Industrial Facility Energy Efficiency: Worth a Second Look

Robert Bruce Lung, Jeffrey Harris and Paul Bostrom, Alliance to Save Energy

ABSTRACT

The U.S. industrial sector accounts for approximately one-third of total energy use in the U.S. and slightly more than one-fourth of the country's greenhouse gas emissions. Because facility or building envelope energy use in industrial facilities – non-process and cross-cutting systems energy use - accounts for approximately 5% of industrial energy consumption, industrial process and cross-cutting technologies receive more attention for energy efficiency improvements. As a result, some energy savings opportunities in industrial facilities may be overlooked despite high shares of energy use by non-process applications in certain industrial subsectors. And, in certain energy-intensive facilities such as clean-rooms, laboratories, and data centers the line between process and facility energy use are fuzzy, due to significant "facility" energy demands for heat removal from servers , air filtration, and tightly controlled space conditioning.

Commercial and residential building energy codes have significantly improved energy efficiency over the past two decades, complemented by technology advances, the impact of utility programs, voluntary ratings like LEED and Energy Star, and appliance standards. Despite relying on many of the same envelope and mechanical systems as their commercial counterparts, industrial facilities have sometimes been overlooked by both building code advancement and beyond-code programs.

This paper investigates the opportunities for energy savings at the facility level in U.S. industrial plants—particularly in selected facility types with high non-process energy use. We explore the relatively limited market penetration of effective beyond-code programs such as utility DSM programs and LEED within the industrial sector. We conclude with policy and program recommendations.

Summary of U.S. Industrial Facility Energy Consumption

The U.S. industrial sector accounts for approximately one-third of U.S. energy consumption - 32.8 quadrillion Btu in 2006 (EIA, 2006). Process-related applications account for approximately 80% (Butters, 2009) and another 15% is used by cross-cutting motor-drive systems, e.g. pumping, fan, compressed air) and combined heat and power (CHP) generation (MECS, 2002). Industrial energy used strictly building-envelope applications i.e., heating ventilating and air-conditioning (HVAC) systems, lighting, and appliances (e.g. computers) make up the rest (Butters, 2009; DOE, 2006), equating to approximately 1.6 Quadrillion Btu. (EIA, Annual outlook 2009).

In comparison, total building envelope-related energy in the U.S., consumed by applications such as HVAC, lighting, appliances, was almost 39 quadrillion Btu (QBtu) in 2007 (BEDB, 2009) which equates to approximately 39.6% of the total energy used in the United States that year. Of this total, more than 37 QBtu is consumed by the residential and commercial sectors, 52% and 43% respectively (Butters, 2009). Together residential and commercial buildings consume about 72% of U.S. electricity and 55 % of U.S. natural gas (EIA energy outlook, 2009).

Key Recommendations

Energy efficiency has gained increased relevance as energy prices have risen to historically high levels in the past decade and are still subject to wide price fluctuations. As industry seeks to improve energy efficiency, industrial facilities and the building-related applications in them can represent a source of easily achievable efficiency gains. This study assesses building-related energy use in industrial facilities and code and beyond code programs that address energy consumption of such applications. By incorporating measures to improve facility energy use, industrial companies can achieve appreciable energy savings.

To achieve greater efficiency in industrial facilities, the industrial sector needs to take several actions at the program, policy, and facility levels. These actions include better facility energy data collection, energy management and workforce training. In addition, clear codes and standards for new industrial facilities and adequate financial incentives from federal and state governments, as well as utilities, to encourage greater energy efficiency in industrial facilities.

Energy efficiency codes that address energy consumption in commercial and residential buildings have effectively reduced energy use and the concomitant greenhouse gas (GHG) emissions associated with low-performing buildings. Some industrial facilities with significant facility energy use have conformed to such codes, while some have not. If energy efficiency building codes, standards or guides are uniformly adopted by industrial facilities they could achieve important energy savings. Such codes could address:

- Demand response technologies and programs
- Data collection
- Building envelope
- New construction/renovations
- Lighting
- HVAC
- Exhaust

