resistance	Chris Scruton, CEC		0.08%	RES	HEAT	ELEC	NEW
Attic heat recovery	considered complex for potential, day-night availability mismatch, too	ETCC		0.10%	RES	HEAT	ELEC	NEW

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Advanced biomass fireplace	integrated heating by burning pellets or wood in advanced stoves; changing energy carriers does not reduce energy but may have other values	Skip Hayden			RES	HEAT	ALL	RET NEW
Condensing unit heaters	relatively small total savings	Harvey Sachs			COM	HEAT	G&O	RET NEW
Infrared heaters	50% savings on warehouse and storage heating; low overall savings	Harvey Sachs		0.15%	COM	HEAT	G&O	RET NEW
Integrated services with water loops (zone heat pumps for space conditioning, water heating, ice-making refrigeration etc.)	very limited applications to date, such as convenience stores with high DHW load (car wash); bears watching.	Harvey Sachs			COM	WSH	ALL	NEW
Lighting								
Integrated motion sensor controlled luminaire for emergency stairways and hallways	bi-level operation dims to 10% standby light level when space is unoccupied	Peter Douglas, NYSERDA		0.07%, too low	COM	LIGHT		RET NEW
Advanced lighting distribution systems (light pipes & guides, fiber optics, etc.)	technology needs both efficient lighting distribution system and a high efficacy central light source, latter not likely	LBNL, NYSERDA			C&I	LIGHT	ELEC	
Coated filament incandescent, hafnium carbide and ceria lamps	research level low, will not be soon.	ETR (1993)			C&I	LIGHT	ELEC	

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
DC lighting system	little progress found	ETR (1993)			COM	LIGHT	ELEC	RET NEW
Dimmable HID electronic ballasts	relatively small total savings	ETR (1993)		~0.16%	C&I	LIGHT	ELEC	
Electrode-less lamps, power supplies and luminaires	niche product, low total savings potential	LBNL			COM	LIGHT	ELEC	
Polarizing lenses	very limited benefits	ETR (1993)			COM	LIGHT	ELEC	
Fluorescent bulbs for refrigerators	very small savings since bulbs off when door closed	Ned Ford (FUSE)			ALL	LIGHT	ELEC	OEM
GloBrite Exit Signs	signs are designed to glow in total darkness after exposure to normal ambient fluorescent light	Al Carlson, Jessump Mfg. Co.		low	C&I	OTH	ELEC	RET NEW OEM
Exit signs light panel technology		Ken Anderson, NEEA			COM	ELEC	ELEC	RET NEW ROB
LunaPlast-Photoluminiscent materials for signs	PL lighting product that is 15X plus brighter than zinc sulphide-based products that have been the industry standard	Kimberly Landry, LUNA Technologies		not known	COM	ELEC	ELEC	RET NEW
Power and Drives								
Non-intrusive load monitor (NILM)	written up for CA report	Chris Suton, CEC			COM	OTH	ELEC	RET NEW

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Flow batteries, mostly for power quality	uses two salt solution electrolytes, which store or release electricity by means of reversible electrochemical reactions	ACEEE Summer Study Proceeding			COM	OTH	ELEC	RET NEW
Residential and commercial fly wheels		Laura Goldberg McNaughton, Residential Energy Efficiency Programs			RES	OTH	ELEC	RET NEW
High efficiency, low emissions biofuel energy systems	long commercialization path for infrastructure, low savings from energy carrier substitution	Evgueniy Eentchev			RES	OTH	ALL	RET NEW
PV- residential roof shingles	PV that looks like & installed like asphalt shingles; too expensive for energy, may work for demand	Laura Goldberg McNaughton, Residential Energy Efficiency Programs	~28c/kWh		RES	ELEC	ELEC	RET NEW ROB OEM
High-density thermal energy storage (TES)	low energy savings, may have higher value from peak-shifting	Skip Hayden, Rob Brandon			RES	HC	ALL	RET NEW
Practices								
NGI-Integrated Design Approach/Building Design Advisor	design tool—fully integrated design software that understands energy use; savings hard to estimate	ETCC	not known	not known	COM	OTH	ALL	NEW
SkyCalc	skylighting computer analysis and design tool; savings hard to estimate for "practice"	Lisa Heschong, HMG			COM	OTH	ELEC	RET NEW ROB
Improved labels for fluorescent lamps, fixtures, and ballasts	labeling to indicate which fluorescent products are efficient; is this viable given new ballast law—NO				ALL	OTH	ELEC	

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
INNLON: Balancing Heating, Ventilating, and Air Conditioning Systems using LonWorks Control Networks	may reduce balancing costs; energy savings unclear, but may look like automated building diagnostics	CADDET		0.18%	COM	HC	ALL	RET NEW
MLM Design Method	sizing using Most Likely Maximum reduces size of chiller and distribution; reducing size may not save energy (IPLV, cooling tower size, etc.)	Karl Brown		0.18%	COM	HC	ELEC	NEW
Refrigeration								
Discus reciprocating compressor	semi-hermetic reciprocating compressors with efficient valve design	ETCC		relatively low	COM	OTH	ELEC	OEM
EE soft drink dispensing systems (fountain serve)		Noah Horowitz, NRDC		low	COM	OTH	ELEC	RET NEW
2-layer air curtains for supermarket freezer applications	need more information	Harvey Sachs			COM	REF	ELEC	RET NEW
Thermo-acoustic refrigeration	acoustic power drives heat pump; longer term effort, will have to out-compete linear compressors with DC motors	E Source			R&C	REF	ELEC	NEW
Low-refrigerant supermarket refrigeration systems	saves refrigerant, but may not save much energy (depending on evaporator controls)	EPRI & DOE			COM	REF	ELEC	NEW

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Advanced HVAC refrigerants (HFC & "natural")	>2% market share, no longer emerging	Harvey Sachs			ALL	REF	ALL	NEW OEM
Magnetic refrigeration	certain materials that heat when magnetized can be used to cool space (possibly 20% more efficient than conventional cooling methods); beyond our time horizon.	E Source, *ASHRAE Journal,* January 2002, Ames Laboratory at Iowa State University, Toshiba			RES	REF	ELEC	NEW
Linear compression refrigeration	on the market by LGE in U.S. in 2004; could become important	Marbek			RES	COOL	ELEC	NEW
Shell								
Aerogel glazings	significant commercial use not expected in timeframe	LBNL. http://advancedbuild ings. org			R&C	Envelope	ALL	NEW
Low-e interior surfaces/ low-e interior paint	low emissivity (0.9 --> 0.6) paint reduces MRT and increases comfort—little in validated info available; savings assumed at 3%	SS (1996)	~5c/kWh	~0.10% (low)	ALL	Envelope	ALL	NEW RET
Radiant barrier paint (for attics)	low emissivity coating for roof deck reduces heat gain in attic; savings assumed to be 3%,	DEG	>10c/kWh	~0.05% in new and retrofit markets	RES	Envelope	ELEC	RET NEW
Rammed earth	low savings	ETR (1993)		Low (Nadel et al. 1998)	RES	Envelope	ALL	
Thermally resistive concrete	savings less than threshold	ETR (1993)		Low (Nadel et al. 1998)	C&I	Envelope	ALL	

Measure Name	Notes	Source	Cost of Saved Energy	Energy Savings Estimate	Sector	End-Use	Energy Type	Segment
Snap-Cap	insulated steel framing that uses steel studs and sheathes the entire steel studding in an outdoor layer of plastic, exterior, extruded polystyrene foam.	Chris Scruton, CEC	Unknown	~0.1 to 0.15% in new commercial construction	R&C	Envelope	G&E	NEW
Optimized air curtains and door closers for retail and material handling areas	need more information	Harvey Sachs		low?	COM	OTH	ALL	RET NEW
Miscellaneous								
High performance fume and kitchen ventilation hoods	limited savings estimated	Dale Sartor, LBNL			COM	HC	ALL	RET NEW ROB
The Bennett system	seals the garbage chute save except to let the garbage pass through; limited applicability	Daniel Wybo, Bennett Manufacturing			COM	HC	ALL	NEW
Improved Kitchen Ventilation	reduced hood velocities and two speed make-up air fans	Peter Turnbull, PG&E		0.12%	COM	VENT	ELEC	RET NEW
Out-of-Scope								
Off-grid manufactured housing	did not find good analyses	WSU			RES	OTH	ALL	
AM400 Soil moisture Data logger	device provides irrigators with onsite access to soil moisture data irrigation scheduling; industry/agriculture—out of scope	Ken Anderson, NEEA			IND	CONTROL	ELEC	RET NEW OEM

APPENDIX B: CALIFORNIA-SPECIFIC EMERGING TECHNOLOGIES AND PRACTICES, AND DIFFERENTIATED SCREENING OF CLIMATE-SENSITIVE MEASURES[9]

Summary

In the main section of this report, ACEEE, Davis Energy Group, and Marbek Resource Consultants describe emerging technologies and practices that could lead to greater efficiency in the buildings sector. The methods used were adapted from those of two earlier ACEEE-led studies (Nadel et al. 1993; Nadel et al. 1998). The sub-study described in this appendix added two principal tasks: to use the main report's national study methods with costs from California to evaluate technologies that might have particularly great value there; and to create a more fine-grained evaluation of the climate-sensitive emerging technologies and practices evaluated in the national study.

In the first task, we evaluated three emerging technologies and prepared descriptions of two others for which savings potential could not be estimated:

- **Variable-output compact fluorescent lamps** (CFLs), units that either have multiple, discrete lighting outputs or have a continuous dimming range. The three-way lamps studied cost less than the sum of the shorter-lived incandescents they replace, so the simple payback calculates as immediate, and the cost of saved energy is negative (-$0.01/kWh). Dimmable CFLs are almost as attractive: despite a $12 price premium over the inexpensive conventional bulbs they replace, the cost of saved energy is still only $0.01/kWh. (In both cases, our calculations do not include labor for bulb changes or other maintenance.) The total savings possible from substituting these advanced CFL types are 3,000 and 14,500 GWh/yr, respectively, in California in 2020.[10] These lamp types and controls are not very common, compared to mainstream products.
- **Advanced controls for packaged HVAC** (heating, ventilating, and-conditioning) units for light commercial applications. Packaged units, typified by roof-top units (RTUs), are rated by refrigeration efficiency only, but also provide ventilation and *economizer* services, the latter being the ability to bring in cooler outside air when available to avoid use of the refrigeration cycle. In hot-dry climates with large daily temperature cycles, economizers alone can save almost half of the energy use of RTUs but are often absent or not operating. Advanced controls would optimize use of ventilation for savings and indoor environmental quality (IEQ) and give key fault diagnostics—but look and work much like thermostats. With very conservative assumptions, we compute potential California savings of 1,740 GWH in 2020, at a cost of saved energy of $0.03/kWh.[11] Demand savings would be real, but depend on the ability of CO_2 or equivalent monitors to estimate occupancy (and thus ventilation requirements) at peak times.
- **Integrated whole-house ventilation systems**. Houses in areas with hot days and large diurnal temperature swings can significantly reduce summer peak load and cooling energy use through nighttime ventilation cooling. Residential air conditioning is responsible for about 45% of California's peak load but only consumes about 7% of household electric energy (Coito 2003). Such ventilation systems could be considered as integrated replacements for whole house fans, with air filtration. Projected energy savings vary widely with climate, ranging from less than 5% for coastal climates to greater than 60% in transition climates (coastally influenced inland areas). Savings in hot inland areas range from 20 to 50%. If combined with measures to improve building envelope summer performance, ventilation cooling is projected to

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[9] Commissioned by the California Energy Commission, through the California Institute for Energy Efficiency, Office of the President, University of California.

[10] Lau (2004) reports that CFLs have a much shorter life than the manufacturers' claims, based on findings from the SCE measurement and verification (M&V) program. Consequently, the DEER database will be revised to reduce energy savings by about 22%, mainly due to early burnout in the field. This would somewhat increase the cost of saved energy, but it remains about $0.01/kWh.

