# Emerging Technologies/Practices: Finding the Next Generation

*H. Sachs, S. Nadel, J.T. Amann, and M. Tuazon, ACEEE*
*L. Rainer, Davis Energy Group*
*G. Todesco, D. Shipley, and M. Adelaar, Marbek Resource Consultants*

**ABSTRACT**

Adopting new energy-efficient technologies and practices is key for 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. However, this was compensated for by increasing the numbers of "practices" that reflect new systems views of older issues. Particularly attractive candidates include two distribution system improvements (leak-proof 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, but we identified 20–27 medium priority measures, as well.

## 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 over the next five years. The studies examined technologies in appliances, lighting, HVAC, water heating, drivepower, 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 brought many technologies to the attention of utilities, government agencies, and other energy efficiency professionals and 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 Department of Defense's incandescent replacement light bulb procurement, and 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, others have faced difficulties, and new technologies continue to be developed. 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. Among the objectives of this new study are (1) to identify new research and demonstration projects that could help advance high priority emerging technologies, (2) to identify potential new technologies and practices for market transformation activities, and (3) to gain new insights into the technology development and commercialization process by comparing 1998's expectations with 2004's reality.

Our scope covers the residential and commercial sectors. We include both energy-saving technologies (e.g., a new air conditioner) and practices (e.g., improved air conditioner installation procedures). Only measures that save energy, including more efficient generation sources (e.g., fuel cells) and renewable energy sources appropriate for buildings, are included.

In this study, we define "emerging T&Ps" as those which either (1) are not yet commercialized but we judge to be likely to be commercialized and cost-effective for a significant proportion of end-users (on a lifecycle cost basis) by 2009, or (2) are commercialized but currently have penetrated no more than 2 percent of the appropriate market.

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 are rounded to one significant digit. Furthermore, the data we report should be viewed as the midpoint of a range, with endpoints 10–50 percent higher and lower than the midpoint. The size of the range varies with the quality of the data available for each measure.

## Methods

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 databases and reports compiled by the project team; recommendations from energy research organizations, major utility R&D departments, 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 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, or can reduce U.S. or Canadian buildings energy use by 0.50% or more. Medium potential measures have neither "high" nor "low" potential, and also any measures for which the team had insufficient information at the time of the initial triage, so further analysis was needed.

We also include several special cases—measures that would save less than 0.25% nationally but still should be included. 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 would 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, such as 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 screen, we identified 76 candidates as medium and high priority emerging technologies. For each, we collected over 30 pieces of data in a database. Each included *market information,* and a *base case* and a *new measure* characterization for analysis. We also included the current status of each technology, the estimated year of commercialization, and the estimated measure life. We computed *savings,* including U.S. and Canadian electricity (and peak demand) and gas savings, and the *feasible applications*, the estimated proportion of total applications that are likely to be feasible for each measure.

From these data, we computed the *savings potential* in 2020 in GWh (million kWh) and TBtu (trillion Btu). Our cost data include purchase price and additional or avoided maintenance costs. From these data, we computed the costs of saved energy in both $/kWh and $/MMBtu—i.e., the levelized costs for each measure. In some cases, the cost of saved energy is negative, meaning that the annualized capital and operating costs are less than the old measures. The cost of saved energy is rounded to the nearest cent because of uncertainties in the analysis. Next, we developed qualitative measures of likelihood of success in the market (major market barriers, effect on customer utility, current promotional efforts, etc.). These range from 1 (difficult, multiple major barriers to overcome) to 5 (excellent chance of success, barriers clearly surmountable).

For this study, measures were divided into “high,” “medium,” “lower,” “special,” and “not a priority” categories, based on potential energy savings, cost of saved energy, and likelihood of success. Criteria and number of measures identified are given in Table 1. Additional details can be found in the full project report (Sachs et al. 2004).

## Results

Table 2 summarizes our findings for the 70 measures studied in detail. Savings are not additive since there is overlap between measures. For example, the savings from adopting an advanced air conditioning method plus an improved shell measure will be less than adding together the sum of the savings for each measure by itself. In this case, the improved shell would reduce the baseline energy use, thus giving smaller kWh savings from the same per cent savings.

