Smart Buildings: A Deeper Dive into Market Segments

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Executive Summary

Smart buildings use interconnected technologies to provide building owners and occupants with both energy savings and nonenergy benefits. These technologies can display real-time data, diagnose faulty equipment operation, and reduce energy waste. Commercial buildings, including office, retail, hotel, and hospital buildings, can all benefit from installing smart technologies. However each of these sectors has its own unique business goals to achieve, stakeholders to satisfy, and barriers to overcome, so the opportunities are different for each sector. The most favorable technologies will also change over time, as smart technologies continue to grow into interconnected systems that learn and adapt to human behavior.

Smart technologies are defined by their interconnectedness. Although building operators have had the ability to schedule their equipment for many years, more recently equipment can be connected (wired or wirelessly) and controlled from one central point, responding to changing conditions inside and outside the building.

In the commercial building sector, energy savings are often only one consideration in the smart technology decision-making process. Nonenergy benefits, such as improvement in the productivity of office workers or the health of hospital patients, are frequently as important to building owners as energy savings, or even more so. Other factors that influence their decision to invest in smart technologies include the building type, ownership structure, and available budget.

Of the 18 quadrillion Btus of energy consumed annually by commercial buildings, the office, mercantile, lodging, and health care sectors together use roughly 50%. Each of these sectors accounts for a substantial portion of total buildings and floor area as well.

Understanding the technologies already present in these sectors helps shape recommendations for installing smart technologies. For instance, almost three-quarters of the health care sector uses a building automation system. As a result, this sector might be better prepared to install advanced smart technologies and analytics than the lodging sector, in which less than 40% of buildings contain a building automation system.

So far, the buildings that have embraced smart technologies are primarily the large showcase buildings with sufficient budgets to be early adopters. Although they provide great case studies, they typically represent only a small portion of the market. Subsectors like Class B offices, small chain and independent retail stores, middle-tier franchise hotels, and regional nonteaching hospitals must also embrace smart technologies to truly influence the commercial building sector. Within these subsectors, the addition of smart technologies will save an estimated 8–18% of total building energy consumption and provide a host of nonenergy benefits.

OFFICES

Offices represent the largest commercial building sector in terms of energy consumption, number of buildings, and floor area. Office buildings have a wide range of sizes, classifications, and lease structures, which will determine the energy-efficient upgrades that are possible for a given building. For instance, large Class A offices in the downtown areas of major cities may have more flexibility to install smart technologies like energy management and information systems and HVAC system controls.[1] Class B and C office buildings may not have the capital to invest in these types of systems but could still benefit from less costly technologies like advanced power strips at employee workstations.

The growing trend of telecommuting means that the modern office worker is not always physically present in the office. Occupancy sensors, which continue to fall in price and increase in capabilities, can help offices take advantage of this absence of employees from work spaces and conference areas. Paired with smart thermostats or other HVAC controls, such sensors can be used to reduce conditioned and ventilated air to low-use or unoccupied areas of the office. Some tenant energy management systems even solicit occupant feedback, which can save energy, reduce maintenance costs, and improve comfort. Smart lighting controls can reduce or turn off lighting when employees are not present. In addition, smart outlets and advanced power strips can control employee workstation and office equipment plug loads when they are unused. The average office building can save 18% of its whole-building energy use through the installation of smart technologies.

Smart technologies provide nonenergy benefits that may make them more appealing to office owners and managers. Studies suggest that improved lighting and ventilation can help raise employee productivity. Employees make up the largest cost in an office building, so this can be especially compelling to an office manager. Insights based on smart building data can also help a company optimize the office floor plan. This, in turn, can improve a company's bottom line and increase the value of the building. Improving asset value can be a major selling point for smart technologies in office buildings.

RETAIL STORES

Like offices, retail stores present different opportunities for smart technologies to save energy, depending on the store's size and ownership. With the growing popularity of e-commerce, some people may think brick-and-mortar stores are a thing of the past. However it is more accurate to think of them as simply undergoing a change. Rather than just being a building with shelves stocked full of goods, the store of the future will focus on customer experience and engagement.

Embracing smart technologies can help propel retail stores into the future. For example, most stores use packaged rooftop HVAC units. When these units are equipped with the proper actuators and controls, they can be directed through smart thermostats or energy management and information systems. Since retail stores often operate within small margins, a cloud-based energy management and information system may be more affordable than a wired system. In addition, lighting is a major energy user in buildings, and smart lighting controls can help reduce this cost. Many retail stores still use relatively inefficient lighting, such as linear fluorescent fixtures, and these stores can benefit from an

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[1] Class A buildings are larger, offer more amenities, and command higher rents than Class B and C.

LED retrofit that includes lighting controls. The average retail building can cut its whole-building energy use by 14% through the installation of smart technologies.

In implementing smart technologies, retail stores face challenges that include financing and avoiding cybersecurity hacks, the costs of which can hurt the business's bottom line. However smart technology's ability to tightly control lighting and temperatures can enhance the customer experience, which may be an important benefit for storeowners.

HOTELS

The average hotel is of medium size and franchised. While such hotels may operate with a limited budget, they have the same goal as all hotels, from small roadside establishments to luxury resorts: providing the best possible experience for their guests. With more than one-third of guest rooms unrented on average, hotels present a great opportunity for smart technologies to save energy.

Hotel owners can truly realize the benefits of smart technologies if they have an energy management and information system that is connected to the guest check-in system. When these systems detect that a room is unrented, HVAC and/or lighting can be reduced or shut off in that room. In rented rooms, smart thermostats can use occupancy sensors to detect when the guest leaves the room and adjust the temperature and lighting to save energy.

Smart technologies can also save lighting and ventilation energy in hotel conference areas. Like offices, demand-controlled ventilation using carbon dioxide sensors can help cut down on wasted energy from over-ventilation in those areas. Smart equipment can also reduce pool pump operation when a pool is not in use. The average hotel can save an estimated 8% in whole-building energy use through the installation of smart technologies.

Hotels face many barriers similar to those of other commercial building types. Smart technology increases the risk of data breaches, potentially compromising guests' valuable information. In addition, hotel managers can be hesitant to install new technologies that might negatively impact guest satisfaction. However smart technologies will be a key component of future hotels, where apps and automation will be used to customize a guest's experience on the basis of his or her preferences.

HOSPITALS

Hospitals are larger and more energy intensive than offices, retail stores, and hotels. The majority of hospitals are not affiliated with a university (i.e., are nonteaching) and typically prioritize hospital equipment purchases over energy efficiency upgrades. However, since most hospitals have embraced electronic health care management systems, they are better prepared than most sectors to adopt smart energy-saving technologies.

Hospitals contain complex heating and cooling systems. Submetering large pieces of equipment like air handlers, chillers, and cooling towers can help these facilities monitor and control their energy consumption through a central energy management and information system. Hospitals often use steam for purposes like heating water and cleaning medical equipment, and a smart steam trap monitoring system helps ensure that steam energy is not being wasted. Additionally, equipment like MRI machines may be equipped with sleep and low-power modes, which should be enabled when possible. Smart lighting systems can have the dual benefit of reducing lighting energy use and improving patient health. For example, studies show that lighting that cycles in parallel with natural daylight can help increase a patient's comfort and even improve healing. The average hospital can reduce its whole-building energy consumption by an estimated 14% through the installation of smart technologies.

However, for the sake of safety, installing smart technologies in hospitals may require more consideration than in other building types. For instance, to prevent the spread of airborne pathogens, certain parts of hospitals must be pressurized; therefore, reducing HVAC airflow to save energy may not be an option in these areas.

COST AND SAVINGS

Table ES1 lists the smart technologies covered in this report and their relative cost and savings potential for office, retail, hotel, and hospital buildings.

Table ES1. Smart technology costs and savings

Technology	Office		Retail		Hotel		Hospital	
	Cost	Savings	Cost	Savings	Cost	Savings	Cost	Savings
HVAC								
Occupancy-based wireless thermostats	M	H	L	H	H	M	---	---
Learning thermostats	M	H	L	H	H	M	---	---
Submeters (tenant/end-use)	M	M	---	---	---	---	L	H
Advanced rooftop controller	M	H	M	H	---	---	---	---
CO_2 demand-controlled ventilation package	M	H	M	M	L	L	---	---
Electronic window solar film	H	L	H	L	H	L	L	L
Wireless window and patio door contacts	---	---	---	---	M	L	---	---
Electronic control kit	---	---	---	---	M	M	---	---
Smart kitchen hood exhaust controls	---	---	---	---	M	L	L	L
Automated shade system	---	---	---	---	H	L	L	L
Wireless steam trap monitoring	---	---	---	---	---	---	M	H
Upgrade from pneumatic to electronic controls	---	---	---	---	---	---	H	H
Wireless pneumatic thermostats	---	---	---	---	---	---	H	M

Technology	Office		Retail		Hotel		Hospital	
	Cost	Savings	Cost	Savings	Cost	Savings	Cost	Savings
Combined HVAC and lighting								
Wireless passive infrared ceiling occupancy sensors	---	---	---	---	M	M	---	---
Wireless/batteryless infrared ceiling occupancy sensors	---	---	---	---	M	M	---	---
Lighting								
Smart lighting controls (sensors, retrofit kit, wireless gateway)	H	M	H	H	H	L	H	L
Exterior lighting controls	L	L	L	L	M	L	L	L
Cat-6A cabling	---	---	---	---	---	---	H	L
EMIS								
Cloud-based energy management information system (EMIS)	Varies	H	Varies	H	Varies	H	Varies	H
Tenant comfort feedback system	N/A	H	---	---	---	---	---	---
Networked guest room building automation system	---	---	---	---	H	M	---	---
Other								
Tier 1 advanced power strips	L	M	L	L	---	---	L	L
Tier 2 advanced power strips	M	H	L	L	---	---	L	L
Smart plugs	L	L	L	L	L	L	L	L
Vending machine controls	L	L	L	L	L	L	L	L
Distributed energy smart inverter	---	---	H	H	---	---	H	M
Refrigeration system controls	---	---	M	M	---	---	L	L
Smart pool pump controls	---	---	---	---	L	L	---	---

L = low, M = medium, H = high. See Appendix A for cost and savings calculation methodology.

