Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances

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ABSTRACT

We investigated numerous energy-saving technologies for commercial appliances and assessed in detail the top 30 by technical potential. In our analysis, we define "commercial appliances" as energy-consuming appliances and equipment used in commercial buildings, excluding heating, ventilation and air-conditioning, lighting, commercial refrigeration, and distributed-generation systems. The most important appliance categories evaluated include: water-heaters, pool-heaters, laundry equipment, cooking equipment, information technology (IT) and office equipment, and dishwashers. While many of the technologies are already mature, they may not be currently used in targeted appliances, and some design and demonstration work may be needed to incorporate them. Water heating and IT/office equipment offer the greatest technical potentials for energy savings.

The appliances we analyzed account for 2.92 quadrillion Btu (Quad) of primary energy consumption. However, there is a large discrepancy between our results and the U.S. Department of Energy's (DOE's) 2008 Building Energy Data Book (totaling 6.92 Quad), and we recommend further analysis to investigate possible sources of this inconsistency.

Based on estimates of technical potential and consideration of market and technical barriers, we offer suggestions for possible actions to promote energy savings in commercial appliances. Our recommendations fall into three categories: research, development and demonstration (RD&D); voluntary programs; and regulatory programs. Recommended RD&D topics include absorption heat-pump water-heaters, supercritical CO_2 dishwashing, and reliable electronic-ignition systems for cooking equipment. Recommended demonstration programs include solar-thermal water heating and drain-water heat recovery.

This paper is based on a study commissioned by the DOE Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Program (BT) (Zogg et al. 2009).

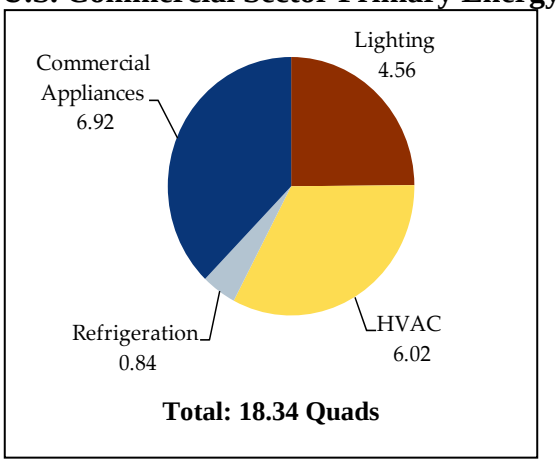
Introduction

Commercial appliances represent a significant portion of commercial building energy consumption; approximately 40% by DOE estimates (see Figure 1). DOE last characterized the energy saving potential of commercial appliances in 1993 (Dieckmann, et al. 1993). Since then, the way energy is used by the commercial sector has significantly changed. The DOE Office of Energy Efficiency and Renewable Energy (EERE), Building Technologies Program (BT) commissioned a new study (Zogg et al. 2009) to characterize and assess appliance technologies for commercial buildings, on which this paper is based. This study:

- Determined the energy consumption of the various segments of the commercial appliance and equipment market
- Identified and characterized substantial energy savings opportunities

- Identified barriers to implementation and analyze economics
- Recommended DOE-BT activities that can address these savings opportunities, including R&D, demonstration projects, standards activities, and tool development.

Figure 1: 2008 U.S. Commercial Sector Primary Energy Consumption



Source: Estimate based on DOE 2008

For the purposes of this analysis, "commercial appliances" are defined as energy-consuming appliances and equipment used in commercial buildings, excluding heating, ventilation and air-conditioning (HVAC) for comfort conditioning, building lighting (interior or exterior), commercial refrigeration equipment, and distributed generation systems (including combined heat and power systems).

Approach

We estimated energy consumption and energy savings potential across a diverse range of appliances and equipment types. Our analysis is based on publicly available sources such as technical literature, as well as interviews with industry experts. Since new equipment is generally more efficient than the existing stock (because of appliance standards, or simply because of advances in product design), we calculate energy savings relative to typical new equipment (i.e., the baseline technology). First, we estimated Unit Energy Consumption (UEC) for each appliance employing the baseline technology. Although UEC can vary widely depending on climate, capacity, usage patterns and other factors, we estimated a value that we believe is representative of typical conditions in the U.S.