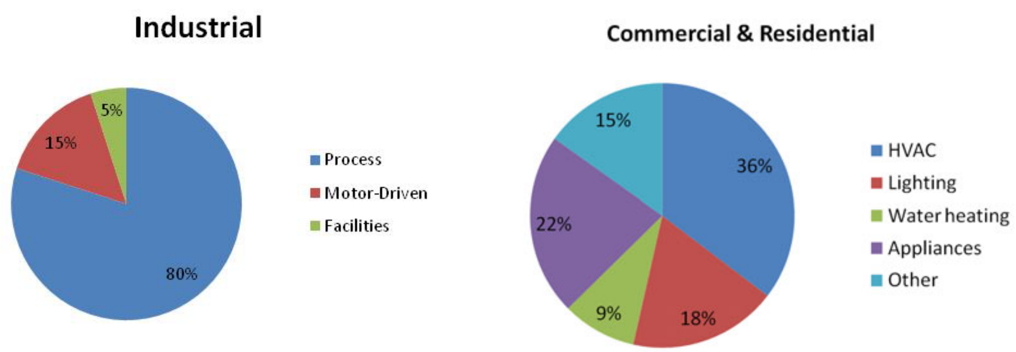
Industrial Facility Energy Use

Industrial facility energy use is the smallest share of total industrial energy consumption, yet still represents 1.6 Quadrillion Btu annually. When evaluating industrial facility energy use, it is important to note that energy use in commercial buildings includes energy required for most of the activities within them. Likewise, residential buildings include most of the energy use associated with daily living activities. Industrial facility energy use is grouped together with sector-wide industrial data in the Manufacturing Energy Consumption Survey (MECS) while energy consumption by buildings in the commercial and residential sectors is documented in the Commercial Building Energy Consumption Survey (CBECS) and the Residential Energy Consumption Survey (RECS).

For commercial and residential buildings, energy is used for a wide variety of applications including HVAC, lighting, water heating, consumer, office and kitchen-related electronic appliances, and miscellaneous applications. This is shown in figure 1. In contrast to industry where these applications account for approximately 5% of energy consumption, these applications account for 92.9% of commercial building energy use and 87.5% of residential building energy use, respectively (BEDB, 2009).

Figure 1. Site Energy Use Comparison; Commercial, Residential and Industrial Buildings