RECOMMENDATIONS

Energy efficiency program administrators should devote more resources to designing smart technology initiatives. Rather than considering smart technologies only for custom offerings, they should design prescriptive programs to support them. As an example, the New York State Energy Research and Development Authority (NYSERDA) has implemented a successful program around real-time energy-monitoring systems. However smart building programs like this one are still rare.

Program administrators struggle to incentivize smart building technologies because their energy savings vary with building type, occupant habits, climate fluctuations, and other factors. Addressing this problem will require data-driven solutions. Leveraging data that smart buildings are already collecting through energy data reporting could help advance the smart building industry. Once program administrators are able to estimate smart technology energy savings from thousands of data points rather than a few case studies, they will have the certainty they need to develop effective programs. These might include prescriptive rebates based on proven average savings or enhanced custom programs that combined up-front payments with ongoing earnings for actual building-specific performance (e.g., a fixed payment for each kWh saved).

Transforming the smart building market will require collaboration among program administrators, industry, and government. Industry input is key to helping government develop regulations that protect proprietary information and are fair to all manufacturers. Administrators can identify the data points they need and use them to help develop effective smart building programs. Continued government research into advanced sensors and controls can help introduce new technologies into the market and lower the costs of existing ones. Government, industry, and program collaboration can also help overcome smart buildings barriers like interoperability and cybersecurity.

Introduction

Systems like lighting, HVAC, and security are interconnected in smart commercial buildings. Building operators use data collected by sensors to optimize operations and energy consumption, and automation is often used to control certain building functions. For example, algorithms might automatically adjust a hotel guest's room to her preferred temperature settings at check-in, or they might dim the hallway lights in a hospital during peak electricity usage to prevent blackouts.

Smart technologies increase a building's energy efficiency in a variety of ways. Occupancy sensors can control HVAC, lighting, and plug loads to cut energy use when offices or rooms are vacant. Smart window shading can respond when it senses sunlight to reduce cooling costs. Smart plugs can be programmed to automatically shut off when nonessential equipment has been in standby mode for a preset amount of time to reduce plug load energy use. Fault detection and diagnostic algorithms can locate and prioritize equipment inefficiencies and malfunctions for the user (or perhaps the automation system) to correct. Smart systems can provide building operators with real-time energy consumption data to help them identify savings opportunities. On a larger scale, smart buildings have the potential to help quantify energy savings and transform the energy efficiency industry.

Our previous report, *Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings* (King and Perry 2017), introduced the topic of smart building technologies in commercial buildings. The report described the most commonly installed technologies, their energy and nonenergy benefits, and the opportunities they offer for greater insights into building energy, fault detection, and automation. However barriers to implementation, like unclear energy savings, equipment interoperability issues, and cybersecurity risks, prevent many building owners from investing in these technologies. We recommended that program administrators use incentives to encourage the adoption of smart technologies. We also suggested that the smart buildings industry would benefit from further research and demonstration projects that measured energy savings.

This report investigates key commercial market segments that we only touched upon earlier. We take a deeper dive into the commercial sectors that can benefit the most from smart technologies: office, retail, hospitality, and health care. Leaders in each of these industries are already starting to adopt these technologies, typically in large "showcase" buildings. Here we seek to understand how to reach *all* varieties of these building types, even those with small budgets. Since every sector has its own unique business goals, stakeholders, barriers, and opportunities, we recommend different smart technologies and approaches for each of them.

This report is intended primarily to provide a framework for program administrators who may be considering creating new smart building programs or incorporating smart technologies into their current programs. The report could also be useful to building owners or operators interested in understanding the smart technologies that may be effective in their buildings. Case studies highlight specific applications of some of these technologies. Additionally, we outline some nonenergy benefits of smart technologies, which could be used to persuade upper management (such as a chief financial officer) to invest in smart technologies. We conclude the report with a set of recommendations for program administrators, government, and industry.

This is mostly a report about current trends, but we also include some speculation on the future. We identify today's smart buildings by their ability to connect, provide data, detect faults, and connect the dots within and across systems. Future smart buildings, however, may be characterized by their ability to learn, adapt, and adjust to various conditions with little human intervention. Some industry experts feel that our society is starting to enter a new period in which the Internet of Things will revolutionize the way humans live.

> "Decades from now, when historians write the story of technological evolution, they will argue that the moment the Internet became a ubiquitous force in the world was when we started integrating it into everything we did." (Case 2016)

Methodology and Scope

Our research for this report consisted of a literature review and expert interviews. Our sources for the former included government research, peer-reviewed journals, university publications, manufacturer brochures, industry studies, conference presentations, and other relevant materials. We also incorporated the perspectives of utility program coordinators, smart technology researchers and manufacturers, corporate energy managers, and other experts.

One of the challenges of writing about smart technology is defining what makes a building or device smart. Read any of the dozens of reports about the industry and one will find dozens of definitions. In addition, the meaning of *smart* changes as we move from system to building to portfolio to city level.

Since future buildings will include an ecosystem of linked technologies, connectedness is central to our own definition. A $75 photo sensor turns off outside lighting when it detects daylight, but is it smart? For the purposes of this report, it is not. We limit our use of the term *smart* to components that are connected or have the ability to be, either through a wired link or through wireless protocols like Wi-Fi, Bluetooth, Zigbee, or Z-Wave. Although some technologies like demand-controlled ventilation have existed for decades without necessarily being connected to a central system, we include them because they have the potential for such connectivity. On the other hand, we exclude technologies like phase-change materials, which could be considered smart but are not connected.

This report starts at the building level for each of the four sectors, providing an overview of that sector's characteristics. Then it zooms in to the smart component level, providing the best publicly available cost and savings data. Although our primary goal is to highlight the energy savings that smart buildings can achieve, we also explore some of the nonenergy benefits of smart technologies (e.g., improving customer experience or patient health). Our research shows that these nonenergy benefits are among the strongest selling points for smart technologies in certain sectors. According to Jason Hartke of the US Department of Energy (DOE), some of the best smart technologies successfully straddle several objectives simultaneously (J. Hartke, commercial buildings integration program manager, DOE, pers. comm., August 9, 2017).

Another focus of our research was determining the key decision makers for each sector. In many cases, a relatively small number of individuals can be targeted to influence smart technology in these commercial sectors, and we tried to address this when possible. For instance, we attempted to differentiate between influencing small, owner-occupied buildings, mostly at the local level, versus large commercial chains, more often at the national level.

To describe technologies that connect, evaluate, automate, optimize, and/or communicate with building systems, we mostly use the terminology found in King and Perry (2017), which was derived from the Lawrence Berkeley National Laboratory's Technology Classification Framework guidelines (Granderson 2013). We use the term *energy management and information system* (EMIS) to describe any system that collects data or manages energy in a building. The traditional *building automation system* (BAS), which provides basic controls and often limited data, falls under the umbrella of EMIS. An *energy information system* (EIS) typically provides real-time data analytics, often through the cloud. *Automated fault detection and diagnostics* (AFDD) technology finds inefficient operations or malfunctions in the system and alerts the user. In reality, most systems are a combination of at least a couple of these categories, which is why we refer to most systems as EMIS. Refer to Appendix B for our methodology for determining the EMIS cost.

This report contains many tables that list technologies and offer a range of costs and savings. In an attempt to simplify the tables, we report whole-building costs and savings, designated as low, medium, or high. These designations provide a general guideline for whole-building costs and savings; how they were derived is detailed in Appendix A. Note that this report includes only those measures that are generally cost effective on a life-cycle cost basis. Therefore a "high" cost is a relative term and does not imply lack of cost effectiveness.

Additionally, this report excludes rarely used smart technologies. For instance, an owner of a very small commercial building could potentially install residential-style smart lights, with controls embedded in each lamp, and control them through a smart home system. However these systems are infrequently installed in commercial buildings and are not included in this report.

Commercial Buildings Sector

SECTOR IN GENERAL

As of 2017, the US commercial building stock consumes approximately 18 quads of energy annually (EIA 2017a). According to the *2012 Commercial Building Energy Consumption Survey* (CBECS), the office, mercantile, lodging, and health care sectors account for approximately 45% of all US commercial building energy consumption, as shown in figure 1.