Second, we estimated national energy consumption using estimates of the installed base for each appliance/equipment type. We obtained the installed base from available resources, or estimated it based on shipment data and typical equipment replacement cycles. We multiplied the installed base by the UEC to obtain national energy consumption.

Third, we identified alternative technologies that can reduce energy consumption of commercial appliances, and calculated their unit energy savings (UES) compared to the baseline technology. UES may be expressed as a percentage or an absolute savings. We determined the technical potential[1] energy savings associated with each alternative technology. Technical

[1] Technical potential is the theoretical national primary energy savings that could be achieved if all technically suitable appliance/equipment installations are replaced with a particular energy-saving technology.

potential is expressed relative to the baseline technology and was calculated by multiplying the UES (in absolute savings) for a particular energy-saving technology by the installed base.

Finally, we focused our recommendations on the top 30 alternative technologies. Recommendations focused on overcoming key barriers to current efficiency technologies. Key barriers were obtained from interviews with industry experts. Part of the consideration for barriers included cost. In our full report (Zogg et al. 2009) we document cost data for both the baseline and energy-savings technologies, and estimate simple payback periods for those technologies. When cost data were not available, we calculated an allowable first-cost premium based on what we assumed to be an acceptable payback period to provide a sense of the cost challenge involved and help establish cost targets for potential RD&D programs.

Baseline Energy Consumption

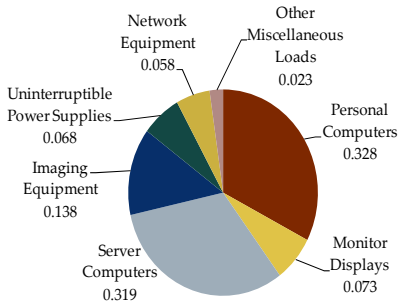
Annual Energy Consumption

Our estimates are based on bottom-up analyses, with the exception of the miscellaneous equipment category. The largest energy-consuming appliance classes include IT and Office equipment, Water Heating, and Kitchen Appliances.[2] All energy consumption figures below are based on primary energy consumption.[3]

IT and office equipment account for about 1.0 Quad (all electricity) of commercial building energy consumption. As illustrated in Figure 2, servers, personal computers and auxiliary display monitors account for about 65 percent of this consumption.

Figure 2: 2008 National Primary Energy Consumption for Commercial IT/Office Equipment

By Appliance Type (Quads)



Total Energy Use: 1.01 Quad

Appliance Type Definitions

Personal Computers
- Desktop PCs
- Laptop PCs

Desktop Monitors
- CRT Monitors
- LCD Monitors

Server Computers
- Volume Servers
- Mid-Range Servers
- High-End Servers

Imaging Equipment
- Multifunction Devices
- Laser Printers
- Inkjet Printers
- Fax Machines
- Scanners
- Impact Printers
- Other Printers

Network Equipment
- LAN switches
- WAN switches
- Routers

Uninterruptible Power Supplies (UPSs)
- Standby UPSs
- Line-Interactive UPSs
- Double Conversion UPSs

Miscellaneous Loads
- Voice Mail Systems
- Handheld Devices
- Electric Typewriters
- Desktop Calculators