[11] Lau (2004) reports that 5-ton or smaller packaged HVAC units do not need an economizer cycle. Further, some building owners who require a 10-ton AC will prefer two 5-ton units to avoid the first cost increment of the economizer.

eliminate the need for mechanical air conditioning in some coastal areas.[12] NightBreeze systems (including the variable speed hydronic air handler with heating coil, damper, and controls) are expected to sell for about $2,800. The cost of saved energy is high ($0.22), but the measure may be justified by peak reduction. The potential electricity saving is 879 GWH reduction in 2020, but interest may be warranted by the opportunity to reduce peak demand by night-time pre-cooling with this technology. The projected incremental cost of $1,200 with mechanical air conditioning would avoid 1.3 kW of peak demand, which will be attractive in some areas. Where NightBreeze eliminates the need for mechanical air conditioning, first costs are reduced, leading to $0 cost demand and energy savings.

In addition, within this task we developed descriptions of two other technologies, with qualitative evaluation of their potential roles in energy efficiency. One of these is a wireless thermostat that just replaces conventional units. It does not itself save energy relative to conventional units but may enable savings (or increase use), depending on the application. The other is a (pre-commercial) load monitor/diagnostic tool.

Wireless thermostats (WTs) use batteries and radio signals instead of "hard" wiring, but otherwise have the same features of comparable standard thermostats, including programmability. Wall-mounted WTs are available for residential units, fan-coils, baseboard electric heat, window air conditioners, "mini-split" air conditioners, and PTACs (packaged terminal air conditioners and heat pumps). Wall-mounted WTs are simply wireless replacements for conventional units in situations such as: (1) system modernization, where new equipment functions may not be compatible with older wiring; (2) thermostat placement that does not meet user needs; and (3) rezoning, so controls match new distribution systems. Counting installation, WTs may be less expensive than wired units. Another class of WT is portable, analogous to remote controls for televisions. These allow the user to adjust the temperature to the desired level in the room where she is. This is likely to be used particularly in houses or other structures where construction defects (insulation, infiltration, fenestration, or ductwork) lead to wide temperature differences from room to room, during the day (as the sun moves), or as seasons change. Wireless thermostats may facilitate energy savings by enabling better control where otherwise cost-prohibitive or less flexible.

The other technology described, the Non-Invasive Load Monitor (NILM), is a pre-commercial concept to improve diagnostics by continuous monitoring of system performance as reflected in motor dynamics (particularly at start-up). By itself, NILM does not save energy, but its diagnostics can lead to energy-saving maintenance actions. NILM and HVAC Fault Detection and Diagnosis (FDD) use quick-sampling power meters and computer analyses to monitor and/or diagnose problems in HVAC systems. They detect on and off switching of major HVAC loads in commercial buildings, track variable-speed drive loads, and detect operating faults from a centralized location at moderate cost. The data can help optimize operations, and aid commissioning and diagnostics. The advantage of NILM methods is the ability to monitor several motors with a single device and to "look" at systems purely with motor electric load information, without needing flow or other sensors. The drawbacks are that the motors to be monitored must be relatively large compared to the total current in the branch circuit, and that applicability to motor systems with variable speed drive is very limited. The first "production" application may be as part of a controller (or a free-standing device) for roof-top packaged air conditioners for light commercial applications, work being funded now by the California Energy Commission. The concept is still pre-commercial, so no information on costs or benefits is available.

The second major task for this sub-study is to produce a more fine-grained evaluation of the climate-sensitive emerging technologies and practices evaluated in the national study. In particular, our goal was to look at the variability of savings with climate for three selected areas of California—coastal, transition, and inland. These areas were selected to include as much of the population and as diverse a suite of climates as feasible. From the list of all emerging technologies and practices, we first isolated the 33 measures for which savings would be reasonably climate-sensitive. These include HVAC, building shell, glazing/windows, and similar measures. Some HVAC measures were excluded because they are specifically designed for climates that are rare or non-existent in California, such as air-conditioners for hot-humid climates and cold-climate heat pumps. We also excluded those measures for which climate effects were small, such as lighting (hours needed per year varies little with climate per se). For the 33 measures for which climate may affect savings and the cost of saved energy in California applications, we estimated savings from base case annual energy use compared with efficiency case energy use. We did this for the three different California climate areas noted above by applying appropriate degree-day corrections for each zone relative to the national savings. This gave a total of 99 zone-measure evaluations. We used California-

[12] Lau (2004) reports that field performance tests continue.

specific costs of saved energy for screening. In particular, we started with $0.1244/kWh as the average residential tariff and $0.1447/kWh as the average commercial tariff.[13] Adapting the methods of the national study, we divided these values by two for our screening parameters for high-priority measures, thus using $0.062 residential and $0.072 commercial.

Highlights of this analysis are:

- *Most measures are either cost-effective in all climate areas, or not cost-effective in any climate area: climate is rarely a key discriminating variable.* Twenty-four of the 33 measures are cost-effective in all climate zones considered. Conversely, six are not cost-effective in *any* climate zone. Only three are cost-effective in some zones but not others, and one of those is borderline.
- Of the 33 measures, 12 are commercial, seven have both residential and (light) commercial applications, and seven are almost purely residential.
- In addition, of the cost-effective zone/measure combinations, 18 are coastal, 21 are transitional, and 24 are inland climate zones. As would be expected, more measures are cost-effective in hotter regions.
- Finally, our 33 measures included 25 that are predominantly technologies, six are considered practices, and two combine technology and practice.

The analysis of climate sensitivity also has policy implications for California. First, the potential value of many emerging technologies is fairly insensitive to climate for the relatively small variability considered among coastal, transitional, and inland zones in California. Of the 33 technologies and practices considered, 24 were projected to be cost-effective in all climate zones and six were considered too expensive (in cost of saved energy or "CSE") in all zones. Only three measures were cost-effective in some climate areas but not in others. Indeed, for most of the measures that were cost-effective in some but not all zones, the variability in estimated CSE for the measure is only about $0.005/kWh. From this, we infer that climate is not a very important variable in screening emerging technologies for California. On the other hand, the variation in estimated savings in 2020 is very large, more than a factor of 200. This strongly suggests that the most attractive measures are those that combine reasonable cost of saved energy with relatively large (>100 GHW) out-year savings.

We found a wide variation in the savings per measure and zone. Three measure groups gave savings estimates greater than 20 TBtu of source energy in 2020: micro CHP (whether using fuel cells or micro-turbines), integrated design process (LEED or 30% better than code), and aerosol-based duct sealing. The first two were for the commercial sector and the last for the residential. Another six zone/measure combinations would save more than 10 TBtu, but 40 zone/climate combinations would save less than 1 TBtu in 2020.

Finally, we again see the relatively high importance of "human-ware," the emerging *practices* that improve efficiency through proper design and sizing, installation, and maintenance. Increasingly, continuing the trajectory of improved efficiency will require investing directly in people and incentives for people, and in showing customers (decision-makers) the economic, comfort, and other values of investments in doing the right jobs the right ways.

Background

This appendix is designed to treat some emerging technologies and practices issues that could be particularly important in California. In the main body of this report, almost 200 national measures were screened. We then selected 72 for detailed analysis, based on estimates of their likelihood of success. Using these analyses, we classified measures as high, medium, or low priority. This was based on three parameters: magnitude of prospective energy savings; cost of saved energy; and likelihood of success. The **high priority measures** are diverse. Two (leak-proof ducts and duct sealing) are distribution system improvements and two are practices (design of high-performance commercial buildings and retrocommissioning.) Automated diagnostics complements retrocommissioning as a building operation improvement. The final high-priority measure, 1 Watt standby power for home appliances, is the only "pure" equipment measure in the high priority list. These measures were described more fully in the main body.

Seven of the 20–26 **medium priority measures** are lighting, primarily commercial measures (premium T8 lighting, one-lamp fluorescent fixtures, commercial LED lighting, and scotopic lighting). However, at least two (airtight

[13] These are average investor-owned rates, from http://www.energy.ca.gov/electricity/current_electricity_rates.html.

compact fluorescent downlights and CFL portable fixtures) are primarily residential. Twelve of the measures are primarily residential. Five of these deal with refrigeration-cycle equipment: improved refrigerators, air conditioners, and heat pump water heaters. Commercial measures include better management of networked computer energy use and carbon dioxide-controlled ventilation to reduce fan power as well as chiller energy. The common element among **low priority measures** is the low likelihood of success, frequently because they represent major changes from present methods and technologies. Low likelihood of success in the near term is exemplified by the very large savings associated with commercial "combined heat and power" (CHP) technologies incorporating microturbines and fuel cells, and even for residential CHP with Stirling engines. We also noted "**special" measures** that have high value for specific regions or new construction, even though they may not have enough countrywide savings to warrant national priority. About half of the special measures are feasible for new construction, but prohibitively expensive as retrofits. These measures include low energy designs and construction methods. "Special" also includes half a dozen measures specific to hot or hot and humid climates, typically advanced air conditioners such as the Cromer Cycle (combining desiccant and refrigerant systems in a single unit). The category also includes air conditioners optimized for hot-dry climates and two-speed pool pumps. Northern climates rate three special measures, including gas-fired absorption heat pumps, advanced condensing boilers for commercial applications, and roof-top year-round units with condensing furnace sections. Two further measures are applicable to guest rooms in the hospitality industry. These include "smart" door card keys that incorporate energy management and bathroom lighting that better matches use patterns. These may be indicative of opportunities that will arise when other industries are targeted for close examination.

Perhaps the most important finding of this study is that the well of emerging technologies and practices continues to yield many promising measures. Including special measures for new construction or regional applicability, we found more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 20–26 this time, but this study added 10–21 special measures that warrant serious consideration. Of course, the reservoir is changing. Some of the measures that would result in the largest savings would also require the greatest changes in the present mode of operations, such as CHP at commercial and residential scales with emerging technologies such as fuel cells and Stirling engines. Measures to assure ductwork integrity are another example of the need to change the business model. Achieving real results will require that industry and consumers recognize the importance of energy distribution within the building (for comfort and air quality). Finally, retrocommissioning and advanced design practices have great importance and potential, as do training, incentives, and other "human-ware" services.

Goals

In this context, this California-specific analysis has two specific goals:

1. To analyze technologies of particular interest in the state, specifically, variable-output compact fluorescent bulbs, advanced controls for small commercial air conditioners (roof-top units), and integrated whole house ventilation systems for climates with large diurnal temperature swings. We also provide descriptions of two other technologies, wireless thermostats and Non-Invasive (motor) Load Monitors.
2. To extend the national study to examine costs and benefits for specific California climate areas. We isolated 33 measures for which savings would be reasonably climate-sensitive. These include HVAC, building shell, glazing/windows, and similar measures. We excluded those measures for which climate effects were small, such as lighting (hours needed per year varies little with climate per se), and those specific to climates not important in California.

Methods

Analysis of California Technologies

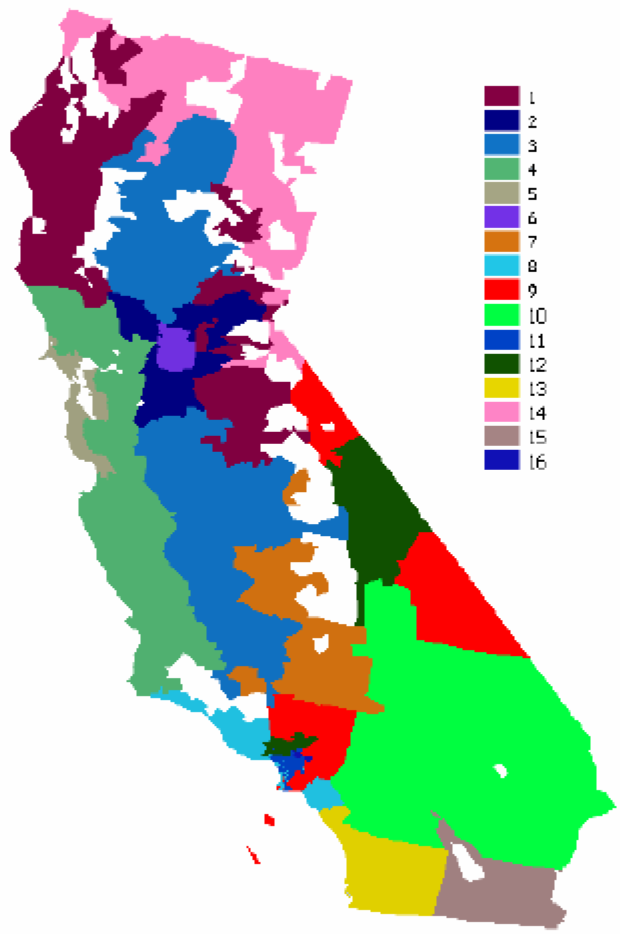
The methods used to evaluate the three technologies are those of the national study, except that we have used California base case and energy use data in calculating savings, as noted below.