**Table 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 | 5–6 |
| Medium | >= 0.25% | ≤$0.081/kWh | ≤$6.33/MMBtu | 3–5 | 20–27 |
| Low | < 0.25% | ≤$0.081/kWh | ≤$6.33/MMBtu | 2–5 | 10–14 |
| Special | >~0.05% | ≤$0.081/kWh | ≤$6.33/MMBtu | 2–5 | 10–21 |
| Not a Priority | | ≥$0.81/kWh | >$6.33/MMBtu | 1–5 | 15–25 |
| Total | | | | | 70 |

**Notes**:

1. To qualify in a given category, a measure must qualify with *all* elements in the row. For example, high priority measures show potential energy savings of at least 1 percent 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 three or more.
2. 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 5–6 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.

## High Priority Measures

The high priority measures in Table 2 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 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 (Sachs et al. 2004), and briefly summarized here.

**Automated Building Diagnostics Software (ABDS).** Building Automation Systems (BAS) use computerized monitoring and control to optimize the operation of HVAC equipment in large commercial buildings. Because operating BAS is so hard for facilities' personal, performance has fallen short of its goals. Automated Building Diagnostic Software (ABDS) uses more advanced self-tuning control algorithms and automatic data analysis with "expert systems" to continually or episodically perform building commissioning. Energy savings are similar to those from recommissioning (5–20%). Implementation of an ABDS can cost $0.50/ft², yielding a CSE of $0.04/kWh.

**Table 2. Findings for 70 Measures Studied in Detail, with Savings Potential, Cost of Saved Energy, Likelihood of Success (Rating), and Priority**

| Measure | Name | Savings Potential (TBtu) | Percent Saved | CSE, $/kWh | CSE, $/MMBtu | Rat-ing | Prior-ity |
|---|---|---|---|---|---|---|---|
| PR3 | IDP LEED level (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 |
| PR1 | Advanced Automated Building Diagnostics | 704 | 1.48 | $0.04 | $4.00 | 3 | H/M |
| PR4 | Retrocommissioning | 443 | 0.93 | $0.03 | $2.60 | 3 | H/M |
| H12 | Aerosol-based duct sealing | 443 | 0.93 | $0.03 | $2.50 | 3 | H/M |
| H11 | Leakproof duct fittings | 489 | 1.03 | $0.00 | $0.40 | 4 | M/H |
| L16 | Airtight compact fluorescent downlights | 393 | 0.83 | ($0.01) | ($1.20) | 4 | M |
| L1 | High efficiency premium T8 lighting (100 lumens/W) | 348 | 0.73 | $0.01 | $0.90 | 4 | M |
| O1 | EZConserve Surveyor Software | 286 | 0.6 | $0.02 | $1.70 | 3 | M |
| H7 | "Robust" A/C | 278 | 0.59 | $0.04 | $3.80 | 3 | M |
| L13 | Residential CFL portable (plug-in) fixtures | 216 | 0.46 | $0.03 | $3.10 | 3 | M |
| L14 | 1-lamp fluorescent fixtures w/ high performance lamps | 215 | 0.45 | $0.01 | $0.80 | 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 |
| H9 | Adv. cold-climate heat pump/frost-less heat pump | 173 | 0.36 | $0.05 | $4.60 | 3 | M |
| R1 | Solid state refrigeration (cool Chips$^{TM}$) | 171 | 0.36 | 0 | 0 | 3 | M |
| H18 | $CO_2$ ventilation control | 163 | 0.34 | $0.03 | $2.70 | 4 | M |
| W3 | Residential heat pump water heaters | 158 | 0.33 | $0.0218 | $2.20 | 3 | M |
| L15 | Scotopic lighting | 154 | 0.33 | 0 | 0 | 3 | M |
| S5 | Residential cool color roofing | 144 | 0.3 | $0.04 | $3.70 | 3 | M |
| S1 | High performance windows (U<0.25) | 144 | 0.3 | $0.03 | $2.70 | 3 | M |
| A2 | 1 kWh/day refrigerator | 140 | 0.3 | $0.04 | $3.90 | 4 | M |
| L6 | Low wattage ceramic metal halide lamps | 130 | 0.27 | $0.03 | $2.80 | 3 | M |
| H15 | Designs for low parasitics, low pressure drops | 94 | 0.2 | 0 | 0 | 4 | M |
| D1 | Advanced appliance & pump motors; CW example | 58 | 0.12 | $0.00 | $0.20 | 4 | M |
| R3 | Efficient fan options for commercial refrigeration | 29 | 0.06 | $0.02 | $1.60 | 4 | M |
| 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 |
| W4 | Integrated home comfort systems | 43 | 0.09 | $0.03 | $3.80 | 2 | L/M |
| P2a | Commercial micro-CHP using fuel cells | 767 | 1.62 | $0.07 | $7.40 | 2 | L |