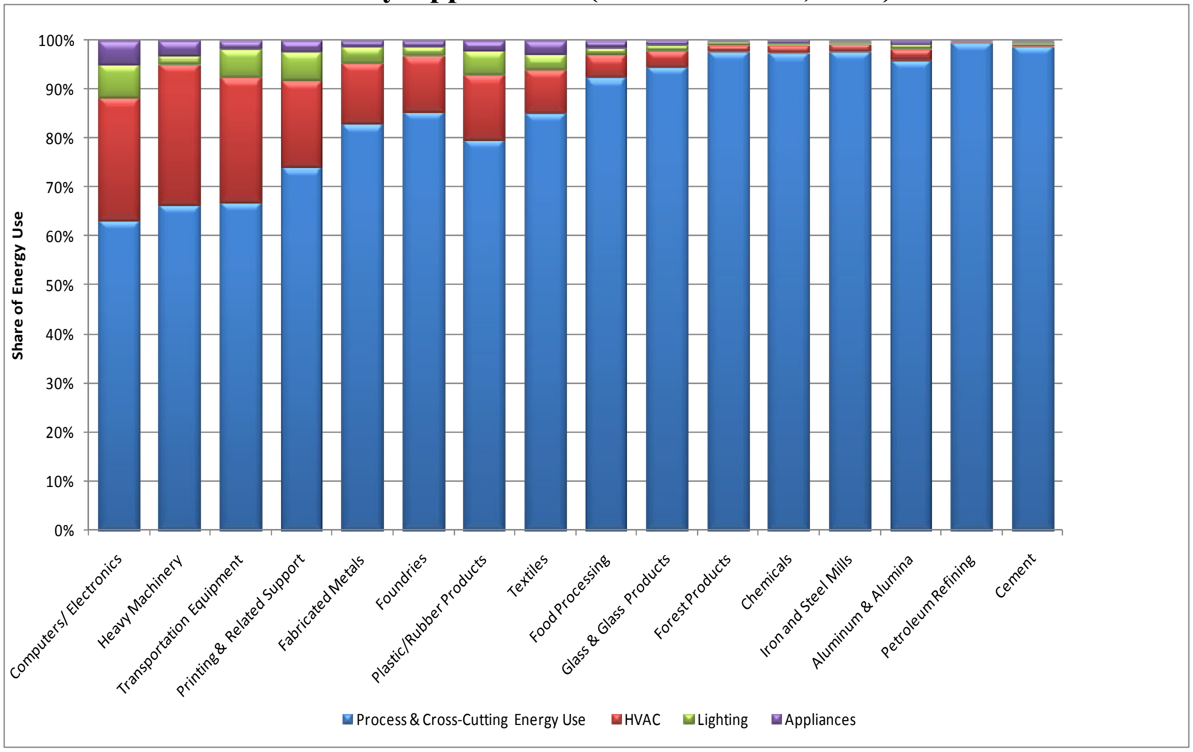
Source: DOE, 2008, EIA AEO



Because industrial plants use energy primarily for production processes and cross-cutting applications (steam, process heating and motor-driven systems, etc.) facility energy use is comparatively small. In some industries, facility energy use can represent less than 1 percent of the sector's energy use while in other sectors it can account for more than 40 percent of total energy consumption. Figure 2 displays the degree to which primary energy use for industrial processes overshadows the non-process energy use as well as the variance of facility energy consumption for many industries. This figure does not take into account the energy intensity of facility energy use, which can also vary significantly depending on the sub sector, e.g. energy use per square foot, by number of employees or by output.

Figure 2 shows the shares of energy used within industry. Facility energy use ranges from less than 1 percent to more than 40 percent in these selected subsectors. This suggests that energy efficiency measures at the facility level will have greater impact in sectors with high fractions of facility energy consumption than sectors with low facility energy use. Based on the information in figure 2 the sectors with high fractions of facility energy use are Computers/Electronics, Heavy Machinery, Transportation Equipment, Printing and Related Support, Fabricated Metals, Foundries, Plastic/Rubber Products, and Textiles. For industries such as cement or petroleum refining where the fraction of facility energy use is relatively low, energy efficiency measures in the facilities may still yield appreciable energy savings.

Figure 2. Proportions of Industrial Energy Use for Process and Cross-Cutting Systems vs. Facility Applications (Source: MECS, 2006)



According to MECS data, industrial facility energy use declined between 2002 and 2006 along with total industrial energy use. However, this decline was not proportional as total fuel consumption declined by 3.9% while facility energy use declined at a smaller rate of 1.4% which shows that energy use reductions in those subsectors may have been more significant for the process and support equipment.

Industrial Facilities with High Fractions of Facility Energy Use

While facility energy use accounts for only 5% of industrial energy consumption in the U.S., the fraction of facility energy use is higher than 15% in 8 of the 21 NAICS industrial subsectors. These industries include textile and apparel mills, printing and related facilities, plastics and rubber products, foundries, fabricated metal products, machinery, computers and electronic appliances, and transportation equipment. The shares of facility energy use as well as the number of facilities and the energy use per facility are shown for these industries as well as for laboratories and data centers in Table 1.

Table 1. Energy Consumption by Industrial Facilities with High Shares of Facility Energy Use

NAICS Code	Subsector	Number of Facilities	Total Industrial Facility Energy Use (TBtu)	Average Industrial Facility Energy Use (MMBtu)	Total Subsector Energy Use Excluding Feed stocks (TBtu)	Facility Energy Use as a % of Subsector Energy Use
323	Printing and Related Facilities	18,917	22	1,163	85	25.9
326	Plastics and Rubber Products	9,823	67	6,821	336	19.9
3315	Foundries	1,520	23	15,132	158	14.6
332	Fabricated Metal Products	35,520	68	1,914	397	17.2
333	Machinery	16,296	75	4,602	204	36.8
334, 335	Computers and Electronic Appliances	8,188	84	10,259	228	36.8
336	Transportation Equipment	7,024	158	22,494	479	33.1
541380 541710	Laboratories	9,000	150	16,667	200	75.0
518210	Data Processing	17,069	104	6,093	208	50.0

Sources: U.S. DOE Manufacturing Energy Consumption Survey 2006; U.S. DOC, Economic Census; EPA datacenters; CBECS 2003, LBNL, DOE ITP

Building-Related Applications in Industrial Facilities

While HVAC, lighting and appliance loads are relatively small for most industrial facilities, some industries have high HVAC and lighting loads, and longer operating hours in plants with multiple shifts (DOE, 2009a). This is the case with clean rooms in semiconductor manufacturing in which particulate levels must be kept to very low levels. In foundries and laboratories, noxious fumes and particulate emissions must be exhausted to comply with safety requirements, leading to greater HVAC use - HVAC, dust collection and cooling account for 22.5% of a typical foundry's electricity use (Eppich). A select group of quasi-industrial facilities with a high fraction of building energy use are detailed below and their shares of facility energy use are shown in Figure 3.