Selection of Climate Zones

California consists of many unique and diverse climate zones, varying from cool coastal to hot inland-valley to mountain. Accurate estimates of energy use and savings potential require that the analyses be done in multiple zones, rather than using an average climate. Building standards and simulation analyses for California rely on 16 standard climate zones, each represented by weather data from a single city. On the other hand, utility survey and forecast data, such as is needed for this analysis, use climate zones based on utility service areas, and climate boundaries that are entirely different. Most of the areas with significant population can be grouped into one of three climate types: coastal, transition, and inland-valley. Coastal climates are moderated by the ocean and have small daily ranges and low heating and cooling loads. Transition climates are influenced by nearby marine effects, but have higher heating and cooling loads and can have hot peak conditions. Inland-valley climates have hot, dry summers and moderate winters. Climate data for this analysis was derived from CEC (2004a) for residential unit energy consumption (UEC) and PG&E (1999) for commercial end-use intensities (EUIs).

CEC (2004a) uses 12 of the16 CEC forecast climate zones shown in Figure 1 to provide regional summaries (zones 6 and 14–16 are for utilities that did not participate in the study). Each of the climate zones was assigned to one of the three climate areas based on their cooling degree days (CDD) shown in Table B-1. Climate zones with less than 1,000 CDD were mapped to coastal, zones with greater than 1,000 CDD but less than 1,500 CDD were mapped to transition, and zones with greater than 1,500 CDD were mapped to inland, using CEC (2004a).

Figure B-1: California Forecast Climate Zone Map



Note: If reading this information as a printed black-and-white document,

please refer to the posted Acrobat Reader version at http://aceee.org/pubs/a042_apndxb.pdf,

which preserves the color information that differentiates climate zones.

Figure 2 shows the climate zones used by the PG&E (1999). The coastal zone was used as is, the hill zone was used for transition, and the valley and desert/mountain zones were combined into inland. Clearly, the broad outlines of these climate areas track the climate zones of Figure 1.

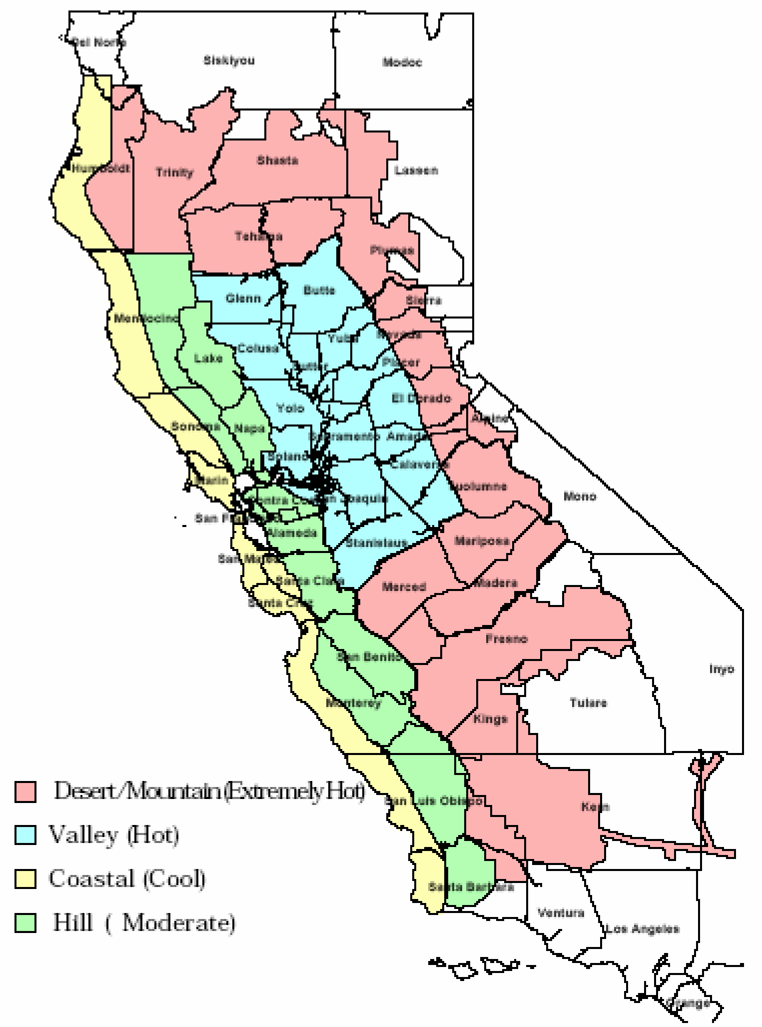
Table B-1: Summary of California Forecast Climate Zones

CZ	*Area*	*Climate*	*Population*	*CDD*
1	North Coast	Coastal	272,949	767
2	Delta Effect	Transition	340,998	1,173
3	Central Valley	Inland	816,480	1,880
4	Central Coast	Coastal	1,592,666	619
5	Bay Area	Coastal	1,227,998	133
7	South Valley	Inland	193,170	1,919
8	South Coast	Coastal	1,567,414	590
9	LA Transition	Transition	1,233,479	1,072
10	Desert	Inland	1,017,247	2,028
11	Coastal LA	Coastal	624,270	879
12	LA Transition	Transition	270,932	1,101
13	San Diego	Coastal	1,190,204	433
State		Coastal	6,475,501	570
		Transition	1,845,409	1,115
		Inland	2,026,897	1,942
		All	10,347,807	1,050

What We Did for the Climate Zone Study

The national study used national average unit energy consumption (UECs) or end-use intensity (EUIs) to calculate energy savings and cost of saved energy, and used projected 2020 sector energy uses to estimate potential savings. Analysis of weather-sensitive emerging technologies and practices requires estimates of UECs or EUIs and 2020 statewide energy use for each selected climate area. Residential UECs and commercial EUIs for each climate area were calculated by combining the UECs and EUIs from each climate zone based on the mapping described previously (see Table B-2). Residential AC and HP heating and commercial electric heating exhibit the largest variation with climate. Most of the other end-uses are less variable. Surprisingly, commercial cooling and gas heating show very small variation with climate area.

Figure 2: Pacific Gas & Electric Climate Zone Map



Note: If reading this information as a printed black-and-white document,

please refer to the posted Acrobat Reader version at http://aceee.org/pubs/a042_apndxb.pdf,

which preserves the color information that differentiates climate zones.

Statewide 2020 energy use estimates were derived from the end-use projections in CEC (2003a). Growth rates from 2003 to 2013 were extrapolated to 2020 and the resulting total end-use was distributed between climate areas by weighting by population and EUI. Although the coastal zone has the lowest EUIs for most of the end-uses, its large population results in it having the largest share of energy use.

Table B-2: Unit Energy Consumption and End-Use Intensity Variation by Climate Area

End-Use	*Inland*	*Transition*	*Coastal*
Residential Electric (kWh) Total	7,223	5,726	5,605
Air Conditioning	1,786	1,253	743
Resistance Heat	1,145	886	886
HP Heat	957	471	580
DHW	2,930	2,043	2,113
Furnace Fan	495	495	495
Pool Pump	2,671	2,671	2,671
Residential Gas (TBtu) Total	4.0	3.2	3.0
Heat	2.4	1.9	1.9
DHW	2.1	2.0	1.9
Commercial Electric (kWh/sq. ft.) Total	16.11	13.77	11.96
Cooling	4.16	4.69	3.99
Heating	5.14	5.91	2.72
Ventilation	1.27	1.38	1.20
Commercial Gas Heat (kBtu/sq. ft.)	19.93	20.92	21.64

Note: some technologies, including electric water heating and pool pumps, have large unit consumption but less than 10% market share.

Table B-3: Statewide Energy Use Projections

End-Use	*2003*	*2013*	*2020*	*2020 Inland*	*Transition*	*Coastal*
Residential Electric (GWh) Total	78,416	94,534	105,817	25,189	18,179	62,449
Air Conditioning	4,864	5,420	5,810	1,957	1,251	2,602
Resistance Heat	3,376	3,317	3,275	784	552	1,938
HP Heat						
DHW	4,869	5,484	5,915	1,502	954	3,460
Air handler fan	1,420	1,581	1,694	332	302	1,060
Pool Pump	3,590	4,068	4,403	862	785	2,755
Residential Gas (TBtu) Total	523	572	606	144	108	354
Heat	229	227	226	54	37	135
DHW	211	243	265	54	49	162
Commercial Electric (GWh) Total	92,142	107,601	118,422	28,542	22,205	67,675
Cooling	13,746	15,443	16,630	3,267	3,353	10,010
Heating	2,472	3,213	3,731	998	1,045	1,688
Ventilation	9,449	10,937	11,979	2,400	2,365	7,215
Commercial Gas Heat (TBtu)	96	106	113	21	20	72

Sources: CEC (2004a) for residential; PG&E (1999) for commercial

Results for the 3 Technologies Evaluated

Variable output, screw-base CFLs. We differentiate between two categories of screw-in CFLs: 3-way and dimmable lamps. The former replace 30–70–100 and 50–100–150 incandescent bulbs in table and floor lamps. The latter can be used in portable and ceiling fixtures with current-limiting dimmers designed for incandescent lamps. Although considered largely residential, there are some 200 million dimmable incandescents in the commercial sector, typically in conference room and hospitality industry applications (IAEEL 1997). Variable output pin-based CFLs were implicitly considered previously in the main body of this report as part of national study measure L13, High Quality Residential CFL Portable Fixtures.

At least three major manufacturers sell both dimming and 3-way CFLs, and they are available from on-line retail sources. They are important niche products to fill in gaps where consumers now continue to use incandescents.

As developed below, we infer 85W and 75W respectively for base case 3-way and dimmable lamps, but with one lamp in each 3-way fixture and two lamps in each dimmable fixture. The respective CFL new measures are 12–18–29W 3-way, and 29W dimmable lamps. For 3-way fixtures, we compare a $2 incandescent with a $10.50 Phillips CFL; for dimmable fixtures, we compare a $0.50 incandescent with a $14.75 GE dimmable (costs from Web catalogues and exclude delivery). These costs are a substantial reduction from the >$20 costs that prevailed a few years ago. Cost scaling for reflector bulbs should be approximately the same. We use 10,000 hr for CFL life and 1,200 hr for incandescent. Although these products have significant incremental costs ($9 for 3-way and $14.25 for dimmable), they outlast base case products by a factor of 8 (3-way) or 5 (dimmable, since incandescents should last longer at lower voltage).

Based on Tacoma Public Utilities data on lamp control types as reported by HMG (1997), 3-way switches control about 8% and dimmers about 4.5% of residential fixtures. For simplicity, we analyze one 3-way lamp per fixture, an equal mix of 30–70–100W and 50–100–150W incandescents, operated in the medium position, or an average of 85W (medium output). Three-way fixtures are dominantly portable (plug-in). For dimmables, we assume two lamps/fixture, rather than the overall 1.6 lamps/fixture in HMG (1997), and 75 watts/lamp.

One key barrier is low visibility in the market. These devices must compete for shelf space with an ever-broader array of (fixed output) CFLs and incandescents. The other is high first cost relative to incandescent bulbs. We recommend that market transformation organizations use the same stimuli that have accelerated acceptance of single-output CFLs, such as incentives (or coupons) for consumers and incentives to retailers to improve product visibility and price. Variable output CFLs have an additional significant advantage over incandescents: they maintain color temperature better at lower light output (Rea 2000).