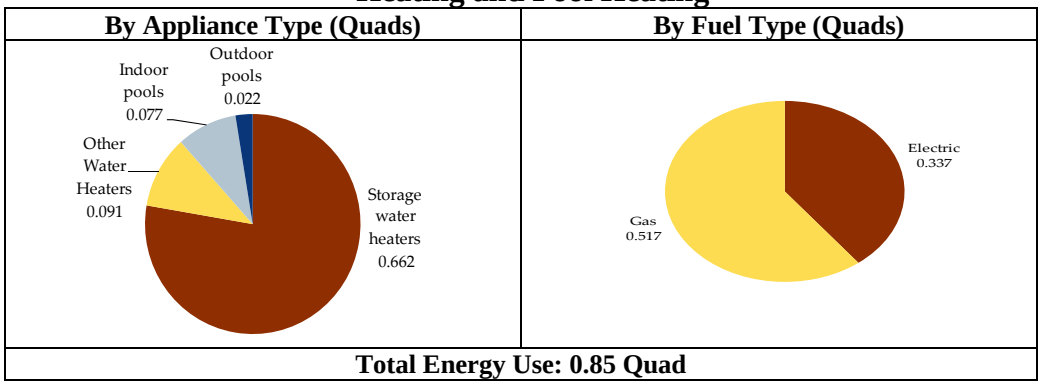
Sources: Zogg, et al. 2009

Water heating and pool heating is the second largest energy consuming equipment class, accounting for about 0.85 Quad of commercial building energy consumption. Service water

[2] Kitchen Appliances, as used in this paper, includes cooking, food preparation, and dishwashing equipment.
[3] Primary energy accounts for the losses in generation, transmission and distribution, based on national-average data. We generally only account for these losses for electricity, as the transmission and distribution losses for natural gas and other fossil fuels tend to be small. Primary energy does not account for the losses associated with extraction.

heating (including storage tank heaters only) constitutes the bulk of this consumption, as indicated in Figure 3. Approximately 60 percent of water heating uses natural gas, and the remainder is electricity. We did not consider other fuels such as oil, propane, or renewable fuels.

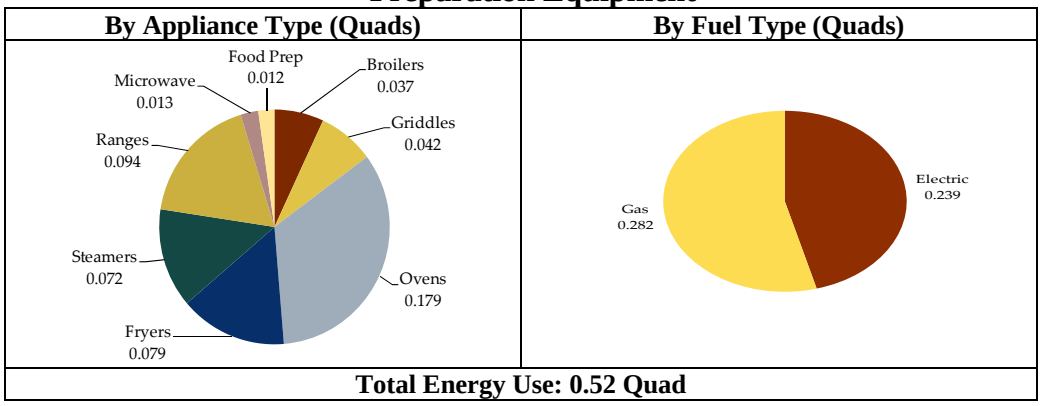
Figure 3: 2008 National Primary Energy Consumption for Commercial Service Water Heating and Pool Heating



Sources: Zogg, et al. 2009

Cooking and food-preparation equipment account for about 0.5 Quad of commercial building energy consumption. As indicated in Figure 4, the largest contributing appliances include ovens and ranges. The energy consumption associated with food-preparation equipment is a very small contributor compared other cooking appliances.

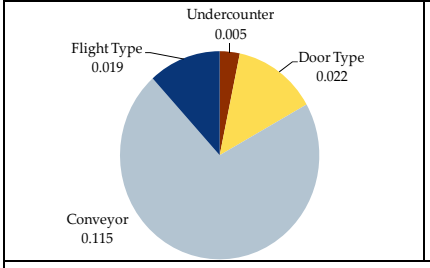
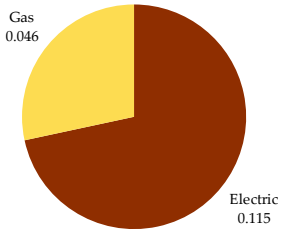
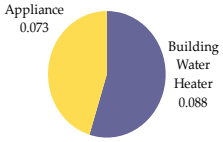
Figure 4: 2008 National Primary Energy Consumption for Commercial Cooking and Food-Preparation Equipment