Laboratories. Laboratories tend to have higher equipment loads than commercial buildings that can vary widely, from as little as 2 watts per foot^2 to more than 15 watts per foot^2. In addition, some types of laboratory equipment tend to increase ventilation and cooling energy requirements [Mathew et al., p. 3-235]. Fume hoods in particular consume large amounts of energy and increase the load on a laboratory's HVAC system. Laboratory fume hoods are needed to contain and exhaust hazardous fumes and materials. These fumes are exhausted out of the hood using fans. Though small, they are very energy intensive – a typical fume hood can consume 3.5-times more energy than an average house and can cause typical laboratories to be 4 to 5times more energy intensive than many commercial buildings (Mills, p. 1860). In addition to fan energy, fume hoods also exhaust large amounts of conditioned air, resulting in larger energy demands from HVAC systems to heat or cool make-up air (Mathew et al., JCHAS article). As a result, fume hood energy requirements significantly affect the size and energy usage of HVAC systems, chillers and boilers, causing these systems to be oversized in laboratories due to the added capacity required to condition make-up air. Also, fume hoods often operate 24 hours a day, 365 days a year. Laboratory fume hoods in the U.S. directly consume approximately 0.27 Quadrillion Btu (Feustel, p. 4)—and are indirectly responsible for significantly more energy consumption based on their relationship to facility HVAC systems.

Data Processing. Data processing which includes data centers are another type of quasi-industrial facility in which building-related applications, particularly HVAC, represent a large part of total energy use. The main reason for the high HVAC loads in data centers is to cool the servers and computers. The power supply and cooling assets serving the IT equipment in data centers can account for as much as 50 percent of total data center energy consumption (EPA, p. 7). Because of these loads data centers can consume up to 40 times more energy than a typical commercial building of the same size (Greenberg, 3-76).

In 2006, aggregate data center energy consumption was estimated at approximately 61 billion kilowatt-hours (kWh) representing 1.5 percent of total U.S. electricity consumption (EPA, p. 7). According to a McKinsey study data center energy use grows by 9.6% annually, so by 2011 aggregate data center energy use could be as much as 90 billion kWh (Granade, p. 69).

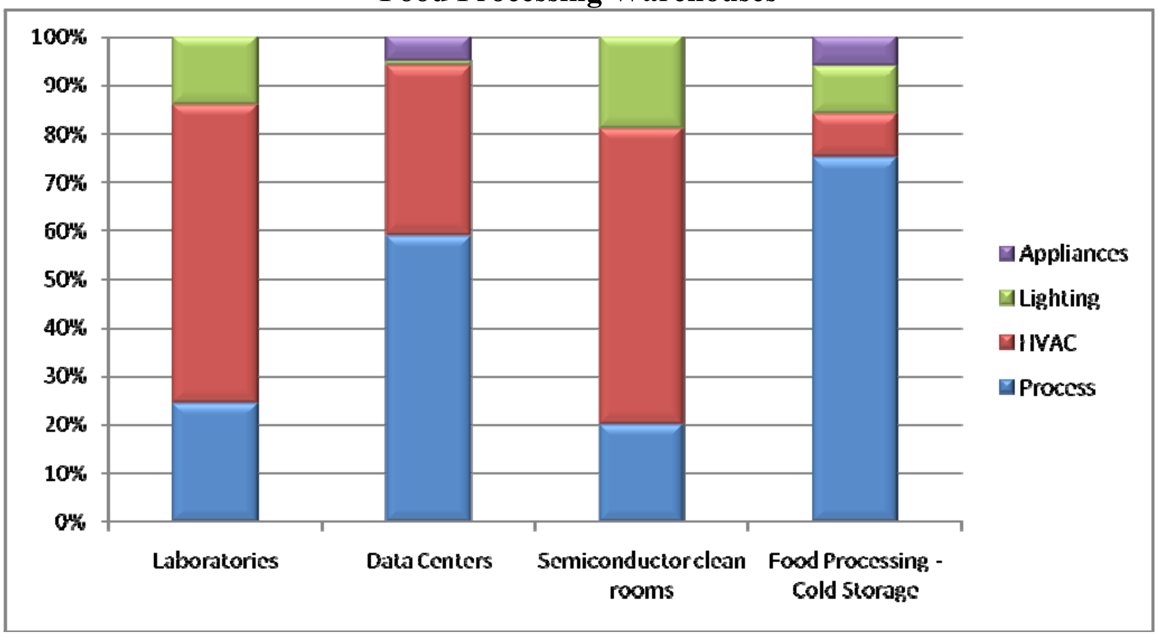
Semiconductor Clean Rooms. Within semiconductor fabrication facilities, manufacturing clean rooms account for a significant amount of the total subsector's energy use. A clean room is a manufacturing environment that has a controlled (usually low) level of contamination that is specified by the number of particles per unit of air volume, and by maximum particle size (Rumsey, p. 8). Clean rooms require much process cooling and reheating of supply air after dehumidification.