The 3-way lamps studied cost less than the sum of the shorter-lived incandescents they replace, so the simple payback calculates as immediate, and the cost of saved energy is negative (-$0.01/kWh). Dimmable CFLs are almost as attractive: despite a $12 price premium over the inexpensive conventional bulbs they replace, the cost of saved energy is still only $0.01/kWh. (In both cases, our calculations are "residential," in that they do not include labor for bulb changes or other maintenance.) The total savings possible from substituting these advanced CFL types are 3,000 and 14,500 GWh/yr, respectively, in California in 2020. The lamp types and controls are not very common.

The combination of cost of saved energy less than half of the residential rate, relatively large energy savings potential, and high likelihood of success makes this a high priority measure. We deem the likelihood of success high, since the products are closely related to other compact fluorescent bulbs.

Table B-4: Analysis of Variable Output Compact Fluorescent Bulb Technologies

Emerging Technology Database	Units	Measure	Notes
Number	CA1		
Name		Variable Output CFLs	
Description		3-way CFLs	
Market Information:			
Market sector		RES	
End-use(s)		LIGHT	
Energy types		ELEC	
Market segment		RET, ROB	
Basecase Information:			
Description		3-way incandescents	
Efficiency		30-70-100W	mix of 30-70-100+50-100-150 3-way, medium base
Electric use	kWh/year	62	Operating hours from HMG 1997
Summer peak demand	kW	0.004	5-20% res. Lights on from 2:00-6:00 pm
Winter peak demand	kW	0.02	5-20% res. Lights on from 2:00-6:00 pm
Gas/Fuel use	MMBtu/year	0	
New Measure Information:			
Description		3-way CFL	
Efficiency		12-18-29W	
Electric use	kWh/year	13	
Summer peak demand	kW	0.001	
Winter peak demand	kW	0.004	
Gas/Fuel use	MMBtu/year	N/A	
Current status		COMM	
Date of commercialization		ca. 2000	
Life	Years	13.7	GE-rated 10,000 hours, 2 hr/day
Savings Information:			
Electricity	kWh/year	49	
Summer peak demand	kW	0.003	
Winter peak demand	kW	0.013	
Gas/Fuel	MMBTU/year	N/A	
Percent savings	%	79%	
Feasible applications	%	90%	of 3-way fixtures
2020 Savings potential	GWH	1,202	CA only, about 12% of residential fixtures
2020 Savings potential	TBtu (source)	12	CA only
Industrial savings > 25%	(YES/NO)	NO	
Cost Information:			
Projected Incre. Retail Cost	2003 $	($7)	Wash. Electric Co-Op Prices; CFL= 8.3 incan. Lives
Other cost/savings	$/year	$0	no credit taken for avoided bulb change labor
Cost of saved energy	$/kWh	-$0.01	
Cost of saved energy	$/MMBtu	-$1.47	
Data quality assessment	(A-D)	B	
Likelihood of Success:			
Major market barriers		first cost, awareness	
Effect on utility			far fewer bulb replacements
Current promotion activity		mfgs, some utility groups	
Rating	(1-5)	3	
Rationale	low CSE, small technology step		
Priority / Next Steps			
Priority	L		saves about 0.1% of CA electricity
Next steps	promotion and incentive programs		
Sources:			
Savings	Lighting data sheets, comparison with specified base cases		
Peak demand	Used L13, HMG 1999, PGE 2000.		
Cost	Washington Electric Co-Op, http://www.washingtonco-op.com/pages/order.htm		
Feasible applications	Analyst judgment: simple plug-and-play substitution		
Measure life	General Electric Energy Star CFL data sheet		
Other key sources	HMG 1997 Lighting Efficiency Technology Report		
Principal contacts			
Notes			

Advanced HVAC controls. Packaged roof-top units (RTUs) are ubiquitous, accounting for almost half (44%) of the air-conditioned commercial floor space in California (AEC undated). They are typically small (mode = 5 tons) commodity products. They are rated only on refrigeration efficiency, i.e., steady-state EER for larger units or seasonal efficiency (SEER) for units up to 65,000 Btuh. On the other hand, conventional applications rely on the packaged unit to provide outdoor air to meet ventilation requirements and often to implement and control an *economizer cycle* that uses cool outside air instead of mechanical refrigeration when cost-effective. In some cases (particularly cold climates and humid climates), *energy* or *enthalpy recovery ventilation (ERV/HRV)* would also improve efficiency. Thus, a product rated on one parameter is expected to provide multiple services, generally relying on third-party components (economizers, heat recovery, controls) with field integration. This measure explores an alternative, an advanced RTU designed, installed, operated, and maintained to efficiently provide the full range of required services.

Fully optioned units from major manufacturers combine an impressive array of characteristics. As one example, consider the Lennox L Series, which offers SEER up to 13.25 and EER up to 12.2, integrated DDC control with humidity control (hot gas reheat) and demand control (CO_2) options, multi-stage cooling, heat recovery wheel, and premium fan motors (Lennox 2004). On the other hand, neither the CEE High Efficiency Commercial Air Conditioner program (CEE 2004) nor the FEMP procurement (PNL 2004) includes controls or non-refrigeration aspects of performance.

Lennox (2004) claims 45% energy savings in California from optimum economizer use alone, because the California climate is generally dry with large diurnal temperature swings. In contrast, Jacobs (2003) shows that 53% of 123 economizer-equipped California RTUs studied were working badly or not at all. We used 45% as total savings from working economizers in the 50% of units at 5 tons or larger with the advanced controls package.[14] For costs, we assumed the cost of national measure H1, Advanced Roof-Top Packaged Air Conditioners, plus $750 for an advanced controls package. With economizers, we computed a cost of saved energy of $0.06/kWh. This number excludes the value of demand savings.

We assume that the baseline performance is 10.3, as per measure H1b, but correct for absent and non-working economizers (80% of units). We do *not* correct for low airflow, which would raise fan energy to 0.34 kW/ton and reduce efficiency from 10.3 to 9.1, since this correction would be difficult to carry forward to the new measure in a controls measure analysis.

The principal barriers in California seem to be inertia and lack of knowledge about the savings that can be readily achieved, since the economics would be very attractive (CSE of $0.06 /kWh, compared to light commercial tariffs in the range of $0.18/kWh). One measure that would help greatly is an integrated rating method that would account for the contribution of the economizer and recognize the need for continuous ventilation. New FEMP and CEE programs could augment California utility efforts in this area.

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[14] Lau (2004) reports savings less than 20% in field studies, which would impact economic calculations. The reasons for the discrepancy between these results and those of Lennox (2004) remain to be resolved.

Table B-5: Advanced HVAC Controls Analysis

Emerging Technology Database	Units	Measure	Notes
Number	CA2		
Name	Advanced packaged-A/C controls		
Description	Packaged Rooftops with optimized performance		
Market Information:			
Market sector	COM		
End-use(s)	COOL		
Energy types	ELEC		
Market segment	NEW, ROB		
Basecase Information:			
Description	10 ton, 90.1-Compliant; 20% with working optimizers, standard controls		
Efficiency		10.3	ASHRAE 90.1 for 65-135 packaged equipment
Electric use	kWh/year	15,903	FEMP calculator, 1500 hr/yr
Summer peak demand	kW	10.5	.9 coincidence
Winter peak demand	kW	1.8	ventilation fan only, CA average
Gas/Fuel use	MMBtu/year	0	
New Measure Information:			
Description	10-ton, with working economizer and optimum controls		
Efficiency		12.2	
Electric use	kWh/year	8,115	FEMP+Lennox 45% economizer gain, proxy for ctrls+econ.
Summer peak demand	kW	9.4	.9 coincidence, 10% savings from control in real time
Winter peak demand	kW	1.8	ventilation fan only, CA average
Gas/Fuel use	MMBtu/year	0	
Current status		COMM	Fully optioned Lennox L series as example
Date of commercialization	ca. 2002		
Life	Years	15	
Savings Information:			
Electricity	kWh/year	7,788	
Summer peak demand	kW	1.0	10% savings estimated from controls staging, etc.
Winter peak demand	kW	0	ventilation fan only, CA average
Gas/Fuel	MMBTU/year	0	
Percent savings	%	49%	
Feasible applications	%	22%	Packaged units 5 tons and larger
2020 Savings potential	GWH	1,161	corrected for CA population
2020 Savings potential	TBtu (source)	12	corrected for CA population
Industrial savings > 25%	(YES/NO)	NO	
Cost Information:			
Projected Incre. Retail Cost	2003 $	$2,250	Current cost of super-efficient GEG (measure H1)+ $750 controls
Other cost/savings	$/year	$0	
Cost of saved energy	$/kWh	$0.03	
Cost of saved energy	$/MMBtu	$2.76	
Data quality assessment	(A-D)	C	
Likelihood of Success:			
Major market barriers	first cost, poor understanding, poor maintenance		
Effect on utility	improved IAQ from continuous operation and economizer		
Current promotion activity	manufacturer activity only		
Rating	(1-5)	3	
Rationale			Savings very large because economizers can contribute so much.
Priority / Next Steps			
Priority	H		
Next steps	Education re economizers and controls, Promotion and Incentives		
Sources:			
Savings	FEMP 2003		
Peak demand	Power draw corrected for coincidence		
Cost	Inferred from H1 analysis		
Feasible applications	Design Brief: Integrated Design for Small Commercial HVAC (Pier)		
Measure life	FEMP 2003		
Other key sources	FEMP 2003		
Principal contacts	Peter Jacobs, Architectural Energy (303) 444-4149; Cathy Higgins, NBI, (509) 493-4468,x11		
Notes			

Residential integrated whole house ventilation systems. Houses in areas with hot days and large diurnal temperature swings can significantly reduce summer peak load and cooling energy use through nighttime ventilation cooling. Residential air conditioning is responsible for about 45% of California's peak load, but only consumes about 7% of household electric energy (Coito 2003). Night ventilation cooling could be considered as an alternative integrated replacement for whole house fans, with air filtration. A project titled *Alternatives to Compressor Cooling* (ACC) was initiated by the California Institute for Energy Efficiency in 1994 to develop attractive house designs and mechanical systems that take maximum advantage of this resource. The most recent phase, supported by the Public Interest Energy Research (PIER) program, was completed in March 2004 and has resulted in commercialization efforts by PIER contractor Davis Energy Group of a product called NightBreeze. This product integrates ventilation cooling with variable speed hydronic forced-air heating, air conditioning, and fresh air ventilation functions (EDU 2004). A similar product (SmartVent) was developed by a Sacramento HVAC contractor and has demonstrated market success.[15] The systems use the same damper for the outside air intake and indoor air relief. Sensitivity studies performed by Davis Energy Group indicate that ~1cfm/sqft of night ventilation is optimal in most California locations. Duct sizing and damper space requirements make retrofit opportunities impractical in some cases.

A current PIER project is integrating control functions developed for NightBreeze systems in the prior ACC project phases with the furnace-based SmartVent system to improve comfort, offset more air conditioner load, and reduce fan energy use, while retaining the superior market acceptability of furnace systems. Ultimately, SmartVent and NightBreeze control functions may be nearly identical, except that SmartVent branding will apply to add-on controls for gas furnace systems and NightBreeze to packaged "hydronic furnace" systems with variable speed heating and ventilation cooling.

The SmartVent system is commercially available from RCS of Sacramento and is being marketed by Beutler Corporation to builders in Northern California. RCS, who manufactures the controls, sells a small quantity to other HVAC contractors. According to RCS, over 25,000 SmartVent systems have been installed. Nine prototype NightBreeze systems, which utilize variable speed hot water air handlers, have been installed for testing and demonstration purposes; extensive monitoring has been completed at three of these sites. Southern California Edison is installing eight more in Habitat for Humanity homes. Production units are expected to be available from Advanced Energy Products by September 2004.