Sources: Zogg, et al. 2009

As shown in Figure 5, dishwashers account for about 0.16 Quad of commercial building energy consumption. Over 70 percent of this energy consumption is associated with large, conveyor-type dishwashers. We include the energy associated with heating the water supplied to the dishwasher (which accounts for over 50 percent of total energy). Electricity accounts for over 70 percent of dishwasher energy consumption, as shown in the middle chart on the figure. This is because dishwashers themselves use electricity generally to maintain the water temperature or heat it further to temperatures required for sanitization.

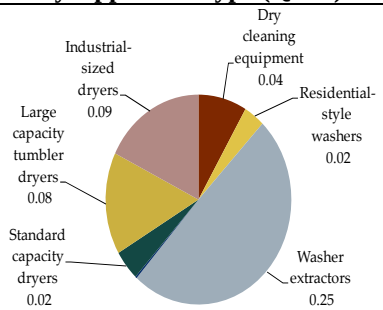
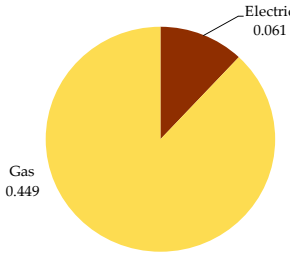
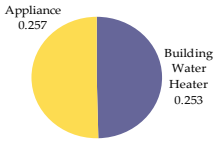
Figure 5: 2008 National Primary Energy Consumption for Commercial Dishwashers[4]

By Appliance Type (Quad)	By Fuel Type (Quad)	Appliance/Water-Heater Split (Quad)
		
Total Energy Use: 0.161 Quad		

Source: Zogg, et al. 2009

As illustrated in Figure 6, laundry equipment accounts for about 0.5 Quad of commercial building energy consumption, including the energy used to heat water supplied to clothes washers. Almost 90 percent of this is natural gas or other fossil fuels.

Figure 6: 2008 National Primary Energy Consumption for Commercial Laundry Equipment[4]

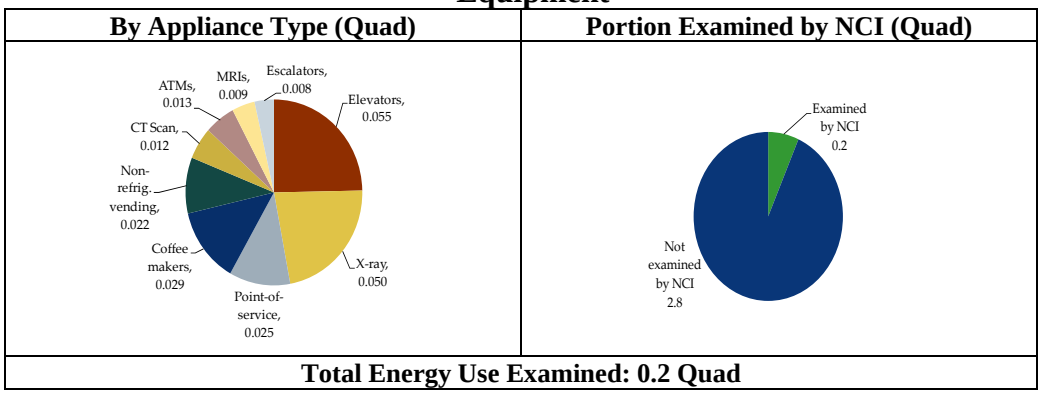
By Appliance Type (Quad)	By Fuel Type (Quad)	Appliance/Water-Heater Split (Quad)
		
Total Energy Use: 0.51 Quad		

Sources: Zogg, et al. 2009

As shown in Figure 7, the miscellaneous equipment we analyzed consume about 0.2 Quad (all electricity) of commercial building energy consumption. Our bottom-up analyses of these appliances accounts for about 7 percent of the total energy consumption in the "Others" category, as defined by the 2008 Buildings Energy Data Book (Data Book) (DOE 2008). DOE's Energy Information Administration (EIA) is the original source for the Data Book estimates. More discussion on this topic follows in the next section.