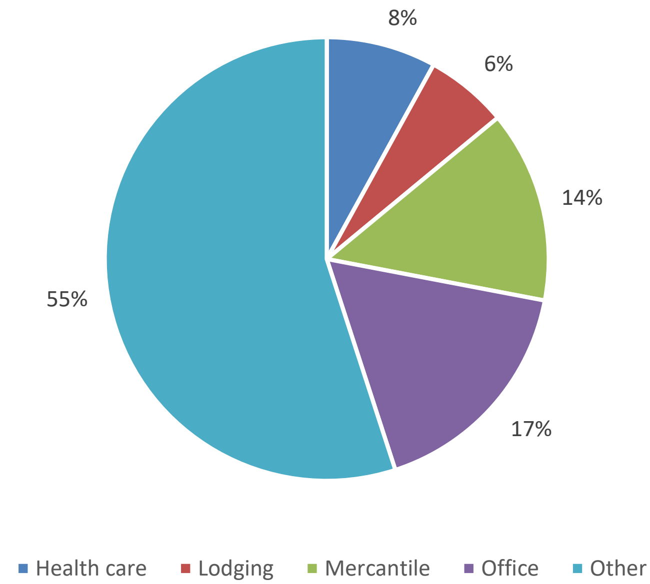

Figure 1. US commercial building energy use by building sector. *Other* includes education, food service, public assembly, warehouse, and other building types. *Source:* EIA 2017b.

Offices are the largest sector in terms of energy consumption, number of buildings, and floor area. According to CBECS, the office sector consumes roughly 3 quads of energy each year and is composed of about 16 billion square feet of space across more than 1 million buildings, almost one-fifth of the total number of commercial buildings. Buildings in the office sector may have installed HVAC and lighting controls (perhaps scheduled through a building automation system) but are unlikely to have installed demand-controlled ventilation or plug load controls. This is noteworthy, since of the four largest commercial building sectors, offices stand to gain the most from plug load controls due to the large number of computers, monitors, servers, and other office equipment.

Per CBECS, at 11 billion square feet, the mercantile sector has the second-largest footprint, mostly spread over small and medium-size buildings. At 2.5 quads, it consumes almost as much energy as the office sector. Surprisingly, 76% of the mercantile sector is reported to have installed lighting controls, a proportion twice as large as the office sector's and five times larger than that of lodging or health care.

Of the four largest sectors, lodging uses the smallest amount of energy, 1.2 quads per year, and occupies a relatively small number of medium-size to large buildings. At the same time, lodging is less likely than the other sectors to have installed automation and controls, so it represents an interesting opportunity. Compared with office and mercantile, lodging uses a disproportionately high amount of natural gas and could be a target for smart natural gas technologies.

Although the health care sector represents the smallest footprint at 1.6 billion square feet, its energy consumption is disproportionately high at 1.5 quads annually. This is due to the high energy intensity of hospitals, which make up the largest part of the health care sector. Because of the computerized and automated nature of hospitals, the health care industry as a whole is the most likely to have adopted a building automation system. In addition, like lodging, health care uses a relatively high amount of natural gas.

The remaining 55% of the energy used by commercial buildings is consumed by education, food service, and warehouse facilities, among others. We do not explicitly cover these sectors in this report; however many of the smart technologies outlined here can benefit these other sectors as well.

Table 1 presents data on characteristics, energy use, and automation for the four largest commercial building subsectors.

Table 1. Commercial building sector statistics

	Office	Mercantile	Lodging	Health care
Building characteristics				
Number of buildings (thousand)	1,000	600	160	160
Floor area (billion ft^2)	16	11	5.8	1.6
Energy consumption				
Total energy consumption (quads/year)[a]	3.0	2.5	1.2	1.5
Electricity consumption (quads/year)	2.6	2.2	0.9	1.1
Gas consumption (trillion Btus/year)	280	290	220	270
Automation and controls[b]				
Has building automation system	52%	55%	38%	73%
Lighting controlled by automation system	31%	76%	14%	15%
Uses demand-controlled ventilation	7%	10%	6%	9%
Uses plug load controls	2%	5%	4%	2%

[a] Based on source energy, which includes losses from generation of electricity. [b] Percentage of total floor area, not the number of buildings. These characteristics from the 2012 CBECS are used as a proxy measurement of smart buildings. The existence or absence of automation and controls does not necessarily reflect a building's smartness. *Source:* EIA 2017b.

SUBSECTORS WE FOCUS ON

This report is focused on subgroups within the office, mercantile, lodging, and health care sectors. While we understand that smart technologies can potentially affect all types of buildings within a sector, there are particular subsectors within each that provide greater opportunities for energy savings than do others. Our recommendations are not limited to those particular subsectors, however; smart technologies that we recommend for each of them may also apply to others. For instance, a university might be interested in applying a technology we recommend for a hotel to its dormitories.

Each sector is undergoing profound changes, mostly as a result of rapidly advancing technology. These changes are often happening independent of energy efficiency gains that the new technologies may provide. However each sector we analyze in this paper has a unique opportunity to leverage its adoption of various technologies to include energy-saving smart technologies.

Offices. The office landscape has changed with the advancement of audio and video technologies that give employees the option to telecommute. When employees choose to work from home, smart technology and strategic office layout can help reduce energy consumption in unoccupied areas. Additionally, office managers are starting to learn that some smart technologies can help improve worker productivity and comfort. Class A buildings typically have the biggest budgets and are more likely to be early adopters of smart technologies. In this report, we focus on ways to incorporate smart technologies into Class B offices, which represent medium-budget buildings, and to an extent Class C as well.

Retail. With growing competition from the online market, retail stores are starting to focus more on enhancing customer experience. Some smart technologies, like smart lighting controls, can both enhance customer experience and save energy. Freestanding retail stores typically have greater control over their energy than those in strip and enclosed malls and are the focus of this report. Because of higher process and refrigeration energy consumption, food service and grocery stores are outside the scope of this report, although some smart technologies may be applicable to them.

Hotels. Similarly, hotels invest in technology to improve customer experience. In recent years, some hotels have begun to provide customers with a smartphone app that allows them to check in and control room temperature. These technologies can save energy when tied to controls that shut off HVAC and lighting when the guest leaves the room. Due to their interest in improving guest comfort and their larger budgets, hotels offer a bigger opportunity for smart technologies than do other lodging types, such as motels and dormitories.

Hospitals. Almost all hospitals have converted to computerized systems and rely heavily on them to track patient records, scheduling, and many other hospital functions. This being the case, hospitals are already well positioned to take advantage of smart technologies that provide data they can use to cut down on energy consumption. Large teaching hospitals are more likely than smaller-budget regional hospitals to have already adopted smart technologies, so we focus on the latter in this report.

Table 2 lists the subsectors we focus on in this report, our rationale for choosing them, and our estimates of the average potential energy savings for buildings in each sector. Refer to Appendix C for the methodology used to estimate average savings.

Table 2. Commercial building subsectors in this report

Sector	Subsector focus for report	Rationale	Estimated average savings per building
Office	Class B	Class B offices are often overlooked in favor of Class A properties, which typically have more resources. They are more likely to adopt smart technologies than Class C.	18%
Mercantile	Retail stores (excluding those in malls)	Greater savings opportunities are available in big box stores than in shopping malls and strip malls. Grocery stores have an energy use pattern different from that of retail stores and are not a focus of this report.	14%
Lodging	Hotels	Unoccupied and unrented guest rooms present an opportunity for energy savings. Chain and franchise hotels are more likely to adopt smart technologies than independent hotels and other lodging types.	8%
Health care	Nonteaching hospitals	Hospitals are more likely to adopt smart technologies than medical offices or walk-in clinics. Nonteaching hospitals are often overlooked in favor of large university teaching hospitals, which typically have more resources.	14%

Class B Offices

Composed of more than 1 million office buildings and 16 billion total square feet, the US office sector uses more energy than any other segment of US commercial buildings. Figure 2 shows relevant statistics for the US office sector.

1 million	office buildings
16 billion	total square feet
16,000	average size (square feet)
67	average site energy use intensity (kBtu/sq ft)
42%	use a packaged rooftop unit HVAC system
61%	Class B and C properties (suburban areas)
64%	all or partially leased to tenants
89%	building owner responsible for operation and maintenance of energy systems
2x	more renovation than new construction

Figure 2. US office sector by the numbers. CBECs calculations based on building floor area, not number of buildings. *Sources:* Number of buildings, square feet, average size, rooftop HVAC systems, leased to tenants, energy system maintenance: EIA 2017b, Site energy use intensity: EPA 2016, Class B and C properties: Newbold 2017, Renovation and construction: Dill, Durham, and Foley 2017.

Factors like size, usage, and owner/tenant structure all affect how likely an office building will be to implement energy-efficient upgrades. The average office building is small at 16,000 square feet, with a moderate site energy use intensity (EUI) of 78.[1] Though many energy efficiency programs focus on large office buildings, in fact the majority of office floor area is in either small or medium-size buildings. This is important because, unlike large office buildings, smaller buildings typically do not have energy management systems, making them an untapped market segment for smart technologies. In addition, small offices typically use small commercial HVAC equipment like rooftop units or even residential HVAC systems (Shapiro 2012). These provide unique opportunities for smart control energy savings.

In terms of office classifications, Class A buildings are typically larger, offer more amenities, and command higher rents than Class B buildings, which in turn are larger, offer more amenities, and command higher rents than Class C. Class A building owners tend to pay much more attention to energy efficiency, and an important goal for program administrators is finding ways to reach Class B owners (Nadel and Stickles 2017). From the available data on the US office sector, we know that in suburban areas, Class B and C properties make up the majority of office buildings, at 61%. Downtown areas of most cities usually contain a greater proportion of Class A buildings (Newbold 2017).