No energy savings data for the SmartVent system are available. Dealer price for the SmartVent system from RCS is $613[16] and builders pay $750. Builders offer the SmartVent option to homebuyers for $1,200 to $2,000. Extensive monitoring and simulations have been completed for prototype NightBreeze systems (Springer 2004). Energy savings vary widely with climate, ranging from less than 5% for the coastal areas to greater than 60% in coastally influenced inland areas (roughly, the transition area of this study). Savings in hot inland areas range from 20 to 50%. If combined with measures to improve building envelope summer performance, ventilation cooling is projected to eliminate the need for air conditioning in many coastal and some transition areas. Energy savings of 88% were measured for a NightBreeze demonstration house located in Livermore (a transition area), compared to an identical control house. Peak demand reduction is projected to be from 40 to 80%. NightBreeze systems, including the variable speed hydronic air handler with heating coil, damper, and controls, are currently available commercially from Advanced Energy Products through the Davis Energy Group for about $2,850.

Energy savings for other California climates were calculated using a DOE-2 model that includes a specially written function to emulate NightBreeze control operation. This model was calibrated against one of the demonstration houses by matching the rate of change of indoor air temperatures over 24 hour periods. Annual cooling energy use predicted by the model was 5% lower than monitored energy use. The house monitored and modeled is a 3,080 ft² one-story house located in Livermore. The NightBreeze analysis cases included envelope modifications to improve summer performance.[17]

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[15] Lau (2004) reports that a retrofit product, "DuroDyne" is also available.

[16] Dealer costs for a ZCV2 control, TS-40 user interface (thermostat), and RS12 outdoor sensor total $388. The Model 2030DD damper adds another $225.

[17] These include radiant barrier roof sheathing and 50% hard floor coverings over the concrete slab plus 5/8" drywall (for added thermal mass).

The projected incremental cost is about $1,200 compared to a standard furnace and air conditioning system. The 1.3 kW of peak demand savings will be attractive in some areas and could provide added savings if combined with time-of-use rates. Where NightBreeze eliminates the need for mechanical air conditioning, first costs are reduced, leading to no-cost demand and energy savings.

The furnace-based SmartVent system will continue to be successfully marketed to Northern California production builders with current controls, and after completion of the funded PIER project, with advanced controls that improve energy savings. The primary barriers to extending its application to other appropriate regions are marketing and education. Defective installation has also been identified as a potential barrier to achieving potential savings. These barriers can be overcome through implementing utility programs that would attract market attention by providing modest incentives, and that would provide contractor training. Implementation of a Title 24 compliance option that requires inspection by a HERS rater would also mitigate installation defects.

Despite superior performance and quiet operation compared to SmartVent systems, the hydronic air handler-based NightBreeze system has not been well received by production builders and contractors to date because it requires a hot water heat source with sufficient capacity, because of the mixture of plumbing and HVAC trades involved in its installation, and because it lacks name recognition. However, there is increasing use of tankless water heaters by both production and custom homebuilders, and demonstrations have shown that they are appropriate heat sources for NightBreeze systems. Currently, the best application for these systems is custom homes. This market would also benefit from utility programs and a Title 24 compliance option. Paybacks can be short when the air conditioning is eliminated, but this option is difficult to market in most parts of California due to the perceived need for air conditioning.

Table B-6: Integrated Whole House Ventilation

Emerging Technology Database	Units	Measure	Notes
Number		CA3	
Name		Residential Night-Time Ventilation Cooling	
Description		Low-latent fraction air conditioner systems	
Market Information:			
Market sector		RES	
End-use(s)		COOL	
Energy types		ELEC	
Market segment		NEW	
Basecase Information:			
Description		3 ton central AC/furnace	
Efficiency		12	SEER
Electric use	kWh/year	1,154	Average CA central AC use from 2001 RECS
Summer peak demand	kW	3.24	10 EER on peak
Winter peak demand	kW	NA	
Gas/Fuel use	MMBtu/year		
New Measure Information:			
Description		NightBreeze System	
Efficiency		12	no change to compressor or condenser
Electric use	kWh/year	692	40% energy savings
Summer peak demand	kW	1.94	40-80% demand savings
Winter peak demand	kW	NA	
Gas/Fuel use	MMBtu/year	NA	
Current status		COMM	
Date of commercialization		2004	
Life	Years	18.4	
Savings Information:			
Electricity	kWh/year	462	
Summer peak demand	kW	1.3	
Winter peak demand	kW	0	
Gas/Fuel	MMBtu/year		
Percent savings	%	40%	
Feasible applications	%	80%	
2020 Savings potential	GWh	879	
2020 Savings potential	TBtu (source)	9	
Industrial savings > 25%	(YES/NO)	NO	
Cost Information:			
Projected Incre. Retail Cost	2003 $	$1,200	
Other cost/(savings)	$/year	$0	
Cost of saved energy	$/kWh	$0.22	
Cost of saved energy	$/MMBtu	$21.73	
Data quality assessment	(A-D)	B	
Likelihood of Success:			
Major market barriers		Lack of knowledge, design tools	
Effect on utility		Improved indoor air quality, higher comfort	
Current promotion activity		PIER research, SBIR support	
Rating	(1-5)	4	
Rationale		Significant demand savings, air quality	
Priority / Next Steps			
Priority	L	High CSE, unless we can value avoided peak.	
Next steps		Contractor education, utility incentives	
Sources:			
Savings		DEG 2004	
Peak demand		DEG estimate	
Cost		DEG 2004	
Feasible applications		DEG estimate	
Measure life		DOE TSD	
Other key sources			
Principal contacts		David Springer, Davis Energy Group 530.753.1100	
Notes			

Notes on Two Technologies Described

In our review of three specific technologies (above), we developed complete narratives and analyses. We also developed narratives without analyses of savings potential and cost of saved energy for two additional technologies, wireless thermostats and "Non-Invasive Load Monitors" (NILMs). In both cases, the technologies may facilitate savings by making other measures more feasible or cost-effective. However, they do not themselves save energy, so our analytical methods are not applicable.

Wireless thermostats (WTs). Thermostats are conceptually simple: a local temperature sensor turns heating and/or cooling on or off depending on the temperature where the thermostat is located. In small buildings with a single zone (most houses), a single thermostat is situated in a "living" area away from sunlight and drafts, an area which is considered to represent user needs. Hall and dining room installations are common. During the past decades, the basic controller has evolved into a programmable unit that allows varying the setpoint by time of day and day of the week. The thermostat is typically connected to the boiler, furnace, or other equipment by low-voltage (24v AC) wiring. More recently, many manufacturers have begun selling WTs that provide the same functionality as "hard-wired" units but promise much easier installation—or portability, if desired by the user. They differ only in including a low-powered radio transmitter in the thermostat and a receiver at the equipment controller.

Wireless thermostats can control many types of equipment. In addition to residential-style central units, controllers are available for fan-coils, baseboard electric heat, window air conditioners, "mini-split" air conditioners, and PTACs (packaged terminal air conditioners and heat pumps).

WTs are available with two different "user interfaces." Some are designed to be wall-mounted and are simply wireless replacements for conventional units. These are alternatives in several common situations, including: (1) system modernization, where new equipment functions may not be compatible with older wiring—it may be less expensive to convert to a wireless thermostat than to open and repair walls to change the wiring; (2) bad thermostat placement—whether because of poor judgment by the original installer, changes in use of the building, or a building addition, moving the thermostat may make the system serve needs better; and (3) rezoning—in some commercial buildings, subdividing spaces (for example, into closed offices instead of an open area) may require changing ductwork in a multi-zone system. In all of the cases, a thermostat that is just hung on the wall can be more cost-effective than a hard-wired alternative.

The other "user interface" is a portable thermostat, analogous to the remote control for televisions. This allows the owner to adjust the temperature to the desired level in the room where she is. This is likely to be used particularly in houses or other structures where construction defects (insulation, infiltration, fenestration, or ductwork) lead to wide temperature differences from room to room, during the day (as the sun moves) or as seasons change.

Available wireless thermostats offer a spectrum of capabilities and features (see Table B-7).

Wireless thermostats are not inherently energy-saving devices. However, they can make large energy savings easier. Consider, for example, a house with baseboard electric heating and window air-conditioners, where there is no central thermostat. If a retrofit to high-efficiency central equipment were done properly, a wall-mount or free-standing wireless thermostat could simplify installation and help achieve the savings potential of the new equipment. As a counter-example, consider a single-zone house with poor ability to maintain the same temperature in each room. The homeowner wants to be comfortable in summer in her home office, which is a converted bedroom. She might choose to carry her portable WT to that room during the day, so she could keep it at 75º. It would keep her office cool, but only at the cost of making the rest of the house much colder, thereby using much more energy. This could be ameliorated by zoning the HVAC system, but that is a substantial additional expense.

The principal barriers are cost and lack of awareness. In addition, the wireless thermostat is not inherently an energy-saving or demand-reducing device, but a means by which a motivated user can more easily achieve savings in some situations. The wireless thermostat competes with the conventional thermostat on the basis of price, convenience, and comfort; it will be chosen when it saves on installation cost (no hard wiring in walls) or provides substantial amenity (portability, for example). In this situation, the WT can allow a person to move from one zone to another, while the temperatures in unoccupied zones can be allowed to drift. This can save air conditioning and heating energy and money.

Table B-7: Features of Some Wireless Thermostat Models

	Carrier 33CS250-RC Debonair	Honeywell T8665A Chronotherm IV Wireless Thermostat	Enernet T900 Wireless Thermostat
Feature	Hand held / table stand	Wall mount	Wall mount
2-Stage Heat & 2-Stage Cool for use with gas / electric or heat pump systems	x	x	
Auto changeover	x	x	
Multiple thermostats can be used with one receiver	x		x
Frequency	418 Mhz	345 MHz	916.5 MHz
Adjustable deadband	x		x
Programming stored in nonvolatile memory	x	x	Change batteries in sequence to retain programming
Backlit display	x	x	
Display shows both set and room temperature simultaneously	x		x
Compressor time guard and adjustable cycle limit		x	x
Fan control to operate the fan for a preset period of time each hour for air circulation	x		
Limitable (maximum heating T, minimum cooling T)	x		x
Occupancy sensor compatible	x		x
Via plug node controls window AC, window fan, or other device not part of the central AC			x
Estimated street price	$219	$320	Depends on array of RCNs

NOTE: All have range of hundreds of feet, 7 day programmability with 4 time periods/day, setpoint adjustment range from 45F to 95F, multiple digital codes to limit interference.

Education must be part of any program, lest the amenity be subverted to increase energy consumption. It may help to bundle other amenities with the WT. In the UK, Honeywell markets wireless thermostats as part of their Hometronic home automation system, offering wireless capabilities analogous to the wired X10 standard: the ability to induce various appliances to wake up and perform their task according to a schedule, seeking greater convenience (coffee is ready when the user wakes) or money savings (laundry is washed when cheaper off-peak electricity is available.) Other “next steps” will be critically dependent on finding situations in which substantial savings are probable.

Non-Invasive Load Monitors (NILMs). Non-Invasive Load Monitoring (NILM) and HVAC Fault Detection and Diagnosis (HVAC FDD) refer to methods to use quick-sampling power meters or submeters with computer analyses to monitor and/or diagnose problems in HVAC systems. The purpose of the NILM is to detect on and off switching of major HVAC loads in commercial buildings, track variable-speed drive loads, and detect operating faults from a centralized location at affordable cost. This information can be used to optimize operations, aid commissioning and diagnostics, or simply to provide the energy manager with short- and long-term energy use intensity information that is key to maintaining and improving plant efficiency. NILM originated in residential studies and FDD for commercial buildings research. Their hardware needs are similar, using rapid sampling power meters (often differentiating real and reactive loads) and personal computers to capture and analyze the data streams. In practice, the terms now seem to be used more-or-less interchangeably.

Conceptually, the simplest FDD systems have one electrical power meter on each motor of interest (e.g., chiller, air handlers, or pumps). As noted by Shaw et al. (2002), generally other sensors are used to develop correlations between motor power (steady state or transient) and airflow, water pressure or flow, and other variables that represent system effects caused by the motors. These submeters would measure motor operation at steady-state, correlating with one of more of these dependent variables. Deviations from the expected ("trained") correlation indicate problems. This approach can be applied to systems as diverse as air handlers, chiller motors, and pumps. It can detect many classes of problems, including slipping fan belts, stuck dampers or fouled filters, and valve failures. Some, but not all, patterns can be given unique diagnoses. Whether or not a particular problem has a unique cause often depends on the operating mode of the system, which generally varies with outdoor temperature. (As a trivial example, a leaky cooling coil valve may not be detected when the chilled water system is shut down during winter conditions with cold outside air being used for cooling when needed. On the other hand, differentiating between a damper stuck closed and one that leaks air depends on the operating mode.) Unique diagnoses mean that mechanics can be dispatched with exactly the right parts to do needed repairs, which is a significant advantage in restoring comfort.