[4] Includes energy associated with building water heating.

Figure 7: 2008 National Primary Energy Consumption for Commercial Miscellaneous Equipment

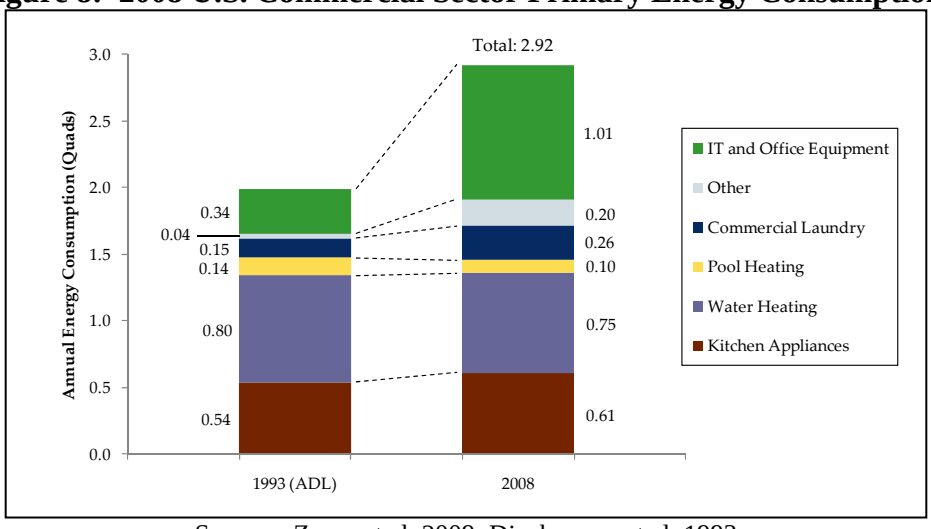


Sources: Zogg, et al. 2009

Comparison with Previous DOE Estimates

Figure 8 shows our estimated 2008 national primary[3] energy consumption for commercial appliances (2.92 Quad total) compared to Dieckmann, et al 1993, segmented by appliance type. The largest change in energy consumption between 1993 and 2008 is by IT and Office equipment, due to the increase in the installed base of computer-related equipment.

Figure 8: 2008 U.S. Commercial Sector Primary Energy Consumption[5]

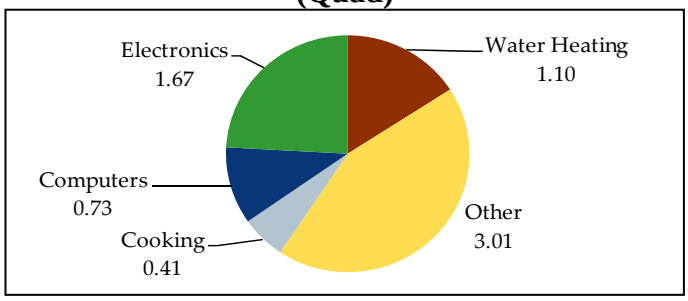


Sources: Zogg, et al. 2009; Dieckmann, et al. 1993

Figure 9 summarizes the 2008 U.S. commercial sector primary energy consumption as reported by DOE 2008. The figure indicates that commercial appliances account for nearly 40 percent, or 6.92 Quad, of U.S. commercial building energy consumption.

[5] We exclude from laundry equipment and dishwashers the energy used to heat the water supplied to the equipment to avoid double counting some of the energy consumption reported under water heating.

Figure 9: DOE Estimate of 2008 U.S. Commercial Sector Primary Energy Consumption (Quad)



Sources: Estimate based on DOE 2008

Our analysis accounts for only about 2.92 Quad, approximately 4 Quad less than the Data Book. While we are not able to conclusively determine the sources of this discrepancy, we believe they lie primarily in two Data Book categories: "Other" and "Electronics," which best correspond to "Miscellaneous Equipment" and "IT and Office Equipment" categories in our analysis, respectively. The "Other" category in the Data Book, accounting for approximately 3 Quad of commercial buildings energy consumption, encompasses a broad range of equipment types. These equipment types are either outside the scope of this analysis (e.g., emergency electric generators, and commercial combined heat and power systems) or are among the many other smaller equipment types not analyzed in our study.