| Measure | Name | Savings Potential (TBtu) | Percent Saved | CSE, $/kWh | CSE, $/MMBtu | Rat-ing | Prior-ity |
|---|---|---|---|---|---|---|---|
| P1b | Residential micro-CHP using Stirling engines | 201 | 0.42 | $0.06 | $5.50 | 2 | L |
| H13 | Microchannel heat exchangers | 132 | 0.28 | $0.02 | $1.60 | 2 | L |
| PR6 | Better, easier to use, residential sizing methods | 113 | 0.24 | $0.01 | $0.70 | 2 | L |
| L9 | Advanced HID lighting | 97 | 0.21 | $0.05 | $4.90 | 2 | L |
| L3 | General service halogen IR reflecting lamp | 74 | 0.16 | $0.03 | $2.40 | 2 | L |
| PR7 | Bulls-eye building commissioning | 47 | 0.1 | $0.01 | $0.60 | 3 | L |
| S8 | High quality envelope insulation | 15 | 0.03 | $0.08 | $7.80 | 2 | L |
| H10-Com | Ground-coupled heat pumps | 15 | 0.03 | $0.00 | $0.00 | 2 | L |
| S3a | Electrochromic glazing for residential windows | 3 | 0.01 | $0.08 | $7.80 | 2 | L |
| R2 | Modulating compressor for packaged refrigeration | 45 | 0.09 | $0.02 | $2.20 | 4 | L |
| 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 |
| L12a | Integrated skylight luminaire (ISL) | 255 | 0.54 | $0.05 | $5.30 | 2 | S |
| PR2 | Ultra low energy designs & zero energy buildings | 199 | 0.42 | $0.01 | $0.60 | 2 | 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 |
| H8 | Residential gas absorption chiller heat pumps | 41 | 0.09 | $0.07 | $6.60 | 2 | S |
| H20 | Advanced condensing boilers (commercial) | 23 | 0.05 | $0.01 | $0.60 | 3 | S |
| H16 | High efficiency gas-fired rooftop units | 20 | 0.04 | NA | $3.40 | 2 | S |
| D4 | High efficiency pool and domestic water pump systems | 19 | 0.04 | $0.03 | $3.40 | 3 | S |
| PR5 | Low energy use homes and zero energy houses | 199 | 0.42 | $0.07 | $6.60 | 2 | S/X |
| H2a | Cromer Cycle air-conditioner, residential | 21 | 0.04 | $0.03 | $3.10 | 3 | S/X |
| H2b | Cromer Cycle air-conditioner, commercial | 16 | 0.03 | $0.07 | $6.80 | 3 | S/X |
| CR1 | Hotel key card system | 15 | 0.03 | $0.01 | $1.30 | 2 | S/X |
| S9 | Engineered wall framing | 12 | 0.03 | 0 | 0 | 3 | S/X |
| H19 | Displacement ventilation | 11 | 0.02 | 0 | 0 | 3 | S/X |
| H5 | Residential HVAC for hot-dry climates | 11 | 0.02 | $0.04 | $4.40 | 4 | S/X |
| H17 | Transpired solar collectors for ventilation air | 7 | 0.02 | NA | $2.40 | 3 | S/X |
| S3b | Electrochromic glazing for commercial windows | 3 | 0.01 | $0.05 | $4.60 | 3 | S/X |

| Measure | Name | Savings Potential (TBtu) | Percent Saved | CSE, $/kWh | CSE, $/MMBtu | Rat-ing | Prior-ity |
|---|---|---|---|---|---|---|---|
| L7 | Hospitality bathroom lighting | 28 | 0.06 | $0.04 | $4.00 | 3 | S/X |
| H4 | CAC dehumid. free-standing dehumidifiers | 5 | 0.01 | $0.05 | $4.40 | 3 | X |
| L10 | Hybrid solar lighting | 270 | 0.57 | $0.27 | $26.30 | 2 | X |
| L11a | Residential LED lighting | 229 | 0.48 | $0.11 | $11.30 | 2 | X |
| W1 | Residential condensing water heaters | 217 | 0.46 | NA | $6.40 | 2 | X |
| P1a | Residential micro-CHP using fuel cells | 171 | 0.36 | $0.18 | $17.40 | 2 | X |
| W2 | Instantaneous gas high modulating water heaters | 127 | 0.27 | N/A | $8.30 | 2 | X |
| H14 | Solid state refrigeration for heat pumps | 106 | 0.22 | $0.16 | $15.60 | 2 | X |
| L8 | Universal light dimming control devices | 97 | 0.2 | $0.08 | $8.10 | 1 | X |
| H10-res., original | Ground-coupled heat pumps | 43 | 0.09 | $0.13 | $12.60 | 2 | X |
| S2a | Active window insulation | 41 | 0.09 | $0.73 | $72.20 | 1 | X |
| S4 | Attic foil radiant barriers | 27 | 0.06 | $0.16 | $16.20 | 2 | X |
| H6 | UV HVAC disinfection | 19 | 0.04 | $0.57 | $56.50 | 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 |