The steady state, one-motor-one-meter approach can be extended in two directions: using a single power meter to centrally monitor multiple motors and looking at motor transients as a source of additional diagnostic information.

Although it is possible to isolate and monitor a single motor with an individual monitoring system, the cost rises rapidly with the number of motors involved. Thus, a central approach is of great interest for FDD in commercial buildings. Shaw et al. (2002) studied the ability of such a system to detect and diagnose faults in a test building. A single sampling meter (NILM) monitored the power line that fed five fans and ten pumps; another NILM was installed on the whole building service entrance. Motor start-up signals can reveal a great deal about condition and loads. In general, short-interval sampling of power shows step changes in real and reactive power when motors turn on or off. For FDD, intensive computer analysis of these data isolates the "behavior" of individual motors, allowing fault detection and (under some circumstances) diagnoses.

In their investigation of the use of start-up transients, Shaw et al. (2002) determined that comparison of a physical model (mathematical description) of the motor with actual start-up transient data from the NILM allowed some fault detection. However, the motors of interest must be relatively large compared to the total current flowing, and the slow ramp-up of variable speed drives drastically limits the utility of transient information for motors with such drives. In theory, these disadvantages are compensated for by freedom of the technique from the need for flow or other sensors that are themselves subject to drift and failure.

We do not find Non-Intrusive Load Monitors available as commercial products now. The most recent work was funded by the California Energy Commission (CEC 2003b). Selkowitz (2003) provided research results for a small commercial building design. The project presentation suggested that a FDD system can be applied to roof-top packaged air conditioners, and that a unit for smaller commercial buildings could be marketed at a price of about $200 if the market exceeds 10,000 units (CEC 2003b). Further, they suggested that information generated by application of NILM will be less expensive than that created using traditional power sub-metering and acoustic/vibration monitoring.

Results from the Climate-Sensitivity Study

We turn now to analyses of the climate-sensitive data (see Table B-8). The table looks at each measure by climate zone. We considered 33 measures, each in three climate zones, for a total of 99 zone-measure evaluations. For the California analysis, we used California-specific costs of saved energy for screening. In particular, we started with $0.1244/kWh as the average residential tariff and $0.1447/kWh as the average commercial tariff.[18] Adapting the methods of the national study, we divided these values by two for our screening parameters for high priority measures, thus using $0.062 residential and $0.072 commercial, but CSE less than $0.1244/kWh and $0.1447/kWh, respectively, for medium and low priority measures.

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[18] These are average investor-owned rates from http://www.energy.ca.gov/electricity/current_electricity_rates.html.

Table B-8: Results from the Climate Sensitivity Study*

Measure	Region	Name	2020 Savings Potential (TBtu Source)	% Saved in 2020	Total for Measure	CSE ($/kWh)	CSE ($/MMBtu)	Likelihood of Success Rating	California Priority
H11	Inland	Leakproof Duct Fittings	6.30	0.27%		$0	$0.23	4	H
H11	Transition		4.82	0.21%		$0	$0.31	4	H
H11	Coastal		15.20	0.66%	1.15%	$0	$0.31	4	H
H12	Inland	Aerosol-Based Duct Sealing	8.88	0.39%		$0.01	$1.43	3	H
H12	Transition		7.34	0.32%		$0.02	$1.89	3	H
H12	Coastal		22.69	0.99%	1.69%	$0.02	$1.93	3	H
PR3	Inland	IDP LEED level (30% > Code)	8.34	0.36%		$0.01	$1.05	3	H
PR3	Transition		6.59	0.29%		$0.01	$1.2	3	H
PR3	Coastal		20.39	0.89%	1.54%	$0.01	$1.35	3	H
PR4	Inland	Retrocommissioning	6.49	0.28%		$0.02	$2.34	3	H
PR4	Transition		5.25	0.23%		$0.03	$2.67	3	H
PR4	Coastal		16.62	0.72%	1.23%	$0.03	$3	3	H
P2a	Inland	Commercial Micro-CHP Using Fuel Cells	24.54	1.07%		$0.07	$6.74	2	H
P2a	Transition		12.12	0.53%		$0.07	$6.76	2	H
P2a	Coastal		10.91	0.48%	2.07%	$0.07	$6.77	2	H
P2b	Inland	Commercial Micro-CHP Using Micro-Turbines	24.14	1.05%		$0.05	$4.64	2	H
P2b	Transition		11.76	0.51%		$0.05	$4.65	2	H
P2b	Coastal		9.65	0.42%	1.98%	$0.05	$4.66	2	H
D2	Inland	Advanced Air-Conditioning Compressors	2.03	0.09%		$0.04	$3.64	3	M
D2	Transition		1.30	0.06%		$0.05	$5.19	3	M
D2	Coastal		2.70	0.12%	0.26%	$0.09	$8.76	3	M

Measure	Region	Name	2020 Savings Potential (TBtu Source)	% Saved in 2020	Total for Measure	CSE ($/kWh)	CSE ($/MMBtu)	Likelihood of Success Rating	California Priority
D4	Inland	Hi-Eff. Pool and Domestic Water Pump Systems	3.52	0.15%		$0.07	$6.54	3	M
D4	Transition		3.21	0.14%		$0.07	$6.54	3	M
D4	Coastal		11.26	0.49%	0.78%	$0.07	$6.54	3	M
H1b	Inland	Advanced Roof-Top Packaged Air-Conditioners	1.95	0.08%		$0.07	$6.67	3	M
H1b	Transition		2.00	0.09%		$0.06	$5.92	3	M
H1b	Coastal		5.97	0.26%	0.43%	$0.07	$6.96	3	M
H7	Inland	"Robust" A/C	2.87	0.13%		$0.06	$6.8	3	M
H7	Transition		1.83	0.08%		$0.11	$11.73	3	M
H7	Coastal		3.82	0.17%	0.37%	$0.32	$38.57	3	M
PR1	Inland	Advanced Automated Building Diagnostics	1.63	0.07%		$0.05	$5.05	3	M
PR1	Transition		1.63	0.07%		$0.05	$4.51	3	M
PR1	Coastal		5.24	0.23%	0.37%	$0.06	$6.31	3	M
P1b	Inland	Residential Micro-CHP Using Stirling Engines	6.39	0.28%		$0.06	$6.14	2	M
P1b	Transition		3.21	0.14%		$0.06	$5.91	2	M
P1b	Coastal		2.02	0.09%	0.51%	$0.06	$5.85	2	M
S2b	Inland	"Active Window Insulation (Automated), Commercial "	6.89	0.3%		$0.07	$6.46	2	M
S2b	Transition		2.25	0.1%		$0.06	$5.73	2	M
S2b	Coastal		2.31	0.1%	0.5%	$0.07	$6.74	2	M
H10a	Inland	Ground Coupled Heat Pumps, Commercial	0.84	0.04%		$0	$0	2	L
H10a	Transition		0.87	0.04%		$0	$0	2	L
H10a	Coastal		2.32	0.1%	0.18%	$0	$0	2	L

Measure	Region	Name	2020 Savings Potential (TBtu Source)	% Saved in 2020	Total for Measure	CSE ($/kWh)	CSE ($/MMBtu)	Likelihood of Success Rating	California Priority
PR2	Inland	Ultra Low Energy Designs & Zero Energy Buildings	2.66	0.12%		$0	$0.48	2	L
PR2	Transition		2.10	0.09%		$0.01	$0.55	2	L
PR2	Coastal		6.50	0.28%	0.49%	$0.01	$0.62	2	L
PR6	Inland	"Better, Easier to Use, Residential Sizing Methods "	1.14	0.05%		$0.01	$1.41	2	L
PR6	Transition		0.77	0.03%		$0.02	$1.91	2	L
PR6	Coastal		2.38	0.1%	0.19%	$0.02	$2.24	2	L
S1	Inland	High Performance Windows (U<0.25)	3.16	0.14%		$0.07	$6.46	3	L
S1	Transition		2.18	0.1%		$0.09	$8.74	3	L
S1	Coastal		7.39	0.32%	0.55%	$0.11	$10.28	3	L
H5	Inland	Residential HVAC for Hot-Dry Climates	0.72	0.03%		$0.04	$3.85	4	Special
H5	Transition		0.46	0.02%		$0.06	$5.48	4	Special
H5	Coastal		0.96	0.04%	0.09%	$0.09	$9.24	4	Special
H8	Inland	Residential Gas Absorption Chiller Heat Pumps	0.75	0.03%		$0.06	$6.08	2	Special
H8	Transition		0.48	0.02%		$0.09	$8.72	2	Special
H8	Coastal		1.00	0.04%	0.1%	$0.16	$15.6	2	Special
H16	Inland	High-Efficiency Gas-Fired Rooftop Units	0.22	0.01%		N/A	$8.06	2	Special
H16	Transition		0.21	0.01%		N/A	$7.68	2	Special
H16	Coastal		0.77	0.03%	0.05%	N/A	$7.42	2	Special
H17	Inland	Transpired Solar Collectors for Ventilation Air	0.20	0.01%		N/A	$2.41	3	Special
H17	Transition		0.18	0.01%		N/A	$2.41	3	Special
H17	Coastal		0.52	0.02%	0.04%	N/A	$2.41	3	Special

Measure	Region	Name	2020 Savings Potential (TBtu Source)	% Saved in 2020	Total for Measure	CSE ($/kWh)	CSE ($/MMBtu)	Likelihood of Success Rating	California Priority
H19	Inland	Displacement Ventilation	0.20	0.01%		$0	$0	3	Special
H19	Transition		0.20	0.01%		$0	$0	3	Special
H19	Coastal		0.52	0.02%	0.04%	$0	$0	3	Special
PR5	Inland	Low Energy Use Homes and Zero Energy Houses	3.44	0.15%		$0.12	$12.12	2	Special
PR5	Transition		2.51	0.11%		$0.16	$15.16	2	Special
PR5	Coastal		8.51	0.37%	0.63%	$0.16	$15.66	2	Special
S3b	Inland	Electrochromic Glazing for Commercial Windows	0.04	0%		$0.04	$3.55	3	Special
S3b	Transition		0.04	0%		$0.03	$3.22	3	Special
S3b	Coastal		0.14	0.01%	0.01%	$0.04	$3.54	3	Special
S5	Inland	Residential Cool Color Roofing	1.47	0.06%		$0.04	$4.39	3	Special
S5	Transition		0.94	0.04%		$0.06	$6.25	3	Special
S5	Coastal		1.95	0.09%	0.19%	$0.11	$10.55	3	Special
W4	Inland	Integrated Home Comfort Systems	1.23	0.05%		$0.06	$5.85	2	Special
W4	Transition		0.94	0.04%		$0.07	$6.84	2	Special
W4	Coastal		3.31	0.14%	0.24%	$0.07	$6.8	2	Special
H10b	Inland	Ground Coupled Heat Pumps - Residential	0.52	0.02%		$0.22	$21.73	2	Not
H10b	Transition		0.34	0.01%		$0.31	$30.45	2	Not
H10b	Coastal		0.86	0.04%	0.07%	$0.35	$34.04	2	Not
H14	Inland	Solid State Refrigeration for Heat Pump & Power Generation	0.85	0.04%		$0.34	$33.39	2	Not
H14	Transition		0.56	0.02%		$0.54	$53.11	2	Not
H14	Coastal		1.42	0.06%	0.12%	$0.71	$69.19	2	Not

Measure	Region	Name	2020 Savings Potential (TBtu Source)	% Saved in 2020	Total for Measure	CSE ($/kWh)	CSE ($/MMBtu)	Likelihood of Success Rating	California Priority
P1a	Inland	Residential Micro-CHP Using Fuel Cells	6.40	0.28%		$0.17	$16.47	3	Not
P1a	Transition		3.23	0.14%		$0.16	$15.86	3	Not
P1a	Coastal		2.07	0.09%	0.51%	$0.16	$15.71	3	Not
S2a	Inland	Active Window Insulation	0.59	0.03%		$0.83	$80.85	1	Not
S2a	Transition		0.44	0.02%		$1.18	$115.21	1	Not
S2a	Coastal		0.28	0.01%	0.06%	$1.99	$194.29	1	Not
S4	Inland	Attic Foil Radiant Barriers (Retrofit)†	0.28	0.01%		$0.19	$19.01	2	Not
S4	Transition		0.18	0.01%		$0.28	$27.1	2	Not
S4	Coastal		0.38	0.02%	0.04%	$0.47	$45.7	2	Not
S8	Inland	High Quality Envelope Insulation	0.11	0%		$0.18	$17.56	2	Not
S8	Transition		0.08	0%		$0.24	$23.45	2	Not
S8	Coastal		0.27	0.01%	0.02%	$0.26	$25.75	2	Not
S9	Inland	Engineered Wall Framing	0.09	0%		$0	$0	3	Not
S9	Transition		0.06	0%		$0	$0	3	Not
S9	Coastal		0.21	0.01%	0.02%	$0	$0	3	Not

* Savings estimates may be low, since some climate zones with low population are not included.
†CSE based on installation cost of $0.30/sf for retrofit. Measure is likely to be cost-effective for new construction, where installation costs will be much lower.