Similarly, the "Electronics" category in the Data Book, accounting for over 1.6 Quad of commercial buildings energy consumption, most likely includes equipment that we did not include in our study. The Data Book considers "Computers" as a separate category from "Electronics" In fact, our estimate of computer energy consumption alone (0.72 Quad, accounting for personal and server computers and peripheral display monitors for personal computer use) agrees well with the Data Book estimate for Computers (0.73 Quad).[6] However, the Data Book does not provide a precise definition of commercial "Electronics", and it is unclear whether those additional equipment types can account for the full difference between the two energy consumption estimates for non-computer electronics.

Technical Potential for Energy-Saving Technologies

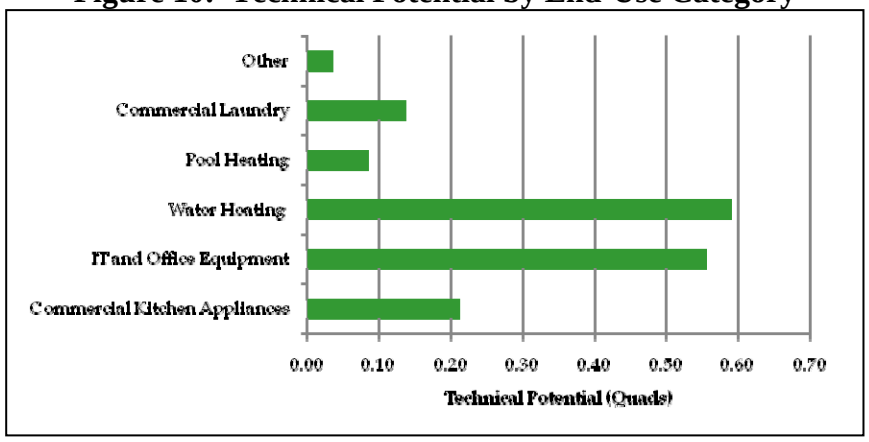
We examined 64 energy-saving technologies applicable to commercial appliances. Figure 10 shows technical potential for all the energy-saving technologies that we evaluated for each end-use category. The total technical potential for all the end-use categories is 1.5 Quad. The calculation considers the effects of interactive and competing technologies, including:

- Competing technologies that are mutually exclusive within a single appliance
- Reductions in technical potential as multiple energy-saving technologies are applied to a single appliance
- Overlaps in allocation of energy consumption by end-use category, such as water heating energy that also applies to clothes washers or dishwashers

[6] Furthermore, our national consumption estimate for IT and Office Equipment is consistent with the year 2000 estimate (Roth, et al. 2002), which classifies IT and office equipment in a fashion similar to our analysis.

Figure 10 illustrates that the greatest technical potentials are in water heating and IT/office equipment, each of which has a technical potential approaching 0.6 Quad. Technical potentials for laundry, pool heating, and kitchen appliances are also significant.

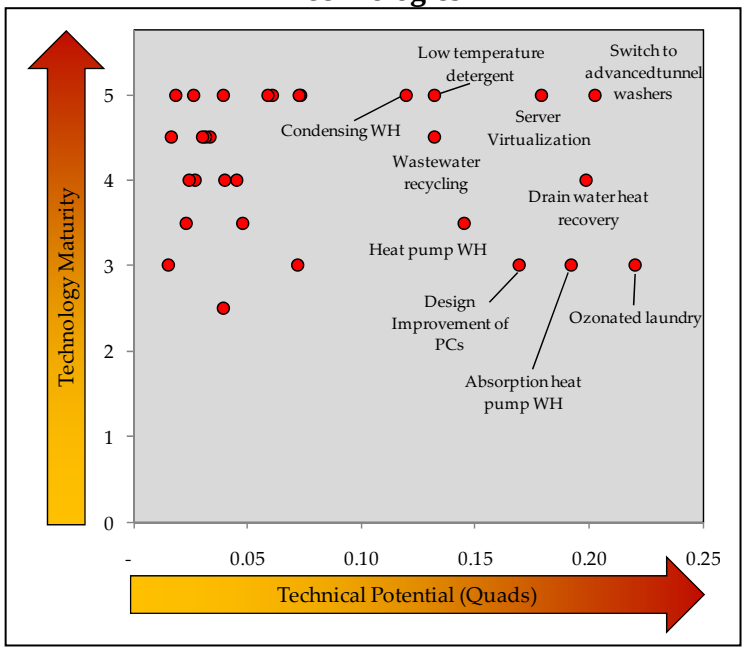
Figure 10: Technical Potential by End-Use Category