Classifying office buildings is more of an art than science. For instance, "a Class B in New York City might be considered a Class A in Phoenix" (Bell, Sienkowski, and Kwatra 2013). In addition, the ratio of Class A, B, and C buildings varies depending on the city. For example, a majority (69%) of Austin's downtown buildings are Class A, while only half of its suburban properties are (Holm 2017). Milwaukee contains a smaller ratio of Class A buildings in both areas, a little less than half downtown and 42% in the suburbs (Colliers International 2017). It is worth noting that while Class A properties are, on average, larger than Class B, this is not a fixed rule.

Historical data show that before the 2008 recession, the US office market focused primarily on the construction of new office buildings, with more than twice as many new construction projects as renovations. However, after the recession, this trend was reversed; as of late 2016, there were nearly twice as many renovations as new construction projects (Dill, Durham, and Foley 2017). Today's propensity to renovate office space combined with the office sector's increasing use of technology provides an opening for the deployment of smart energy-saving technologies.

Split-incentive problems can arise in commercial office buildings. In 64% of office floor area, a building owner leases out all or part of his space to tenants. At the same time, in 89% of office space, the owner is responsible for maintaining the energy systems (EIA 2017b). If the tenant pays for her own utilities, an owner often lacks motivation to upgrade building systems because it may not translate to increased rent. If the owner pays for utilities, a tenant may be less interested in energy-saving smart technology and more resistant to

[1] Site EUI is reflects energy use at the building, measured in thousand Btu per square foot. It does not include the energy used to generate electricity at the power plant.

disruptive changes (Bell, Sienkowski, and Kwatra 2013). Furthermore, in many markets, so-called triple-net leases are used. Leases under this structure include taxes, insurance, and maintenance costs (including energy). Any changes in these three costs are passed on to tenants, reducing the incentive for owners to make energy-saving investments. DOE and organizations like the Institute for Market Transformation seek to overcome these problems through green leases, which are structured to incentivize energy upgrades (Feierman 2015).

The average office uses most of its energy to heat, cool, and ventilate, but a significant amount is used for plug loads like computer workstations and lighting. We estimate that smart building technologies can save the average office 18% in HVAC, 28% in plug load, and 33% in lighting energy, as shown in Figure 3.

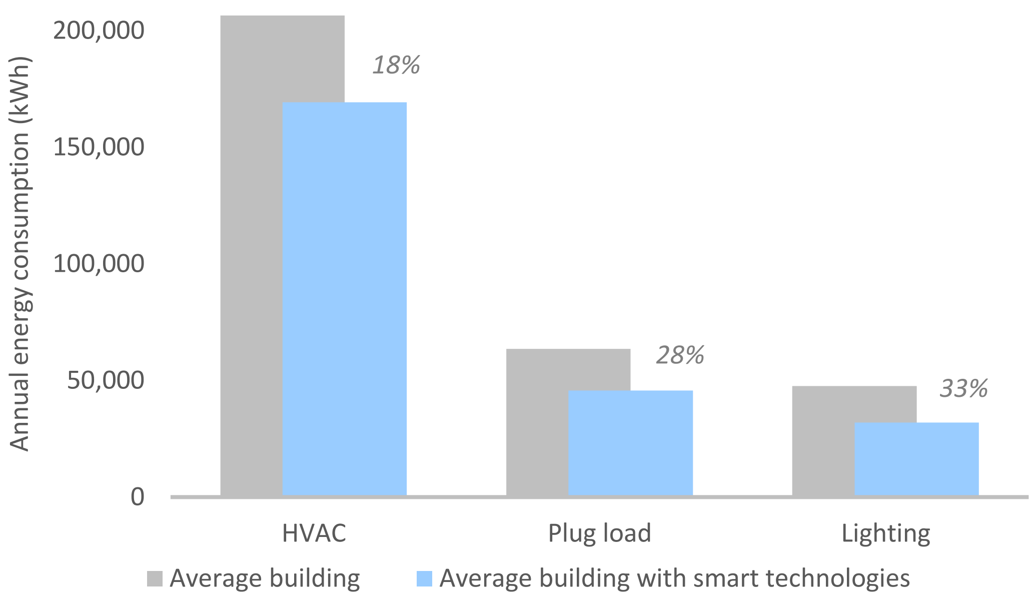

Figure 3. Average office energy savings with smart technology

SMART TECHNOLOGY OPPORTUNITIES

HVAC

Smart HVAC options change depending on an office's size and classification. In small and medium-size office buildings, thermostats are often used to control temperatures. For a relatively small cost, replacing existing thermostats with occupancy-based wireless thermostats can save 5–10% of HVAC energy costs if programmed to allow the HVAC system to reduce its operation when the building or zone is unoccupied (DOE 2017e). For a little more investment, a user might consider installing a learning thermostat. DNV GL installed Nest Learning Thermostats in commercial buildings as a trial to see if they saved more energy than non-learning programmable thermostats. Preliminary evaluations suggested that it is difficult to prove energy savings over a regular smart thermostat; however DNV GL speculated that user satisfaction with the product's usability and dashboard interface, as reported in surveys, could be enough to justify the additional cost (Russell 2014).

As previously mentioned, tenants who do not pay for energy have no direct financial incentive to save it. The owner of an office building with multiple tenants would benefit from installing separate submeters to make each tenant accountable for their own energy consumption. The cost of a networked tenant submeter ranges from approximately $2,000–4,000 (GSA 2013). Jurisdictions and owners are starting to recognize the importance of submetering and are beginning to make it a requirement. For instance, starting in 2025, New York City will require the installation of submeters in tenant spaces greater than 10,000 square feet (NSTC 2011).

Since more than half of office buildings use packaged rooftop HVAC units, another common opportunity for office buildings are advanced rooftop unit (RTU) controls, which have the potential to cut HVAC energy use by 20-40% (Wang et al. 2013). Much of the savings from a smart RTU upgrade comes from the use of economizer controls, which employ temperature sensors or real-time weather data to take advantage of "free cooling" from optimal outdoor temperature and humidity conditions. For the RTU controller to achieve maximum energy savings, the RTU's fans must contain variable-frequency drives (VFDs) to reduce fan speed, and its dampers must have actuators to allow them to modulate. If not already installed, these components represent an additional cost. Companies that offer advanced RTU controllers range from NexRev, which is less expensive but only controls VFDs, to Transformative Wave Tech, which is more expensive but includes a greater number of controls as well as cloud-based analytics.

The decision to upgrade an existing RTU with smart controls or replace it with a new unit with embedded smart controls could be difficult for a building owner.[2] DOE's Advanced RTU Campaign attempts to help building owners with this decision by providing resources like checklists and a decision tree (DOE 2017c). Through its advanced RTU program, Massachusetts-based Mass Save discovered that many existing RTUs did not deliver enough outside air to meet code (A. Kulkanri, engineering supervisor, Eversource, pers. comm., July 24, 2017). Although in these cases smart controls did not necessarily save energy, they helped identify underventilated spaces and increased airflow to improve the health and comfort of building occupants.

Demand-controlled ventilation (DCV) has existed for years, but smart technologies are giving it a facelift. DCV typically uses carbon dioxide sensors, sometimes coupled with occupancy sensors, to detect a building's occupancy and adjust ventilation accordingly. Though these systems are usually costly to install, wireless CO_2 sensors, which are increasingly affordable, can make the most sense in a building retrofit. Currently, a wireless CO_2 sensor with a battery life of 10 years is available for $30–50 per sensor (B. Coflan, vice president, digital services platform: IoT and digital transformation, Schneider Electric, pers.

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[2] In many cases, purchasing new equipment with smart controls will be more cost effective than retrofitting existing equipment. For an incremental cost, most manufacturers offer a smart version of their equipment. As with automobiles, almost all of which typically now contain 50–100 microprocessors, sensors and controls embedded into existing HVAC equipment will become the norm over time (C. Nesler, vice president, global energy and sustainability, Johnson Controls, pers. comm., September 7, 2017).

comm., October 31, 2017). Since DCV is most cost effective in spaces with unpredictable occupancy, the best use in an office setting is in conference rooms. These spaces typically cycle between occupied and unoccupied throughout the day. When sensors detect that the space is unoccupied, the ventilation can shut off to save energy, and then it can ramp up once it becomes occupied. Demand-controlled ventilation can save an estimated 21% of the energy used to move outside air into a building and to heat or cool it (Seventhwave 2016).

Finally, smart solar film, which can be programmed to adjust according to the amount of incoming sunlight, can help reduce cooling load by 10–20% (Lutron 2014). These films can easily retrofit existing windows. Unlike passive films, smart window films enable the user to control dimming settings electronically through Wi-Fi, apps, and other connected means.[3]

Table 3 lists smart heating, ventilation, and air-conditioning options for offices.