In 2006, this industrial subsector accounted for 63 trillion Btu of energy consumption, including 44 trillion Btu primarily for HVAC and lighting, representing 70% of the subsector total and almost twice the facility energy use by the computer & electronics subsector. The greatest energy-consuming applications in clean rooms are HVAC systems, which are estimated to account for more than 50% of clean room energy use (Tschudi, P. 2, 6 & 17). Other non-process energy uses in clean rooms include boilers for hot water and steam (typically for space heating), office lighting & appliances and chillers that provide chilled water for air conditioning. Together, these systems account for 67% of clean room energy consumption according to the "High Performance, High-Tech Buildings/Laboratories, Clean rooms, and Data Centers Project." Other clean room energy uses include processes (13%), compressed air and process vacuum (6%), and miscellaneous applications (8%). Specialized clean room lighting accounts for 1% of clean room energy use.

Food processing (refrigerated warehouses). Refrigerated warehouses are essential to preserve the quality of perishable and frozen foods and other goods and supply materials that require refrigeration. Refrigerated warehouses include space for cold and frozen storage, processing facilities, and mechanical areas. In a refrigerated warehouse, heat is removed from the air inside the warehouse and transferred outdoors to the ambient environment.

According to “Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses in California” the main non-refrigeration energy requirements in refrigerated warehouses are lighting, HVAC, manufacturing processes, and charging fork lift batteries. Refrigeration accounts for approximately 54% of energy end use, electric defrost 21%, lighting 10%, HVAC 9%, battery chargers 3%, miscellaneous office equipment 2%, and exhaust fans 1%. A study commissioned by PG&E determined that a large majority of potential energy savings in refrigerated warehouses could be found in the evaporators (51%) and the compressors (34%) within the refrigeration system (PG&E, P. 29 & 30).

Figure 3. Shares of Facility Energy Use for Laboratories, Data Centers, Clean Rooms and Food Processing Warehouses



* Process in the Food Processing Cold Storage is also HVAC, but is represented separately to distinguish from building heating & cooling for personnel

What Codes Do Not Address with Respect to Industrial Facilities

Historically, industrial facilities were considered exempt from building codes such as ASHRAE and IECC because such codes do not apply to process loads that are required for production or safety reasons. Also, process loads often involve complex or custom-built applications that are periodically reconfigured for which “one-size-fits-all” energy efficiency measures may not be workable. In ASHRAE Standard 90.1, this exemption was listed in the scope with “equipment and portions of building systems that use energy primarily to provide for industrial, manufacturing, or commercial processes.” Datacenters, laboratories, and clean rooms were referred to as “high tech industrial” spaces whose dominant design criteria are to satisfy process needs rather than human comfort.

However, the scope of the 2010 edition of ASHRAE 90.1 has been expanded to cover process loads, including those in data centers. The Standard adds efficiency requirements to HVAC systems serving data centers and computer rooms. The scope also states that the Standard provides minimum energy efficiency requirements for “new equipment or building systems specifically identified in the standard that are part of industrial or manufacturing processes.”

While it still makes exceptions for some functional and safety reasons, ASHRAE 90.1 addresses laboratories by specifying efficiency requirements for fume hoods and lighting power densities.

The 2009 IECC applies to all buildings – residential and commercial. In this code, ‘commercial’ is defined as all buildings other than residential. However, in its current form, the IECC regulates energy used in buildings primarily for human comfort purposes, including HVAC, lighting, service water heating and building envelope systems. The IECC does not address the supply of energy to equipment or systems used primarily for industrial or manufacturing processes. Because the IECC is intended to regulate energy used for “human comfort and convenience” facilities that do not use energy for human comfort are exempted (Halvorsen).

Existing Code and Beyond Code Programs

While industrial facilities are not always covered by building codes, some states and utilities around the country have established energy efficiency and demand-side management programs that offer incentives to their industrial customers for implementing energy efficiency measures throughout the plant. These programs are listed in the DSIRE database (http://www.dsireusa.org/). Some utilities offer incentive programs that apply to quasi-industrial facilities such as clean rooms, production labs, and data centers. In California, PG&E offers incentives for energy-efficient refrigerated warehouses base on new energy efficiency requirements for these facilities (PG&E 2, p. 1). With respect to data centers, PG&E and other California electric utilities established a baseline and incremental incentives for data center energy efficiency. In addition, Austin Energy in Texas has a data center assessment program (Tschudi; EPA, P. 96).