Sources: Zogg, et al. 2009

We investigated the 30 energy-saving measures with the highest technical potential in greater detail. Figure 11 plots technical potential versus technology maturity for the 30 measures investigated. We rated technology maturity on a five-point scale based on the judgments of Navigant Consulting experts; a ranking of five is the highest maturity. As the figure shows, most of the energy-savings potential resides in technologies that are already mature. However, in some of these cases, the energy-saving technology may not be currently used in the targeted appliance, and may require some design and demonstration work to incorporate the technology.

Figure 11: Technology Maturity versus Technical Potential Selected Energy-Saving Technologies



Sources: Zogg, et al. 2009

Key Barriers to Energy-Saving Technologies

Water-Heater Efficiency Barriers

Common barriers to water-heater efficiency technologies include extensive retrofit requirements and the high first cost of equipment. Consumer preference for low upfront costs (e.g. equipment and installation) has limited the adoption of energy-efficient technologies. Also, since many energy-efficient technologies are just entering the market, they do not yet benefit from economies of scale and suffer from concerns related to ongoing equipment reliability. Hence, more equipment demonstrations and targeted marketing programs are needed to overcome the concerns of risk-averse consumers.

IT and Office-Equipment Efficiency Barriers

One of the key barriers to adoption of efficient technologies for IT and office equipment is user preferences. For instance, several key factors that keep residential users from enabling their computers' power-management features, including: inconvenience associated with longer boot-up times; need for remote access; need to run computing jobs while the user is away; and insufficient economic incentives (Chetty, et al. 2009). These may be a greater challenge in a commercial setting, where user needs are more diverse and users are typically not responsible for their company's energy costs. In the context of centralized IT equipment use such as data centers, barriers to adoption include potential (and perceived) impact on the reliability of equipment operation. The primary concern of data-center operators is maintaining reliable operation of their fleet of servers, which may present a barrier to adoption of new technologies.

Commercial Kitchen Equipment Efficiency Barriers

First cost and reliability are concerns for both chain and independent restaurants. Conventional wisdom across the industry suggests that expanding a franchise will lead to better returns than investing in energy efficiency. Thus, capital investments on expansion tend to be prioritized over investments in energy efficiency. Restaurants require highly reliable and durable equipment to minimize revenue lost from broken equipment. A new technology is only accepted after its reliability has been proven. An additional barrier for the chain restaurant industry is the need for consistent taste at each location. Replacing existing appliances with different models may change quality of the food, thus presenting a barrier to equipment replacements.

Commercial Laundry Equipment Efficiency Barriers

The key barriers to implementing energy efficiency improvements in commercial laundry equipment involve lack of technological maturity of many advanced washer and dryer technologies. Laundry cycle time is a major concern of commercial laundry facilities, thus technologies that result in longer wash or dry cycle times have difficulty finding market acceptance. However, energy costs constitute a significant fraction of commercial laundry facilities' costs, so there is incentive for facility operators to implement energy-saving technologies once they do become available.

Pool-Heater Efficiency Barriers

Energy-saving commercial pool-heating technologies are already commercially available, although the technologies have not been widely adopted. Initial cost is a concern for many operators. Past studies indicate that two of the main barriers to implementing energy-saving pool equipment are 1) lack of consumer knowledge about the magnitude of potential energy savings, and 2) lack of consumer knowledge about how the majority of energy is lost (e.g., preventing evaporation by using a simple pool cover can prevent 70% of pool-heat loss).