Table 3. Smart HVAC technologies for offices

Technology	Responsible party	Cost level	Estimated cost	Savings level	Energy savings
Occupancy-based wireless thermostat	Tenant	Medium	$150–330/thermostat	High	5–10% HVAC
Learning thermostats	Tenant	Medium	$250–350/thermostat	High	10–30% HVAC
Networked tenant submeters	Owner	Medium	$2,000–4,000/tenant	Medium	2.5–5% whole building
Advanced rooftop controller (retrofit)	Owner	Medium	$2,000–4,000/RTU	High	20–40% HVAC
CO_2 demand-controlled ventilation package	Owner	Medium	$1–3/cfm designed outside air[a]	High	21% outside air, 10% heating and cooling
Smart window solar film	Tenant	High	$15–20/ft^2	Low	10–20% cooling

Excludes installation costs. Cfm = cubic feet per minute. Designed outside air is the amount of ventilation air (measured in CFM) an engineer designs for a building based on parameters like floor area and expected occupancy. *Sources:* Wireless thermostat cost: Pistochini, Heinemeier, and DeJean 2008. Wireless thermostat savings: DOE 2017e. Learning thermostat cost: ACEEE product cost analysis from Lodgemart.com. Learning thermostat savings: ACEEE analysis. Networked tenant submeter cost and savings: GSA 2013. Advanced rooftop controller cost and savings: Wang et al. 2013. DCV package costs and savings: Seventhwave 2016. Solar film cost: GSA 2014. Solar film savings: Lutron 2014.

Lighting

A typical commercial building lighting retrofit will consist of three main components. First, sensors that detect occupancy, vacancy, or daylight can be used to enable lighting only as needed and shut it off when it is not. Next, electrical or mechanical components can be added to commercial fixtures to enable use of controllable lamps, usually light-emitting

[3] Similarly, smart glass adjusts its tint to block the sun's radiation and reduce cooling demand. While this product can make sense to install in a new building, its high cost will rarely be justified in a retrofit.

diode (LED) lamps, with the solution dependent on factors like the existing lamp type and the user's preferred type of control. While controllability is often achieved by retrofitting the existing fixture with a component (i.e., driver, ballast, or module) that can turn the light on and off, dim it, and/or even tune the color temperature, other solutions require an entirely new fixture.

Finally, gateways or hubs are used to relay information between the lighting controls and sensors through protocols like Zigbee or Z-Wave. In addition, these devices can gather data on lighting operation. A user dictates lighting controls through these gateways, whether it is via an app on a phone or through a central BAS. One gateway can typically communicate with a number of lights. For instance, one of Lutron's hubs can connect with as many as 200 fixtures within a 100-foot radius (C. Cook, senior systems applications engineer, Lutron Electronics, pers. comm., August 28, 2017). We estimate these smart lighting controls can cut lighting energy consumption by an average of 20–40% (CLTC 2015).

A property manager can also invest in controls for exterior lighting, which includes illumination of the outside of the building and the parking lot. Many retail properties leave on exterior lights 24-7; controls can potentially cut exterior lighting energy consumption in half. Exterior lighting retrofits are similar to typical interior lighting retrofits, with control modules, sensors (typically motion and/or daylight), and gateways added. We estimate a retrofit of an existing outside lighting system to cost $200–400 per fixture.

Building owners concerned about the up-front cost of a smart lighting retrofit may consider investigating the lighting-as-a-service model, part of the growing "as a service" industry. These services retrofit a building's existing lighting system with efficient lamps and controls at no up-front cost. Energy savings from the upgrade are then used to pay off the lighting retrofit over the terms of the agreement (Campbell, Calhoun, and Mandel 2017).

King and Perry (2017) estimated a cost of $2–4 per square foot for advanced lighting controls (minus installation costs). In this report, we break down different component costs. Table 4 provides estimated smart lighting technology costs and savings for office buildings.

Table 4. Smart lighting technologies for offices

Technology	Cost level	Estimated cost	Savings level	Energy savings
Occupancy/vacancy/daylight sensors	High	$20–100/sensor	Medium	20–40% lighting
Smart lighting retrofit kit		$50–200/fixture		
Wired or wireless gateway/hub		$300–1,000/ gateway		
Exterior lighting controls	Medium	$200–400/fixture	Low	30–50% exterior lighting

Excludes installation costs and lighting control EMIS. Exterior lighting controls include wireless control module, sensors, and gateway. *Sources:* Sensor cost: ACEEE product cost analysis from Grainger.com. Retrofit kit cost: CLTC 2015. Gateway/hub cost: C. Cook, senior systems applications engineer, Lutron Electronics, pers. comm., August 28, 2017. Lighting retrofit savings: CLTC 2015; BEEx 2015. Exterior lighting control cost: ACEEE product cost analysis from Grainger.com. Exterior lighting savings: ACEEE analysis.

Energy Management and Information Systems

An energy management and information system (EMIS) provides users with insights to help save energy. Such a system can range from a high-cost, traditional building automation system (BAS) to a low-cost, cloud-based analytics energy information system (EIS). These systems can help save 5–15% of building energy by identifying inefficiencies and equipment faults (Gilliland 2016).

Cloud-based control systems can be especially effective in small or medium-size offices without the staff or expertise to maintain the building's energy systems. Allowing a third-party firm to monitor the building, for instance checking HVAC equipment for malfunctions or setting lighting schedules, can be a cost-effective way to save energy. Cloud-based systems are available from companies such as Ecorithm, BuildPulse, and KGS Buildings. For an office building, split incentives may discourage a building owner from purchasing a cloud-based EMIS if tenants are responsible for their energy consumption. However, in offices in which the owner is responsible for paying the energy bill and maintaining the building's HVAC system, ownership may be more inclined to consider investing in a cloud-based EMIS.

An open-source solution for small and medium-size offices

Purchasing smart devices for specific applications can save energy, but the benefits are compounded if the building is able to tie the devices together through a central dashboard that provides controls and analytics. Often owners of small or medium-size offices consider investing in a BAS or an EIS to be cost prohibitive. Virginia Tech's Building Energy Management Open-Source Software (BEMOSS) seeks to solve that problem.

Developed on the VOLTTRON platform, which runs on small computing devices using minimal resources, BEMOSS was designed as an effective "plug and play" program for buildings with rigid cost constraints. So far, BEMOSS has been successfully implemented in a range of small and medium-size commercial buildings, overcoming interoperability issues and connecting devices like smart thermostats, variable air volume (VAV) boxes on rooftop units, and lighting and plug-load controls (Cork et al. 2016). Deployed in a 40,000-square-foot mixed office and retail building to control seven RTUs using wireless thermostats, BEMOSS saved 10–15% of the building's energy load. (BEM Controls 2017).

Tenants who do not control their own HVAC system may consider other options. For instance, in many office buildings, a tenant HVAC system on the 14th floor might be controlled by a BAS located in the basement. If a tenant is uncomfortable, traditionally he would submit a work order to the building operators to adjust the temperature. This wastes valuable staff time and often causes building operators to over-condition spaces, anticipating that it will prevent occupants from creating additional work orders. One solution for offices that experience this is what can be described as a real-time tenant comfort feedback system. One of the most well-known of these systems, called Comfy, solicits its users' temperature preferences through a simple phone or computer app. Over time, the system aggregates the data and, through machine learning, automatically adjusts zone temperatures to provide a comfortable workspace to employees without over-conditioning, saving as much as 20% of the energy that would otherwise be consumed. Comfy has thus far been used most successfully in single-tenant owner-occupied buildings; however there has also been some success when the system is installed for tenants in leased buildings (E. Eaton, director of strategy, Comfy, pers. comm., August 11, 2017).

Table 5 lists the cost and savings of EMIS-related smart office technology.

Table 5. Smart EMIS technologies for offices

Technology	Responsible party	Cost level	Estimated cost	Savings level	Energy savings
Cloud-based EMIS	Owner	Varies	Initial: <\$0.01–0.40/ft^2 Monthly: <\$0.01–0.10/ft^2	High	5–15% whole building
Tenant comfort feedback system	Owner/ tenant	N/A	N/A[b]	High	15–25% HVAC

Excludes installation costs. We were unable to obtain cost data from Comfy. *Sources:* Cloud-based EMIS cost: Granderson, Lin, and Piette 2013; E. Feeny, director of sales, BuildPulse, pers. comm., July 20, 2017. Cloud-based EMIS savings: Gilliland 2016. Tenant comfort feedback system savings: ACEEE analysis; GSA 2015.

Telecommuting

The greatly improved quality of audio and video communications has resulted in an increase in employee telecommuting and the use of satellite sites (Reed et al. 2004). A study of US Census Bureau data shows that the number of employees telecommuting, defined as the substitution of technology for commuter travel, grew 103% between 2005 and 2014, by which time 20–25% of the workforce reportedly telecommuted in some capacity.

The telecommuting trend can help offices justify smart building upgrades. Since studies show that employees are away from their desks 50–60% of the time, Fortune 1000 companies are starting to revamp their work spaces to reduce energy used to condition air and to light these spaces when they are vacant (GlobalWorkplaceAnalytics.com 2017).

GSA's hoteling approach to telecommuting

As offices continue to experience more vacant space from telecommuting, building owners and managers have the opportunity to allow multiple people to use the same office space at different times. For instance, the General Services Administration (GSA) recognized through studies that its offices are utilized at about 50% on any given day. It decided to implement a "hoteling" approach to take advantage of the vacant space. Employees reserve a space through booking software, both individual spaces and conference rooms. The GSA is then able to decrease its energy costs by reducing lighting and/or heating and cooling in the unused spaces (Coleman 2013).

Other

Since most people now use computers at work, employee workstations represent one of the largest energy-saving opportunities for office spaces. The average office uses 16% of its energy for plug loads (EIA 2017b), although this percentage can be much higher in offices with energy-efficient HVAC and lighting systems. The Department of Energy anticipates commercial building plug and process load consumption to increase by 49% by 2030, compared with an overall building energy consumption increase of 24% (Metzger, Cutler, and Sheppy 2012).