At the state level, the New York State Energy Research and Development Authority (NYSERDA) established a range of incentives for existing facilities, including industrial ones. NYSERDA’s program offers incentives for a variety of energy efficiency projects and offers pre-qualified and performance-based Incentives. In addition, NYSERDA established a data center efficiency program in partnership with Consolidated Edison.

In California, the California Building Standards Commission unanimously adopted the first-in-the-nation mandatory Green Building Standards Code (CALGreen) on January 12, 2010. This program went into effect in January 2011, and requires all new buildings in the state to be more energy efficient than previous state building codes. The CALGreen Standard also requires mandatory inspections of applications such as furnaces, heat pumps, air conditioners, and other mechanical equipment for nonresidential buildings having more than 10,000 square feet of floor space to ensure that these applications are operating at the optimum loads to meet their design efficiencies (CEC).

In 2010, the U.S. Environmental Protection Agency (EPA) announced that stand-alone data centers and the facilities in which large data centers are located can earn the Energy Star label. To earn this label, a data center must be in the top 25 percent of its peers in energy efficiency. EPA uses the Power Usage Effectiveness metric, to determine whether a data center qualifies for the Energy Star label. Before giving a data center the Energy Star label, a licensed professional must independently verify the energy performance of each data center.

At the federal level a commercial building tax deduction can be applied to industrial buildings as long as they meet the ASHRAE 90.1 2001 requirements. Industrial buildings are eligible for this credit if the buildings are used both as warehouses and manufacturing facilities under the building area method. One of the EPACT 2005 tax incentives, EPACT 2005, section 1331, is applicable to data centers. EPACT provides a tax deduction of $1.80 per improved square foot to owners of new or existing data centers who build or rebuild their facilities to reduce the building's total heating, cooling, ventilation, water heating and interior lighting energy cost by 50 percent or more compared to the ASHRAE Standard 90.1-2001 reference building.

ASHRAE 90.1 now includes lighting power density (LPD) requirements for new industrial facilities. Under the building area method the LPD for manufacturing facilities is 1.3 W/ft^2 and 0.8 W/ft2 for warehouses. Under the space-by-space method, manufacturing facilities with low bays (<25 ft floor to ceiling height) are allowed an LPD of 1.2 W/ft^2 while manufacturing facilities with high bays (>25 ft floor to ceiling height) are allowed a LPD of 1.7 W/ft^2. In addition, detailed manufacturing spaces are allowed 2.1 W/ft^2, equipment rooms 1.2 W/ft^2, control rooms 0.5 W/ft^2, warehouses for fine material storage 1.4 W/ft^2 and warehouses for medium/bulky storage 0.9 W/ft^2.

What Codes Could Address with Respect to Industrial Facilities

One example of energy codes that address facility energy efficiency that could apply to certain types of industrial facilities is within the federal government in which agencies are required by Executive Order 13423 to reduce building energy use per gross square foot by three percent annually. These requirements extend to energy-intensive facilities owned by the federal government such as data centers. Other regulations define energy efficiency requirements for construction of new and major renovations of existing federal facilities. These regulations include the National Energy Conservation Policy Act, Executive Order 13514 (Federal Leadership in Environmental, Energy, and Economic Performance), the Energy Independence and Security Act of 2007 (EISA), Executive Order 13423 (Strengthening Federal Environmental, Energy, and Transportation Management), the Energy Policy Act of 2005, Executive Order 13221 (Energy Efficient Standby Power Devices), and the Energy Policy Act of 1992. Many Federal agencies are complying with these energy reduction targets and are expected to continue doing so.

In addition, the federal government mandates energy efficiency in federal facilities through its Federal Energy Management Program (FEMP) and the U.S. Department of Defense (DOD). FEMP provides guidance and some requirements for government laboratories, data centers, and other buildings.

With respect to the IECC a recent draft of the ICC International green Construction Code® (IgCC®) intends to regulate energy on a limited basis used in buildings where energy is supplied of energy to equipment and systems used primarily for industrial or manufacturing processes. These regulations would not apply to the equipment and systems involved in the manufacturing process, but rather to certain applications within the building related to personnel comfort and convenience (Myers).