Note: H = high, M = medium, L = low, S = special, X = not a priority.

**Integrated commercial building design (30% > code).** Clients and designers increasingly seek ways to differentiate projects through "green" attributes and efficiency using, for example, the energy performance requirement in the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™. Such buildings can readily achieve energy performance levels 30% beyond current code. Incremental costs for energy savings vary with performance targets, but tend to run from zero to $3/square foot. We assumed 30% energy use improvement over ASHRAE 90.1, 0.7 kW/square foot demand reduction, and a cost of $1/square foot, to derive a CSE of only $0.01.

**1-watt standby power for appliances.** Standby power is the electricity consumed while equipment is switched off or not performing its main function. Remote controls, low voltage power supplies, rechargeable devices, and continuous digital displays all use standby power. Standby power for an individual product is typically 0.5–30 watts, or 50–70 watts per home, about 5% of annual electricity use. Sixty-five percent reduction of this standby power consumption (to 200 kWh/yr) is feasible. Available technologies establish 1 watt or less of standby power as a reasonable performance level. To date, these improvements have been adopted most readily for higher value products (TVs, DVRs, etc). Digital cable boxes and satellite receivers remain big standby users. We estimate a CSE of $0.02/kWh.

**Retrocommissioning.** Many commercial buildings do not perform as designed, and performance also tends to degrade over time. *Retrocommissioning* (RCx) is a systematic process to identify and correct problems and ensure system functionality. RCx focuses on optimizing the building through operations and maintenance (O&M) tune-up activities and diagnostic testing. RCx can diagnose problems in mechanical systems, controls, and lighting, and improve overall performance. The best candidates for RCx are newer buildings over 100,000 sq. ft. with building automation systems. RCx is not yet widespread. Its cost has ranged from $.03 to $.43 per square foot (average of $.19), with a CSE of $0.03/kWh.

**Leakproof duct fittings.** Most duct leakage in residential and small commercial HVAC systems is due to improperly sealed connections. Mitigating residential duct leakage may reduce HVAC energy use by roughly 20%. Mastic, mechanical fasteners, and UL-181-approved duct tapes can reduce leaks, but the process is labor-intensive. Round spiral sheet metal systems have been expensive. The Proctor Engineering Group Snap Duct system of fittings may reduce prices and lower installation barriers. It reduces leakage by 90%. Assuming 90% reduction in duct leakage and incremental costs of $100 for a typical house, we estimate a CSE of half a cent per kWh.

**Aeroseal or other spray-in/comprehensive residential HVAC duct sealing**. Approximately 20% of energy use in residential space conditioning systems is associated with duct losses, split between conduction and leakage (Jump, Walker, and Modera 1996). Sealing ducts reduces air conditioning peak demand for attic duct systems. Fixing existing home duct leaks from the outside is hard or impossible when ducts are in low attic areas, crawl spaces, etc. Aerosol duct sealing can close holes up to ¼″ in size by spraying atomized latex aerosol into the ducts. Savings average about 80% of prior air leakage. We find a CSE of about $0.03/kWh.

### Medium Priority Measures

Seven of the 20–26 medium priority measures are lighting measures. As expected from the larger role that lighting plays in commercial compared to residential space, most of these are primarily commercial (including premium T8 lighting, one-lamp fluorescent fixtures, commercial LED lighting, scotopic lighting). However, at least two (airtight compact fluorescent downlights and CFL portable fixtures) are primarily residential. About a dozen of the non-lighting measures are primarily residential. Three of these deal with refrigeration-cycle equipment: including 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.