For an employee's workstation, an advanced power strip (APS) is currently the best method to control plug loads, and there are two distinct types available. A Tier 1 APS typically uses a "master device" (e.g., a laptop) to shut off peripheral devices (e.g., a monitor or task light) when the master is off or in sleep mode. Even if a computer is set to an eco-friendly management setting, workstation plug load controls could still cut workstation energy use by an estimated 26% (GSA 2012). A Tier 2 APS goes one step further and uses software to track inactivity on a user's computer. When it senses inactivity, it places computers in low-power mode and de-energizes peripheral devices. Although more expensive, these devices save an average of 65% of the energy used at office workstations (Schantz, Konjkav, and Langer 2017).

For other office equipment, such as printers or coffee and tea brewers, smart plugs can be controlled remotely or set on a schedule to turn the equipment off during non-working hours. An additional benefit of smart plugs is that they enable a user to view power consumption trends over time. Some companies like Ibis and Keewi offer networked plug load controls in which smart plugs installed throughout the whole office gather data on plug load energy consumption. Analyzing the data through central software, an office manager can then make decisions to turn off devices or set them on a schedule.

In addition to the smart device and software methods that can be used to manage computer workstation plug loads, an office manager could consider a purely software solution.[4] Some efficiency program administrators even provide incentives for these solutions. Software platforms include NightWatchman by 1E, Cisco Energy Management, and Power Manager by Verismic.

Vending machine controls can also help reduce the energy consumption of a major plug load. Vending machine controls have an added advantage over plug load controls for vending machines because they can shut off parts of the machine's mechanical system and lighting when they detect that there is no occupancy, instead of just scheduling the machine to turn off at night. Some program administrators provide incentives that vary according to whether the controls are used for a refrigerated (e.g., soda) or unrefrigerated machine.

Table 6 lists miscellaneous smart technologies that could be used for offices.

Table 6. Miscellaneous smart technologies for offices

Technology	Responsible party	Cost level	Estimated cost	Savings level	Energy savings
Tier 1 advanced power strips (workstations)	Tenant	Low	$25–50/strip	Medium	26% workstation plug load
Tier 2 advanced power strips (workstations)	Tenant	Medium	$70–100/strip	High	65% workstation plug load
Smart plugs (kitchen and printer room)	Tenant	Low	$100/120v plug	Low	48–53% kitchen and printer room plug load
Vending machine controls	Tenant/ owner	Low	$180/vending machine	Low	20–25% vending machine electricity

Excludes installation costs. *Sources:* Advanced power strip cost: Harry 2016; Schantz, Konjkav, and Langer 2017. Advanced power strip savings: GSA 2012; Schantz, Konjkav, and Langer 2017. Smart plug cost: ACEEE product cost analysis from Amazon.com. Smart plug savings: Boss 2016. Vending machine control cost: Morton 2012. Vending machine control savings: Bert 2013.

SMART TECHNOLOGY BARRIERS

Traditionally, individuals and organizations promoting energy-efficient technology in offices have focused their efforts on building owners. However tenants also play a crucial role in overall office building efficiency. In buildings that have not submetered tenants and made them responsible for their own energy consumption costs, efforts to save energy face an uphill battle. A building owner could install a state-of-the-art HVAC management and control system, but energy savings could be negated if the tenant keeps the windows open

[4] We did not have enough cost or savings data on workstation software platforms to include them in table 6.

while the HVAC is operating. This would be less likely to happen if tenants paid for their energy usage.

Even if tenant spaces are submetered, it can still be a struggle to encourage tenants to invest in energy-efficient technologies because of the split-incentive problem. In reality, most office tenants are uninformed about the benefits of energy efficiency (DOE 2016a). Since Class B and C buildings are located all over the country and often contain many small tenants, they can be especially difficult to target with energy efficiency efforts. Programs like EPA's pilot ENERGY STAR® certification for tenant space attempts to incentivize measuring energy use and installing energy-efficient upgrades (EPA 2017). However efforts focused on tenants are mostly still in their infancy. Further, the ideal window of time to improve a tenant space, while the space is vacant during tenant turnover, is typically so small that it can be difficult to solicit a bid for smart technologies and persuade a tenant to invest in them.

Treating offices as short-term assets can be another barrier to investing in longer-term energy efficiency projects like smart technologies. One type of organization that purchases and sells office buildings as assets is a real estate investment trust (REIT). Since REITs sometimes buy and sell properties within the span of a few years, they require a short payback period for energy efficiency projects, often two years or less. As a result, REIT decision makers strongly prefer low- and no-cost projects to projects with longer-term savings opportunities. Unfortunately, most smart buildings upgrades require an initial investment and offer a range of possible savings (e.g., 10–30%). The uncertainty of the energy savings further decreases the probability that REIT decision makers will approve major smart building retrofits.

Related Sector: Government

Smart technologies that save energy in office buildings may also be applied to government buildings at the federal, state, and local levels.

Retrofits can be difficult in older, historic government buildings. However even these buildings can install components like advanced rooftop unit controls, smart lighting systems, smart plugs, and advanced power strips to save energy. Additionally, certain buildings may benefit from a tenant comfort feedback system or an office restructuring to accommodate the increasing popularity of telecommuting.

Since energy savings enabled by smart technology is highly situation dependent, guaranteeing a quick payback can be difficult. For instance, if an office installs an EMIS that performs automated fault detection and diagnostics and the system immediately detects a malfunctioning damper that's causing severe air leakage, the system could pay for itself in a matter of months. However, if the system does not spot a major fault until a year later, when equipment starts drifting away from its set points, it may take more than two years for an EMIS to pay for itself. The lack of concrete savings numbers can prevent investment in smart equipment even in cases where it makes the most sense. New subscription business models that involve little to no up-front costs can help minimize this problem. However these "as a service" models for smart building systems are still gaining acceptance in the market.

Class B and C offices face their own set of challenges that are often even more difficult to overcome than those facing Class A properties. First, Class B and C buildings usually have smaller budgets and may even be debt constrained. As a result, investing in smart technology with high up-front costs or long paybacks is usually out of the question. So it may be impractical to think that most Class B and C offices will consider being early adopters of smart technology. The diverse and disaggregated nature of the Class B and C owner network makes this group particularly difficult to reach with suggestions of energy efficiency programs (Bell, Sienkowski, and Kwatra 2013). For many of these properties, the building owner may be more likely than tenants to invest in a smart technology. These properties also typically have less on-site staff than Class A buildings, and thus have fewer people to identify and address problems.

Finally, cybersecurity poses a challenge to smart offices. Researchers recently demonstrated how smart lighting in an office building could be hacked by a drone from a quarter mile away. The team used relatively inexpensive equipment to trick the lighting system with a fake firmware update and took control of the lights on one floor of the building (Seppala 2016). If an attack like this were to happen on a larger scale, it is conceivable that hackers could use smart devices to gain access to an office's database to obtain a company's proprietary information.

NONENERGY BENEFITS

Smart technologies will improve employee efficiency directly and indirectly. Using different types of sensors (e.g., facial recognition, mobile phone GPS), smart security systems can automatically unlock doors for building employees. Smart offices of the future may be able to alert staff when office supplies are running low or automatically call an Uber or Lyft to take an employee to a meeting across town. Smart lighting systems can learn user preferences over time and automatically adjust to create the most comfortable environment for that employee.

A simple rule of thumb can help explain why commercial office owners are so interested in maximizing employee satisfaction and productivity. Commercial real estate company Jones Lang Lasalle popularized the 3-30-300 framework, which suggests that a reasonable proxy for office costs (per square foot) is $3 for utilities, $30 for rent, and $300 for payroll (JLL 2014). In other words, employees are expensive. Office managers who understand the correlation between their employees' well-being and their bottom line are very interested to hear if a technology improves metrics like happiness or reduces employee sick days.

Optimizing temperature and outside air ventilation has been shown to help improve employee productivity by 0.6–7.4% (Loftness et al. 2003). Researchers at Harvard, Syracuse University, and SUNY Upstate Medical University estimated that when ventilation rates in under-ventilated buildings are doubled, at an additional cost of just $40 per person, office productivity increases by $6,500 per employee per year (Allen 2017). Of course, smart ventilation controls can also prevent over-ventilation, which wastes energy.

In the near future, smart HVAC control will be able to more easily address most employee comfort issues. For example, a system can increase HVAC airflow in the afternoon to help workers overcome drowsiness after lunch (Memoori 2015). In addition, increased bluecolored lighting has been linked to office productivity (Wile 2017), and an LED lighting retrofit with color-tuning could enable greater lighting controllability throughout the office.

In addition to increasing worker productivity, smart technologies may add value to commercial properties, both by increasing the selling price of the asset and by commanding higher rents from tenants. Some building owners may be interested in installing smart systems if they can help upgrade their building from Class B to Class A. In addition, smart buildings may be used to enhance a company's brand (D. Cloutier, principal, JDM Associates, pers. comm., September 20, 2017). However the extent of the value that commercial office buildings can capture from smart technologies is currently unclear. One possible future scenario includes tenants who are perfectly willing to pay more for buildings with advanced energy management systems and superior security. In another plausible scenario, smart office buildings become the norm (at least in Class A) and do not command premium rents (Manyika et al. 2015).