Miscellaneous Equipment Efficiency Barriers

The energy costs of operating individual miscellaneous appliances are low compared to those of other major appliances owned by commercial customers. This provides a disincentive for businesses to consider energy efficiency as high priority when making purchase decisions regarding these appliances.

Recommendations

We recommend to DOE programmatic options to achieve energy savings in commercial appliances. We divided recommendations among three categories of programs: Research, Development and Demonstration (RD&D); Voluntary; and Regulatory. We did not include rebate or tax-incentive programs. See Zogg, et al., 2009 for a full list of detailed recommendations.

Water-Heater and Pool-Heater Recommendations

Most of our recommendations regarding water-heating efficiency involve development and demonstration of various technology options.

- Demonstrate performance and cost savings benefits of solar-thermal water-heaters and commercialized drain-water heat recovery on federally owned or institutional facilities and distribute results to appropriate private sector decision makers. (RD&D)
- Coordinate and solicit feedback from manufacturers to research alternative materials and design applications for drain-water heat recovery technology. (RD&D)
- Coordinate with researchers and manufacturers to leverage past experiences to further develop heat-pump-water-heater technology for commercial applications, including absorption heat-pump water-heaters. (RD&D)
- In cooperation with ASHRAE, sponsor a research program focused on the integration of water heating equipment and HVAC equipment. (RD&D)
- Launch an educational outreach program similar to the previous DOE RSPEC (Reduce Swimming Pool Energy Costs) program to increase awareness of energy- and cost-saving opportunities for commercial pools. (RD&D)

IT and Office Equipment Recommendations

There are many existing market drivers that will push the industry toward improving the efficiencies of IT and office equipment. As such, our recommendations focus on voluntary programs to support and enhance the ongoing industry efforts.

- Establish an R&D program to address research needs in the area of data center HVAC efficiency. (RD&D)
- Establish a LAN- or a buildings-level IT network efficiency performance program to act as a clearinghouse of best network design practices. (Voluntary)

Commercial Kitchen Equipment Recommendations

Targeting energy efficiency programs in the commercial kitchen market is challenging due to unique characteristics of the market and industry. A balanced portfolio of RD&D and voluntary programs best addresses this sector.

- Sponsor research to assess energy saving potential of CO2 dishwashing and its viability to meet the cleaning needs of the commercial food service sector. (RD&D)
- Develop reliable and durable technology options to reduce idle energy consumption in commercial kitchens, including broiler control systems and electric ignition. (RD&D)
- Create a framework through which cooking equipment manufacturers and chain restaurants can work to overcome food quality and cost barriers of high efficiency appliances. (RD&D)

Commercial Laundry Equipment Recommendations

There are significant RD&D opportunities regarding energy efficient commercial laundry appliances.

- Sponsor a demonstration project for a dryer sensor able to accurately detect end-of-cycle in single-load and commercial tumble dryers. (RD&D)
- Sponsor a demonstration project for modulating gas burners in commercial single-load and tumbler dryers. (RD&D)

Miscellaneous Equipment Recommendations

As explained above, the energy consumption in the miscellaneous equipment sector is not well understood, better characterization of these technologies and their challenges is needed. Meanwhile, DOE should focus on technologies that are broadly applicable, such as control systems and proximity sensors.

Cross-Cutting Recommendations

Cross-cutting recommendations include mostly voluntary and regulatory programs.

- Expand the ENERGY-STAR program to include: commercial water-heaters, single-load commercial and larger capacity tumbler dryers, commercial pool-heaters. (Voluntary)
- Continue to strengthen or consider creating minimum efficiency standards for: commercial water-heaters, commercial single-load and multi-load washers and dryers, commercial pool-heaters, and small electric motors. (Regulatory)
- Investigate the discrepancies in national consumption estimates between Zogg, et al. 2009 and the DOE 2009 in the IT-related and other miscellaneous loads. (RD&D)

Acknowledgements

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