For this California analysis, we also replaced the national priority assignments with California-specific values. This included using the California cost-of-saved energy values (see above) and the estimated fraction of 2020 *California* buildings energy that the measure would save. With these California data values and the national Likelihood of Success (Rating) values, we assigned California priority values (see Table B-8, last column). The resulting California-specific priorities differ for many measures from the national values, reflecting California's climate and energy prices.

In general, for any given measure there is a general trend toward lower cost of saved energy as one goes from inland through transitional to coastal climate areas. Of course, climate-driven loads decrease in the same order. The exceptions are themselves interesting. First, to the precision level we used, three measures show zero CSE—commercial ground source heat pumps, displacement ventilation (commercial), and (residential) engineered wall framing. That is, these measures have no incremental cost relative to their displaced counterparts.

Three other measures have the same CSE (within our precision) across all climate areas. These are high efficiency pool and domestic water pumps, commercial-scale micro-CHP (combined heat and power) using fuel cells, and the same using micro-turbines. In the case of pool pumps, we assumed the same annual energy use, implying the same season length in each zone. This may not be completely accurate, but represents the best data available. For the other two technologies, both CHP, the situation is more complex. Within technologies, we assumed the same electricity savings across each zone, but varying incremental gas use, and the values for CSE coincidently seem to coincide.

Five other measures have anomalies, in the sense that CSE does not decrease as climatic intensity decreases. For reasons that may be beyond our analytical resolution, advanced rooftop A/C, active window insulation, electrochromic glazing, and advanced automated building diagnostics (all commercial technologies) are slightly more cost-effective in transition than other zones. On the other hand, residential micro-CHP using fuel cells (not cost-effective) is inverted: It is least expensive in coastal ($0.159/kWh) and most in inland ($0.166/kWh).

For the 33 measures, we find a wide variation in the savings per measure. When we aggregate savings from all climate zones, several measures give savings estimates greater than 20 TBtu of source energy in California in 2020:

- Micro-CHP, whether using fuel cells or micro-turbines (2 measures)
- Aerosol-based duct sealing for the residential sector
- Integrated design process (LEED or 30% better than code)
- Retrocommissioning
- Leak-proof duct fittings

Several other measures would save more than about 10 TBtu:

- High-efficiency pool and residential water supply pumps
- Advanced roof-top packaged air-conditioners
- Ultra-low energy use and zero energy homes and commercial buildings
- Residential micro-CHP using fuel cells
- High performance windows
- Automated commercial window active insulation

The remaining 21 measures would save less than 1 TBtu each in 2020.

About two-thirds of the 99 combinations of measure and climate are cost-effective by our cost criteria. Indeed, Table B-9 shows that 24 of the 33 measures (about two-thirds) are cost-effective in all climate zones considered. Conversely, only six[19] are not cost-effective in *any* climate zone. Only three are cost-effective in some zones.[20]

[19] These are active window insulation, attic foil radiant barriers, ground-coupled residential heat pumps, high quality envelope insulation, residential micro-CHP using fuel cells, and solid state refrigeration for heat pumps and power generation.

[20] These are "robust" air-conditioning, low energy use homes and zero energy houses, and residential gas absorption chiller heat pumps.

Indeed, almost all measures are either cost-effective in all climate areas, or not cost-effective in any climate area: climate is rarely a key discriminating variable.

Table B-9: Frequency of Measure Cost-Effectiveness by Number of Climate Zones

Cost-Effective	Number of Measures
All climate zones	24
Some climate zones	3
No climate zones	6
N/A (gas only)	2

Note: table uses California energy costs for national study measures.

Table B-10 shows calculated cost of saved energy for each of the measures that are considered cost-effective in some but not all three climate areas. The patterns are logical: measures that reduce climate-related loads or meet cooling needs better are more cost-effective where climate is more intense, and cool roofs have lower value where solar intensity is lower.

Table B-10: Cost of Saved Energy for Measures That Are Cost-Effective in Some But Not All Climate Areas

	CSE, $/kWh		
Measure	Inland	Transitional	Coastal
"Robust" AC	0.064	0.106	0.319
Low Energy Use & Zero Energy Houses	0.124	0.155	0.16
Residential Gas Absorption Heat Pumps	0.062	0.089	0.159

Of the 33 measures, 12 are commercial, seven have both residential and (light) commercial applications, and seven are almost purely residential.

Looking at the data from another perspective, of the cost-effective measures in areas, 18 are coastal, 21 are transitional, and 24 are inland climate zones: where there is greater climate intensity (more heating and cooling load), capital investment in efficiency is warranted.

Finally, our measures include 22 "technologies" and 11 "practices," a 2:1 ratio. Of course, the distinctions between them are not always clear. As an example, we classify "leakproof duct fittings" as a technology, but the hard tasks of moving toward tighter duct systems include major shifts in practice and consumer expectations or perceptions of value. Even given this caveat, the data suggest that seven of the clearly cost-effective measures are practices and nine are technologies. As in the national study, it is important to note that a higher ratio of "practices" (7 of 11 evaluated, or 64%) is cost effective than of technologies (9 of 20, or 45%, excluding the two gas-only technologies).

Discussion

Table B-11 presents results for the three technologies studied for California, with the compact fluorescents divided into variable (stepped) output and (continuously) dimmable.

Table B-11: Cost of Saved Energy and GWH Saved in 2020, California-Specific Measures.

Measure Name	CSE, $/kWh	CSE, $/MMBtu Source	GWH Saved in 2020
Variable (stepped) output CFLs	-$0.01	-$1.47	1202
Dimmable CFLs	+$0.01	+$0.91	216
Advanced RTU & controls	$0.03	$2.76	1161
Integrated whole-house ventilation	$0.22	$21.73	879

The table suggests that specialty compact fluorescents offer the largest opportunity, both because of their low cost of saved energy and their large savings potential. Within this category, the savings are much larger for dimmable units than for stepped-output bulbs, because there are far more of the former than the latter in houses. Stepped-output bulbs are largely restricted to living-room type floor and table lamps, typically with one bulb per fixture. On the other hand, there are both fixture-mounted and wall-mounted dimming switches, often controlling multiple lamps (such as track lighting and recessed can lighting). Thus, within this category the continuously dimming technology appears to be the more promising option for program development. Of the two cooling technologies (advanced RTU and controls and integrated whole-house ventilation), the advanced RTU is quite cost-effective in all California climate zones, while the demand savings benefits of integrated whole house ventilation would have to be specifically evaluated to make it cost-effective in any zone.

The opportunities for packaged air conditioners for light commercial applications are very attractive. The potential for savings may be larger than what our analyses can capture with very high confidence, since present equipment with present controls may be worse than we assume (Jacobs et al. 2003). Although we include the nominal value of economizers, we may underestimate the value of the controls package in assuring that operators keep the economizers operating. We also may underestimate loads and operating costs from meeting ventilation loads (ASHRAE 62.1). Each of our assumptions is conservative. If they are not true, RTUs actually have higher energy consumption—and larger potential savings from fixing the problems.

The value of night-time ventilation (called "Integrated Whole House Ventilation Systems" in this report), the third technology evaluated, is highly dependent on first cost estimates, taken as $1,200 incremental cost for a residential HVAC system in this analysis. It is likely that the cost would be substantially lower in a new-home production environment characterized by high sales volumes and experienced installers. Thus, this technology may be a more attractive target for new construction programs than for retrofits, at least until it is well established in the marketplace.

For analysis of climate sensitivity, we used California-specific priority values (see Table B-8, last column). The resulting California-specific priorities differ for many measures from the national values, reflecting California's climate and energy prices (see Table B-12). It is interesting that the distribution of priorities is rather uniform for the California analysis. We identified six each high and medium priorities, eight "special" (new construction, etc.) measures, and four low priorities. In contrast, the national study found fewer very high priority measures and a larger number of measures that were not priorities.

Table B-12. Distribution of Priorities in California and National Studies

Priority	California (total = 33)	National (total = 72)
High	6 (18%)	5–6 (~7%)
Medium	6 (18%)	20–27 (~33%)
Low	4 (12%)	11–14 (~17%)
Special	8 (24%)	10–19 (~20%)
Not	6 (18%)	14–24 (~26%)

Another perspective on priorities for California is shown in Table B-13, expanded from Table 3-3 of the national report.

Table B-13. Measure Priorities Sorted by Cost of Saved Energy ($/kWh)

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
H11	leakproof duct fittings	489	1.03	0	0.40	4	H
PR3	int. design process (30% > code)	620	1.31	0.01	1.20	3	H
A1	1 Watt standby power for home appliances	497	1.05	0.02	1.90	4	H
CA2	advanced HVAC Controls (California only)	1,161	0	0.03	2.80	3	H
H12	aerosol-based duct sealing	443	0.93	0.03	2.50	3	H/M
PR4	retrocommissioning	443	0.93	0.03	2.60	3	H/M
PR1	advanced automated building diagnostics	704	1.48	0.04	4.00	3	H/M
L16	airtight compact fluorescent downlights	393	0.83	-0.01	-1.20	4	M
R1	solid state refrigeration (Cool Chips™)	171	0.36	0	0	3	M
L15	scotopic lighting	154	0.33	0	0	3	M
L14	1-lamp fluorescent fixtures w/ high performance lamps	215	0.45	0.01	0.80	3	M
O1	EZConserve Surveyor software	286	0.6	0.02	1.70	3	M
W3	residential heat pump water heaters	158	0.33	0.02	2.20	3	M
L13	residential CFL portable (plug-in) fixtures	216	0.46	0.03	3.10	3	M
D2	advanced air-conditioning compressors	200	0.42	0.03	2.40	3	M
L11b	commercial LED lighting	176	0.37	0.03	2.90	3	M
H18	CO_2 ventilation control	163	0.34	0.03	2.70	4	M
S1	high performance windows (U<0.25)	144	0.3	0.03	2.70	3	M
L6	low wattage ceramic metal halide lamp	130	0.27	0.03	2.80	3	M
H7	"robust" a/c	278	0.59	0.04	3.80	3	M