The improvement in sensors not only enables energy savings but can influence office planning and design as well. One up-and-coming technology, low-resolution thermal sensors, uses heat signatures to detect the number of people in a room (unlike a passive infrared sensor that just senses whether people are present). This technology provides a building owner with trending data about the specific number and location of people in a building throughout the day, which can in turn help inform office design. For instance, if a 10-person conference room typically has only two or three people in it, an office manager might decide to partition it into two conference rooms (B. Coflan, vice president, digital services platform: IoT and digital transformation, Schneider Electric, pers. comm., October 31, 2017).

DISCUSSION

Offices provide an opportunity for smart technologies to save energy, but the variety of building classifications and ownership structures makes this challenging. In offices with separate tenants, installing submeters will bring to light each tenant's energy use and enable subsequent efficiency efforts. The energy consumption patterns revealed by smart building systems can encourage changes in tenant behavior. For instance, a building owner can use the data to hold energy-reduction competitions.

Finding a way to optimize the heating and cooling of a building space is also critical to saving energy in offices. Depending on the office's HVAC system and lease structure, this could mean installing smart thermostats or smart rooftop unit controls or implementing an energy management system or tenant comfort system. Conference rooms are an especially important area to target, since they are so often over-ventilated. Other smart technologies like advanced power strips and smart plugs can also help manage office plug loads, which are projected to make up an increasingly large percentage of an office's total energy use over time. The future office will use a number of interconnected devices to enhance employee productivity, and improved control over HVAC, lighting, and plug loads will help save energy.

Retail Stores

With announcements of major store closings commonly appearing in the news cycle, one might be tempted to think that brick-and-mortar stores are becoming an outdated business model (Egan 2016). However retail still represents a large portion of the US building stock, occupying more than 10 billion square feet of space. In fact, the United States still has more retail space per capita than any other nation—and more than twice as much as the second-highest country, Norway (Credit Suisse 2017). Although store layouts and specific retailers may change, there is little reason to think that retail stores are going away, since data show that move-ins outnumber move-outs. From Q1 2016 to Q1 2017, retailers vacated 15.1 million square feet of retail space but also moved in to 24.1 million square feet of space (JLL 2017). Figure 4 provides an overview of the retail sector.

558,000	retail buildings[a]
10 billion	total square feet
2x	more US retail space per person than any other country
18,000	average size (square feet)[b]
47	average site energy use intensity (kBtu/sq ft)
15%	owned by 7 largest chain retailers[c]
63%	tenant responsible for operation and maintenance of energy systems[d]
78%	use packaged rooftop unit HVAC systems
6–10	years between renovation

Figure 4. US retail sector by the numbers. [a] Includes both stand-alone stores and strip malls. [b] Excludes strip malls. [c] Largest chain retail stores include Walmart (689.6 million sq ft), Target (240 million sq ft), Macy's (141.9 million sq ft), JC Penney (104.7 million sq ft), Sears (101 million sq ft), Kmart (89 million sq ft), Kohl's (83.8 million sq ft). [d] Includes owner-occupied stores and stores leased to tenants that indicated that the tenant is responsible for energy systems. *Sources:* Number of buildings, total floor area, average floor area, and packaged rooftop unit HVAC system: EIA 2017b. Site energy use intensity: EPA 2016. 7 largest chain retailers: Hartford 2016. Years between renovation: Reed et al. 2004; ACEEE industry interviews.

The average size of a retail store is 18,000 square feet, with a relatively low site EUI of 47 (EIA 2017b; EPA 2016). The top seven retail chains occupy 15% of the floor area of all retail stores, so one could infer that smaller chains and independent stores make up the majority of stores (Hartford 2016).

The majority of retailers, 63%, are responsible for their own energy systems, and 78% of retailers rely on rooftop unit (RTU) HVAC systems to heat and cool their buildings (EIA 2017b). It is important for a retailer to have control over the store's energy systems if he or she wants to purchase smart technologies to reduce energy.

Retail stores tend to undergo renovations every 6–10 years (Reed et al. 2004). Since one of the major concerns around purchasing and installing smart technology is potential disruptions to customers, periods of major renovation are the perfect time for retail owners to install smart technologies, since the retail space will already be in a state of disruption.

Most retail chains, such as Walmart or Target, make decisions to purchase smart technology from the top, and installations are then slated for the stores, most often during scheduled renovations. However some retailers, such as Whole Foods, use a more regional approach (R. King, lead engineer, Target Corp., pers. comm., July 11, 2017).

Most retail stores use the majority of their energy to heat, cool, and ventilate the building, and a significant amount of energy is used on lighting as well. Retail stores also use energy on plug loads, like point-of-sale equipment. We estimate that smart technologies can save the average retail store 15% in HVAC, 30% in lighting, and 25% in plug load energy, as shown in figure 5.

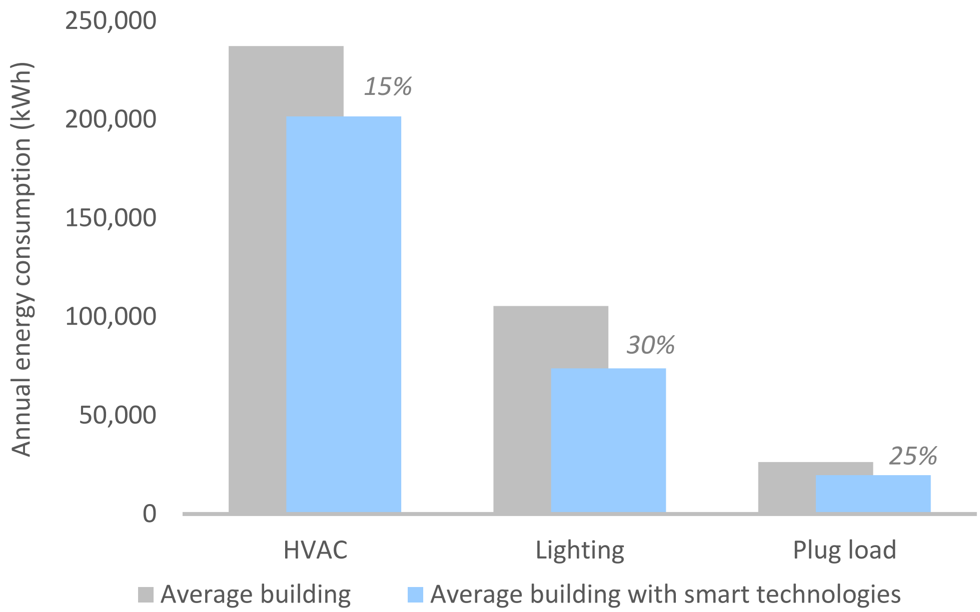

Figure 5. Average retail energy savings with smart technology

SMART TECHNOLOGY OPPORTUNITIES

HVAC

The most appropriate HVAC smart technologies will vary between small shops and larger, big box stores. Smaller retail stores may have the option to install smart thermostats or learning thermostats (such as Nest or ecobee), which may be preferred since they can be controlled through a user-friendly interface. DOE estimates that by giving users the ability to set back temperatures during times when the store is closed, smart thermostats save as much as 10% of heating and cooling energy (DOE 2017e).

By far the most common type of HVAC system found in all sizes of retail buildings is the rooftop HVAC unit. Advanced rooftop unit controllers save energy by directing RTUs to provide conditioned air as needed, taking advantage of moderate outside temperatures with economizer controls and detecting operational faults.

For larger retailers, smart technology can actually operate several units so they work together, instead of individually, which can lead to the units fighting each other. For instance, an average Target store programs its RTUs (typically 12–20 of them) to coordinate with each other and with temperature sensors on the sales floor, so that the units operate at peak efficiency and provide a uniform temperature throughout the building (R. King, lead engineer, Target Corp., pers. comm., July 11, 2017). A number of factors may be considered when deciding whether to retrofit an RTU with smart controls or purchase a new unit. See the office section for a more detailed discussion of smart RTU controls and available resources.

Macy's rooftop unit retrofit

A Washington, DC, Macy's contained two air-handling units, with 400 horsepower of supply and return fans. Though the fan motors were already equipped with variable-frequency drives, the units ran as they were designed, mostly at 100% capacity. The retail store upgraded the dampers and controls and reprogrammed its building automation system to distribute air more efficiently. It also upgraded its lighting. Macy's estimated it saved 30% of its energy consumption through these upgrades (DOE 2017d). Although the store's estimate did not separate the RTU and lighting savings, we calculated that if the RTU controls reduced fan use by 25%, this measure would account for about one-third of the total energy savings, or about 10% on a whole-building basis.

Another smart control choice for RTUs is to install a demand-controlled ventilation package to adjust ventilation based on occupancy. It is ideal for applications with highly variable occupancy, like a retail store. Michael's was able to reduce energy use by roughly 25% across its 1,000 craft stores using demand-controlled ventilation with CO_2 sensors (Siemens 2012). It is important to point out that ventilation is a key concern for many retailers since products on shelves can release fumes, gases, and volatile organic compounds (VOCs). As a result, retailers should ensure that any reduction in ventilation does not come at the expense of the health and safety of building occupants.

Smart solar film, which can be controlled electronically, may be another option to reduce cooling costs in a retail building. Dimmable controls give a retailer control over the amount of sunlight allowed into the building, which can also benefit a building's aesthetics.

Table 7 details smart technologies that can help reduce HVAC energy consumption in retail buildings.