Technical Energy Savings Potential in Industrial Facilities

Several studies of energy usage in the industrial sector have generated estimates of building-related energy savings. In a report by the National Renewable Energy Laboratory, an estimate of approximately 200 trillion Btu per year for industrial facilities was calculated (NREL, p. 33). In a more recent analysis, the McKinsey Institute estimated that energy efficiency upgrades to lighting and appliances along with retrofits of HVAC systems and building shells of industrial facilities could yield as much as 360 Trillion Btu of energy savings (McKinsey, p. 78).

With respect to industrial lighting the Alliance's white paper on industrial buildings (Promoting Energy-Efficient Buildings in the Industrial Sector, 2009) showed that current standard lighting bulbs can be upgraded to more efficient types of lighting at an annual turnover rate of 10% to result in sector-wide energy savings of 37 Trillion Btu by 2016. An example of lighting energy savings is provided for a facility in the transportation equipment subsector. Assuming an average facility size of 161,000 ft^2 with 354 T12, 4 foot ballasts the annual lighting energy consumption is approximately 94,400 kWh. If the 10% of the facility's lighting is upgraded to High Output T5 lighting the annual lighting energy use falls to 87,200 kWh, a savings of 7,200 kWh per year. If the facility upgrades its lights by 10% annually the cumulative savings at the end of 10 years would amount to more than 72,000 kWh, representing 76% of the pre-upgrade total.

With respect to the four quasi-industrial facilities discussed earlier, numerous studies have estimated energy savings potential in these facilities. One study of laboratory fume hoods tested low-flow fume hoods and estimated that fume hood energy use alone could be reduced by 80% or 0.2 QBtu with no decrease in hood containment performance (Feustel, p. 24). One estimate of the refrigerated warehouses subsector in the state of California found a total potential demand reduction of between 43 and 88 MW (Lekov, p. 4). The U.S. DOE has studied data center energy use and estimated several scenarios based on degree of energy efficiency implementation. Under DOE's 'state of the art' scenario, total data center energy use could decrease to 30 billion kWh in 2011 or approximately half total data center energy use in the U.S. in 2006 (http://www1.eere.energy.gov/femp/program/dc_energy_consumption.html). For semiconductor clean rooms, one study showed an energy efficient clean room using existing higher efficiency technologies, particularly HVAC, could reduce energy intensity from 1,000 kWh/ft^2 and 4 GJ/ft^2 per year to 336 kWh/ft^2 and 2.4 GJ/ft^2 per year, respectively (Busch, p. 8).

Conclusion

Energy efficiency in industrial facilities in certain subsectors with relatively high fractions of facility energy use can offer significant energy-savings potential. Because codes and beyond code programs have effectively reduced energy consumption in commercial buildings, similar codes and programs can be designed for industrial facilities having the same properties as commercial buildings. Opportunities for codes and programs fall into several areas:

- Voluntary programs – Voluntary programs for industry could include building-related applications in energy efficiency efforts. This could include programs at the utility, state, and federal levels.
- Utility rebates and tax incentives – Utility energy efficiency programs and market transformation initiatives could provide incentives for manufacturers to invest in more efficient lighting and HVAC equipment and other energy-efficient building technologies.
- Demand response technologies and programs – Deployment and facilitation of demand response technologies and programs for facility energy use.
- Industrial facilities data – better collaboration between the Energy Information Administration and industry, utilities, and others to identify ways to improve MECS and

CBECS data collection and other estimates of non-process energy end-uses, energy-related facility characteristics, and key trends.

- Facility energy benchmarking – the energy assessment community could include metrics for facility energy performance in industrial plant assessments.
- ISO 50001 Energy Management Standard – widespread adoption of ISO 50001 could ensure that energy is managed for all systems in an industrial plant, including facilities.
- New plant construction – Code development bodies and enforcement agencies could strengthen building energy code provisions for construction or renovation of industrial facilities.
- Workforce development - training for energy assessment professionals and plant personnel to address facility energy uses and savings opportunities.
- Equipment efficiency – encourage voluntary testing, rating, and labeling of additional categories of high-efficiency building-related equipment used in industrial facilities.