### Special Case Measures

"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. In Table 2, about half of the measures are feasible for new construction, but prohibitively expensive as retrofits. These measures include low energy designs and construction methods. Some measures, such as integrated skylights and luminaries, are also included because costs will be much lower as new construction measures. "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). It also includes air conditioners optimized for hot-dry climates, and two-speed pool pumps. Northern climates rate only 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 "special" 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 two may be indicative of opportunities that will arise when other industries are targeted for close examination.

## Discussion

### 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 3). 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 1).

**Table 3. Number of Measures by Priority, 1993, 1998, and 2004 Studies**

| | 1993 | 1998 | 2004 |
|---|---|---|---|
| Total Measures Analyzed | 102 | 73 | 75 |
| High Priority | 21 | 12 | 5–6 |
| Medium Priority | 32 | 21 | 20–27 |
| High + Medium | 52 | 33 | 26–30 |

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

The 1998 study identified 12 high priority technologies and practices. Eight of these were identified as high or medium priority in the present study. Three 1998 measures were dropped from this list because they have estimated market shares above 2% (high efficiency washing machines, improved CFLs, and Integrated Lighting Systems [ILS]). In the first two cases, large-scale market transformation programs supported market growth, but the ILS growth has resulted from cost reduction and attractive ways to integrate with building automation systems. In the case of washing machines, this success contributed to new 2004 and 2007 federal standards and brought many new products to the high efficiency market. The compact fluorescent market has seen an enormous influx of new manufacturers, responding to utility programs and the ENERGY STAR® CFL program. Integrated design/construction for commercial use remains a high priority, but more efficient residential construction has entered the mainstream, with ENERGY STAR and other promotion and labeling programs. 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 lower-cost compact fluorescents of comparable efficacy. 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,[1] and the gas- and oil-fired equivalents have had very low market penetration.

[1] There is at least one exception to this: most of the residential ground-source heat pumps installed (perhaps 20,000–40,000/yr) have *desuperheaters* that provide some hot water while the unit runs. A much smaller number have *full*

## 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 application, we find more promising measures than in the 1998 study: the sum of high and medium in 1998 was 33, compared with 26–30 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. 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 will 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 540 TBtu per measure (see Table 4). 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.

**Table 4. Aggregated Savings of Source Energy, 1998 and 2004**

| | 1998 | 2004 |
|---|---|---|
| High Priority Average Savings | 824 (12 measures) | 520 (6 measures) |
| High, Medium, + Low, | 1,239 (71) | 852 (66) |
| High, Medium, Low, + Special | | 913 (20) |

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 but not yet announced. These have prospered in the market and no longer qualify as "emerging technologies."

## Recommended Next Steps

Measure-by-measure recommendations for many technologies and practices are outlined in Sachs et al. (2004) and summarized in Table 5.

---

*condensing* hot water systems that are capable of diverting the entire output of the compressor to heating water. Comparable air-source heat pumps were not a market success.

**Table 5. Recommended Next Steps for the Highest Priority Measures**

| Measure | Name | Recommended Next Steps |
|---|---|---|
| PR3 | Comm. Construction 30%>Code | • Dissemination of successful case studies<br>• Revised fee structures for mechanical designers<br>• Client education<br>• Better software |
| A1 | 1-Watt Standby Power | • ENERGY STAR program for power supplies<br>• Possible manufacturer incentive for using better power supplies<br>• Mandatory standard for power supplies |
| PR1 | Advanced Automated Building Diagnostics | • Additional research<br>• Work on standard protocols for alarm and ID transmission<br>• Case studies on value based on real demonstrations |
| PR4 | Retrocommissioning | • Better define approaches and appropriate applications for different approaches<br>• Benchmarking<br>• MT with promotion, training, and incentives |
| H12 | Aerosol-Based Duct Sealing | • Raise consumer awareness of problems and savings<br>• Utility incentives<br>• HVAC contractors taking on value-added service<br>• Training and certification<br>• Field tests in regions with basements and crawl spaces |
| H11 | Leakproof Duct Fittings | • Raise consumer awareness of problems and savings<br>• Utility incentives<br>• Performance-based codes and standards<br>• Duct system integrity certification<br>• 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.

## References

Jump, D.A., 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.

Nadel, S., D. Bourne, M. Shepard, L. Rainer, and L. Smith. 1993. *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors.* Report A931. 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*. Report A985. Washington, D.C.: American Council for an Energy-Efficient Economy.

Sachs, H.M., S. Nadel, J.T. Amman, L. Rainer, D. Shipley, and G. Todesco. 2004. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector.* Report A042. Washington, D.C.: American Council for an Energy-Efficient Economy.