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
S5	residential cool color roofing	144	0.3	0.04	3.70	3	M
A2	1 kWh/day refrigerator	140	0.3	0.04	3.90	4	M
H9	adv. cold-climate heat pump/frost-less heat pump	173	0.36	0.05	4.60	3	M
H15	designs for low parasitics, low pressure drops	94	0.2	0	0	4	M/L
D3	advanced HVAC blower motors	112	0.24	0.04	3.80	4	M/L
P2b	commercial micro-CHP using micro-turbines	692	1.46	0.05	5.30	2	M/L
CA1	variable output (stepped) Compact Fluorescents*	12	0	-0.01	-1.50	3	L
H10a	ground-coupled heat pumps	15	0.03	0	0	2	L
D1	advanced appliance & pump motors; CW example	58	0.12	0	0.20	4	L
PR7	bulls-eye building commissioning	47	0.1	0.01	0.60	3	L
PR6	better, easier to use, residential sizing methods	113	0.24	0.01	0.70	2	L
R3	efficient fan options for commercial refrigeration	29	0.06	0.02	1.60	4	L
H13	microchannel heat exchangers	132	0.28	0.02	1.60	2	L
R2	modulating compressor for packaged refrigeration	45	0.09	0.02	2.20	4	L
L3	general service halogen IR lamp	74	0.16	0.03	2.40	2	L
L9	advanced HID lighting	97	0.21	0.05	4.90	2	L
P1b	residential micro-CHP using Stirling engines	201	0.42	0.06	5.50	2	L
P2a	commercial micro-CHP using fuel cells†	767	1.62	0.07	7.40	2	L
PR2	ultra low energy designs & zero energy buildings	199	0.42	0.01	0.60	2	S
H20	advanced condensing boilers (commercial)	23	0.05	0.01	0.60	3	S

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
S2b	active window insulation, commercial	93	0.2	0.02	1.80	2	S
L5	advanced daylighting controls	80	0.17	0.02	2.30	3	S
D4	high-efficiency pool and domestic water pump systems	19	0.04	0.03	3.40	3	S
W4	integrated home comfort systems	43	0.09	0.04	3.80	2	S
H1a	advanced roof-top packaged air conditioners	81	0.17	0.04	3.50	3	S
H1b	advanced roof-top packaged air conditioners	81	0.17	0.06	6.00	3	S
H8	residential gas absorption chiller heat pumps	41	0.09	0.07	6.60	2	S
S8	high quality envelope insulation	15	0.03	0.08	7.80	2	S
S3a	electrochromic glazing for residential windows	3	0.01	0.08	7.80	2	S
H16	high-efficiency gas-fired rooftop units	20	0.04	N/A	3.40	2	S
CA3	integrated whole house ventilation	879	0	0.22	21.70	4	S
S9	engineered wall framing	12	0.03	0	0	3	S/X
H19	displacement ventilation	11	0.02	0	0	3	S/X
CR1	hotel key card system	15	0.03	0.01	1.30	2	S/X
H2a	Cromer Cycle air conditioner — residential	21	0.04	0.03	3.10	3	S/X
L7	hospitality bathroom lighting	28	0.06	0.04	4.00	3	S/X
H5	residential HVAC for hot-dry climates	11	0.02	0.04	4.40	4	S/X
S3b	electrochromic glazing for commercial windows	3	0.01	0.05	4.60	3	S/X
PR5	low energy use homes and zero energy houses	199	0.42	0.07	6.60	2	S/X
H2b	Cromer Cycle air conditioner — commercial	16	0.03	0.07	6.80	3	S/X

Measure	Name	Savings Potential (TBtu)	% saved	CSE, $/kWh	CSE, $/MMBtu	Likelihood of Success Rating	Priority
H17	transpired solar collectors for ventilation air	7	0.02	N/A	2.40	3	S/X
H4	CAC dehumidifiers/free-standing dehumidifiers	5	0.01	0.05	4.40	3	X
L8	universal light dimming control device	97	0.20	0.08	8.10	1	X
L11a	residential LED lighting	229	0.48	0.11	11.30	2	X
H10a	ground-coupled heat pumps (comm.)	43	0.09	0.13	12.60	2	X
H14	solid state refrigeration for heat pumps	106	0.22	0.16	15.60	2	X
S4	attic foil radiant barriers	27	0.06	0.16	16.20	2	X
P1a	residential micro-CHP using fuel cells	171	0.36	0.18	17.40	2	X
L10	hybrid solar lighting	270	0.57	0.27	26.30	2	X
H3	commercial HVAC heat pipes	8	0.02	0.28	27.30	2	X
L4	cost-effective load shed ballast & controller	1	0	0.43	42.90	3	X
H6	UV HVAC disinfection	19	0.04	0.57	56.50	2	X
S2a	active window insulation	41	0.09	0.73	72.20	1	X
W1	residential condensing water heaters	217	0.46	N/A	6.40	2	X
W2	instant gas high-modulating water heaters	127	0.27	N/A	8.30	2	X

Notes: * California-specific savings, from Appendix B, Table B-11.
† Value of waste heat is critical.

Two letters such as "M/L" in the "Priority" column suggest borderline situations, given analytic uncertainties. An "X" in that column indicates that the measure is not a national priority (<0.25% savings forecast, high CSE, low likelihood of success).

This table includes three specific California measures. The percent savings assigned to whole house ventilation is inexact, since we have not attempted to estimate the fraction of the country with consistently large enough diurnal temperature swings to use this strategy.

Of the three technologies specifically analyzed for California, the advanced roof-top unit and controls (CA2) is a high priority on the national list, too. Although variable output compact fluorescent bulbs (CA1) have a very low cost of saved energy, the cumulative potential energy savings in the United States is too low (<0.06%) for them to qualify for even medium priority. Similarly, by the parameters of this study, integrated whole house ventilation (CA3) would not rank as a priority item, because our criteria did not include the value of demand reductions associated with using off-peak cooling. This may, nonetheless, be an important measure for California if judged by time-dependent valuation methods.

The analysis of climate sensitivity has policy implications for California. The first implication is that the potential value of emerging technologies is not terribly dependent on climate, for the relatively small variability considered among coastal, transitional, and inland zones in California. Of 33 technologies and practices considered, 16 were projected to be cost-effective in all climate zones, and 10 were considered too expensive (in cost of saved energy) in all zones. Leaving out two gas-only technologies, only five measures were cost-effective in some climate areas but not in others. From this, we infer that climate is a second-order (less important) variable in screening emerging technologies for California. Further, for four of the five measures with mixed screening results (cost-effective in some but not all zones), the variability in estimated CSE, in the range of $0.005/kWh, is comparable to our estimates of uncertainty in the analysis as a whole.

On the other hand, the variation in estimated savings in 2020 from different measures is very large, more than a factor of 200. This strongly suggests that the most attractive measures are those that combine reasonable cost of saved energy with relatively large (>100 GHW) out-year savings.

Finally, we again see the relatively high importance of "human-ware," the emerging practices that improve efficiency through proper design and sizing, installation, and maintenance. Increasingly, continuing the trajectory of improved efficiency will require investing directly in people and incentives for people, and in showing customers (decision-makers) the economic, comfort, and other values of investments in doing the right jobs the right ways.

Additional Bibliography (for Appendix B)

[AEC] Architectural Energy Corporation. Undated. "Design Brief: Integrated Design for Small *Commercial HVAC.* Energy Design Resources." Boulder, Colo.: Architectural Energy Corporation.

Bryant Heating and Cooling Systems: http://www.bryant.com/products/html/80360BryantWrlsProgTherm.asp

Carrier 33CS250-RC Debonair: http://www.commercial.carrier.com/wcs/proddesc_display/0,1179,CLI1_DIV12_ETI434_PRD170,00.html?SMSESSION=NO

[CEC] California Energy Commission. 2003a. *California Energy Demand 2003–2013 Forecast.* 100-03-002. Sacramento, Calif.: California Energy Commission.

———. 2003b. "Final Presentation, Energy Efficient and Affordable Small Commercial and Residential Buildings Research Program." AEC-EEB-PIERFinalPres-r2.pdf. http://www.energy.ca.gov/pier/buildings/presentations/AEC_EEB_PIER_FINAL_PRES.PDF. Sacramento, Calif.: California Energy Commission.

———. 2004a. *California Statewide Residential Appliance Saturation Study.* 400-04-009. Sacramento, Calif.: California Energy Commission.

———. 2004b. *2003 California Average Retail Electricity Rates by Major Utility.* www.energy.ca.gov/electricity/current_electricity_rates.html. Sacramento, Calif.: California Energy Commission.

[CEE] Consortium for Energy Efficiency. 2004. "CEE Super-Efficient High Efficiency Commercial Air Conditioning and Heat Pumps Initiative (HECAC)." http://www.cee1.org/com/hecac/hecac-tiers.pdf. Boston, Mass.: Consortium for Energy Efficiency.

Coito, F., and M. Rufo. 2003. "California Statewide Residential Sector Energy Efficiency Potential Study." Study ID #SW063, Available from http://www.cpuc.ca.gov/published/report/30114.pdf and http://www.cpuc.ca.gov/published/report/30115.pdf. Prepared for Pacific Gas & Electric Company. San Francisco, Calif.: KEMA-Xenergy.

[EDU] Energy Design Update. 2004. "New Products: Nighttime Ventilation Cooling." *Energy Design Update*, 24 (9), 8–10. September. www.aspenpublishers.com.

Enernet T900 Wireless Thermostat: http://www.enernetcorp.com/products/thermostat.html.

[HMG] Heschong Mahone Group. 1997. *Lighting Efficiency Technology Report, V. 1: California Baseline.* California Energy Commission Report P400-98-004VI. Fair Oaks, Calif.: Heschong Mahone Group.

Honeywell T8665A Chronotherm IV Wireless Thermostat and W8665A Receiver: http://content.honeywell.com/yourhome/ptc-thermostats/t8665.htm.

[IAEEL] International Association for Energy-Efficient Lighting. 1997. March/April newsletter. http://195.178.164.205/IAEEL/iaeel/newsl/1997/tre1997/LiTech_a_3_97.html.

Jacobs, Pete. 2003. Small HVAC Problems and Potential Savings Reports. CEC Technical Report P500-03-082-A-25. Sacramento, Calif.: California Energy Commission.

Jacobs, Pete, et al. 2003. *Small HVAC Problems and Potential Savings Reports: Summary of Problems in Each Building (product 4.5.1), Statewide Energy Impact (product 4.5.3).* California Energy Commission Report P500-03-082-A-25. Sacramento, Calif.: California Energy Commission.

Lao, Henry (Southern California Edison) 2004. Email to Harvey Sachs. September.

[Lennox] LG/LC/LH Models L Series® Brochure 76M73, 01/04.

Nadel, S., D. Bourne, M. Shepard, L. Rainer, and L. Smith. 1993. Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors. Washington, D.C.: American Council for an Energy-Efficient Economy.

Nadel, S., L. Rainer, M. Shepard, M. Suozzo, and J. Thorne. 1998. Emerging Energy-Saving Technologies and Practices for the Buildings Sector. Washington, D.C.: American Council for an Energy-Efficient Economy.

[PG&E] Pacific Gas and Electric Company. 1999. *1999 Commercial Buildings Survey Report.* San Francisco, Calif.: Pacific Gas & Electric Company.

———. 2000. *Heating, Ventilating and Air Conditioning (HVAC) Controls: Codes and Standards Enhancement (CASE) Study.* San Francisco, Calif.: Pacific Gas & Electric Company.

Rea, M. 2000, *ed. The IESNA Lighting Handbook, 9th Edition, Reference and Application.* New York, N.Y.: Illuminating Engineering Society of North America.

RCI Automation, LLC: http://ourworld.compuserve.com/homepages/rciautomation/p1.htm.

Selkowitz, S. 2003. *Technical Report: Non-Intrusive Load Monitors (NILMs) Used for Equipment Monitoring and Fault Detection.* California Energy Commission Report 500-03-097-A16. Sacramento, Calif.: California Energy Commission,

Shaw, S.R., L. Norford, D. Luo, and S. Leeb. 2002. "Detection and Diagnosis of HVAC faults via Electrical Load Monitoring." *HVAC&R Research* 8, 13–40.

Springer, D. 2004. "Alternatives to Compressor Cooling," Phase V: *Integrated Ventilation Cooling*. California Energy Commission Report 500-04-009. California Energy Commission, Sacramento. Downloadable from http://www.energy.ca.gov/pier/buildings/reports.html

Totaline Wireless Thermostat Transmitter & Receiver: http://www.theenergyalternative.com/energy_efficient_products/?item=411.

Washington Electric Co-Op: http://www.washingtonco-op.com/pages/ord.