Industrial facilities account for approximately 5% of total industrial energy use. Because industrial plants use energy primarily for processes, energy efficiency codes such as ASHRAE 90.1 and IECC have, until recently, exempted industrial facilities despite the fact that many such facilities use lighting, HVAC, and appliances that these codes cover. This study suggests that energy efficiency codes may be applied to industrial facilities without adversely affecting processes. In some subsectors with high fractions of facility energy use, e.g. electronics, printing & transportation equipment, such energy efficiency codes could yield significant energy savings. For industrial companies that choose to participate in voluntary programs that require energy intensity reductions or to conform to the ISO 50001 Energy Management Standard, tracking and making efforts to reduce facility energy use can help meet such goals.

Acknowledgements

The Alliance to Save Energy would like to thank the U.S. Department of Energy and the Lawrence Berkeley National Laboratory for their support in this research effort. All opinions expressed in this paper are those of the individual authors and the Alliance to Save Energy (Alliance), and in no way reflect those of any supporting organizations.

References

Building Technologies Program. 2009 Buildings Energy Data Book. US Department of Energy, Energy Efficiency and Renewable Energy, October 2009.

Busch, John. "Cleanroom of the Future: An Assessment of HVAC Energy Savings Potential In a Semiconductor Industry Facility." Lawrence Berkeley National Laboratory, 1998.

Butters, Rolf. "Opportunities to Save Energy Now with Intelligent Industrial Buildings." ACEEE Summer Study on Industry, 2009, 1-19 to 1-34.

California Energy Commission. 2008 Building Energy Efficiency Standards. Sacramento, California, December 2008.

Energy Information Administration. Annual Energy Outlook 2009. Washington, D.C., Department of Energy, March 2009.

Energy Information Administration. Commercial Building Energy Consumption Survey 2003. Washington, D.C., Department of Energy, December 2006.

Energy Information Administration. Manufacturing Energy Consumption Survey 2006. Washington, D.C., Department of Energy, February 2010.

Eppich, Robert. Energy Use in Selected Metal Casting Facilities – 2003. US Department of Energy, Energy Efficiency and Renewable Energy, May 2004.

Feustel, Helmut E. et al "Energy-Efficient Fume Hoods." Lawrence Berkeley National Laboratory, 2000.

Granade, Hannah Choi et al. "Unlocking Energy Efficiency in the U.S. Economy." McKinsey & Company, July 2009.

Greenberg et al. "Best Practices for Data Centers: Lessons Learned from Benchmarking 22 Data Centers." ACEEE Summer Study on Buildings, 2006, 3-76 to 3-87.

Halvorsen, Mark and Darren Myers 2010. Personal communication with Mark Halvorsen of Pacific National Laboratory and Darren Myers of the International Code Council. February 23 & 24, 2010.

Howells, Thomas F. and Kevin Barefoot. Annual Industry Accounts, Advanced Estimates for 2006. U.S. Department of Commerce May 2007.

Lekov, A. et al. "Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses in California." Lawrence Berkeley National Laboratory, 2009.

Mathew, Paul et al. "Rating Energy Efficiency and Sustainability in Laboratories: Results and Lessons from the Labs21 Program." ACEEE Summer Study 2006, 3-226 to 3-238.

Mathew, Paul et al. "Major Energy Efficiency Opportunities in Laboratories: Implications for Health and Safety." Journal of Chemical Health and Safety, September/October 2007, Vol. 14, No. 5.

Mills, Evan and Dale Sartor. "Energy use and savings potential for laboratory fume hoods." Energy 30 (2005) 1859–1864.

Myers, Darren 2010. Personal communication with Darren Myers of the International Code Council. February 24, 2010.

National Renewable Energy Laboratory. "Energy Sector Market Analysis." Golden, Colorado. October 2006.

Pacific Gas & Electric Company. "Final Report Refrigerated Warehouses." San Francisco, California, February 2007.

Pacific Gas & Electric Company. "Refrigerated Warehouses Tech Brief." San Francisco, California, January 2010.

Rumsey Engineers. Energy Efficiency Baseline for Clean Rooms. Pacific Gas and Electric, San Francisco, California, October 2009.

Tschudi, William et al. "High Performance Laboratories and Cleanrooms." Lawrence Berkeley National Laboratory, July 2002.

Tschudi, William. 2010. Personal communication with William Tschudi of Lawrence Berkeley National Laboratory. April 6, 2010.

U.S. Department of Energy. Plastics: Industrial Assessment. Washington, D.C., Department of Energy, 2006.

U.S. Department of Energy. Buildings Energy Data Book. Washington, D.C., Department of Energy, 2009.

U.S. Environmental Protection Agency. "Report to Congress on Server and Data Center Energy Efficiency Public Law 109-431." Washington, D.C., August 2007.