Table 7. Smart HVAC technologies for retail

Technology	Cost level	Estimated cost	Savings level	Energy savings
Occupancy-based wireless thermostats	Low	$150–330/thermostat	High	5–10% HVAC
Learning thermostats	Low	$250–350/thermostat	High	5–10% HVAC
Advanced rooftop controller (retrofit)	Medium	$2,000–4,000/RTU	High	20–40% HVAC
CO_2 demand-controlled ventilation package	Medium	$1–3/cfm designed outside air	Medium	21% outside air, 10% heating and cooling
Smart window solar film	High	$15–20/ft^2	Low	10–20% cooling

Excludes installation costs. *Sources:* Wireless thermostat cost: Pistochini, Heinemeier, and DeJean 2008. Wireless thermostat savings: DOE 2017e. Learning thermostat cost: ACEEE product cost analysis from Lodgemart.com. Learning thermostat savings: ACEEE analysis. Advanced rooftop controller cost and savings: Wang et al. 2013. DCV package cost and savings: Seventhwave 2016. Solar film cost: GSA 2014. Solar film savings: Lutron 2014.

Lighting

The most prevalent lamp type in retail stores is the linear fluorescent tube. However, since lighting is such a crucial component of a retail store's aesthetic appeal to customers, stores often contain a variety of lamps, including accent lighting, downlights, and other types of directional illumination. Retailers often develop lighting design guides that specify particular lamps, which are intended to attract customers and increase sales.

A typical retrofit will consist of the installation of a combination of sensors, controller modules, and gateways. Retail stores that are interested in upgrading to efficient LED lamps can achieve an additional 20–40% savings by pairing the retrofit with advanced lighting controls. In addition, if the retailer is responsible for the parking lot and other exterior lighting, he or she can save 30–50% in exterior lighting energy use through the installation of smart controls. The Lighting Energy Efficiency in Parking (LEEP) campaign offers information on parking lot lighting upgrades, including lighting control case studies (LEEP 2017).

Advanced lighting control retrofit in a small music store

Linear fluorescent tubes are among the most common types of lighting found in retail stores and many other commercial building types. New LED linear replacement lamps use a fraction of the energy and can take advantage of advanced lighting controls. The Watermelon Music store in Davis, California, decided to install a Cree retrofit kit at a cost of about $140 per pair of linear fluorescent lamps. The retrofit kit contained its own driver with the ability to control the lamp based on scheduling, occupancy sensing, daylighting, and task tuning. The $14,000 lighting control system included occupancy and photo sensors, control modules, and lighting control software. In total, the system controls more than 200 lights throughout the music store, saving 7% in lighting energy from the LED retrofit and an additional 25% from the advanced lighting controls (CLTC 2015).

Table 8 summarizes possible smart lighting options for retail stores.

Table 8. Smart lighting technologies for retail

<table>
<tr><th>Technology</th><th>Cost level</th><th>Estimated cost</th><th>Savings level</th><th>Energy savings</th></tr>
<tr><td>Occupancy/vacancy/daylight sensors</td><td rowspan="3">High</td><td>$20–100/sensor</td><td rowspan="3">High</td><td rowspan="3">20–40% lighting</td></tr>
<tr><td>Smart lighting retrofit kit</td><td>$50–200/fixture</td></tr>
<tr><td>Wired or wireless gateway/hub</td><td>$300–1,000/ gateway</td></tr>
<tr><td>Exterior lighting controls</td><td>Medium</td><td>$200–400/fixture</td><td>Low</td><td>30–50% exterior lighting</td></tr>
</table>

Excludes installation costs. Excludes lighting control EMIS. Exterior lighting controls include wireless control module, sensors, and gateway. *Sources*: Sensor cost: ACEEE product cost analysis from Grainger.com. Gateway/hub cost: C. Cook, senior systems applications engineer, Lutron Electronics, pers. comm., August 28, 2017. Retrofit kit cost: CLTC 2015. Lighting retrofit savings: CLTC 2015; BEEx 2015. Exterior lighting control cost: ACEEE product cost analysis from Grainger.com. Exterior lighting control savings: ACEEE analysis.

Energy Management and Information Systems

Retail stores may consider installing a cloud-based energy information system to monitor the energy consumption of HVAC alone or HVAC and lighting. If the building already contains a building automation system, a cloud-based energy information system can often connect to the BAS to provide a greater level of trending and control.[5] A BAS is more likely to exist in big box chain stores with large building portfolios, such as a Target, Walmart, or JC Penney. These systems typically require more installation and programming to provide good levels of control.

In smaller retail stores, for instance an Ace Hardware, it is likely that no central building management system exists. For these building types, simpler cloud-based analytics platforms can identify energy-saving opportunities while requiring minimal installation and lower costs.

[5] Trending is the tracking of data points over time. Data trends can provide valuable information to a building operator concerning, for example, potential equipment malfunction or HVAC performance during extreme temperature events.

Small and medium-size smart retail solution: National Stores

For years National Stores, a family-owned business with more than 250 small- to medium-size locations, hesitated to invest in an energy management system. They were considered too expensive and too difficult to install. As a result, in many stores the HVAC systems operated continuously around the clock, and this was reflected in high energy bills.

After researching the market, National Stores selected Zen HQ to try to solve its energy problem. Zen HQ, a wireless smart thermostat made by California-based Zen Ecosystems, is intended for small to medium-size retail stores. At a rate of 2–3 buildings per day, technicians installed Zen HQ units without interrupting normal business operations or requiring any modifications to existing wiring. The product's cloud-based dashboard allowed easy viewing of HVAC and lighting operation. Preliminary measurements showed a 25% reduction in energy costs, primarily from setting HVAC and lighting schedules, but also from prolonging the life of HVAC equipment by not overworking it (Zen HQ 2017). As of February 2017, Zen had reportedly rolled out 704 of its smart thermostats across 131 locations (Zen Ecosystems 2017).

Table 9 details costs and savings for a retail energy management and information system.

Table 9. EMIS systems for retail

Technology	Cost level	Estimated cost	Savings level	Energy savings
Cloud-based EMIS	Varies	Initial: <$0.01–0.40/ft^2 Monthly: <$0.01–0.10/ft^2	High	5–15% whole building

Excludes installation costs. *Sources:* Cloud-based EMIS cost: Granderson, Lin, and Piette 2013; E. Feeny, director of sales, BuildPulse, pers. comm., July 20, 2017. Cloud-based EMIS savings: Gilliland 2016.

Other

Smart plugs, which switch off the power to plugged-in devices that are not being used, may not apply to all retail types, however they can potentially save energy in several settings. For example, if the retail building has an office, advanced power strips (Tier 1 or Tier 2) can be used to ensure that all laptops, PCs, and task lights are turned off when not in use, to achieve small energy savings. The National Renewable Energy Laboratory recommends considering plug load controls on point-of-sale equipment (i.e., cash register systems), self-service kiosks (e.g., coin exchanges, ATMs, and photo printing machines), and all display electronics (Sheppy et al. 2013).

Vending machine controls have also been shown to reduce vending machine electricity use by approximately 20–25% by shutting off the machine when nobody is within 15 feet and compressors are not running (Bert 2013). In retail stores with significant sunlight, solar film may be used to reduce solar gain and subsequent cooling costs.

In addition to energy efficiency upgrades, some stores are installing distributed energy resources (DERs) such as solar power, batteries, and fuel cells to help manage electricity demand and load. For instance, IKEA has installed solar arrays at many of its locations and recently added 1.5 MW of biogas-powered fuel cells at its San Diego location (Weinschenk

2017). Adding a smart inverter to a DER allows a continuous two-way connection between the DER and the electric grid, which enables the DER to respond to load signals, electricity rates, demand response events, and power outages (King and Perry 2017).

Although our consideration of retail stores does not explicitly include restaurants or grocery stores, which contain the bulk of commercial refrigeration systems, other types of retail stores may have commercial refrigerators or freezers. This equipment may include pressure, anti-sweat, adaptive, lighting, and evaporator fan controls, which when combined can cut energy use by 15–30%. However these controls are relatively expensive options and can have payback periods in the range of 2–3 years for freezers and 7–8 years for coolers. Therefore they may make financial sense only in larger retail stores and in restaurants and grocery stores (Zogg 2016).

Table 10 details other various smart control options for retail buildings.

Table 10. Other smart technologies for retail

Technology	Cost level	Estimated cost	Savings level	Energy savings
Tier 1 or Tier 2 advanced power strips (offices)	Low	$25–100/strip	Low	26–65% plug load
Smart plugs (point-of-sale equipment, display electronics)	Low	$100/120v plug	Low	50–60% plug load
Vending machine controls	Low	$180/vending machine	Low	20–25% vending machine electricity
Distributed energy smart inverter	High	$0.16/watt	High	12% electricity
Refrigeration system controls	Medium	$800–900/unit	Medium	15–30% refrigeration electricity

Excludes installation costs. *Sources*: Advanced power strip cost: Harry 2016; Schantz, Konjkav, and Langer 2017. Advanced power strip savings: GSA 2012; Schantz, Konjkav, and Langer 2017. Smart plug cost: ACEEE product cost analysis from Amazon.com. Smart plug savings: Boss 2016. Vending machine control cost: Morton 2012. Vending machine control savings: Bert 2013. Distributed energy smart inverter cost: Fu et al. 2016. Distributed energy smart inverter savings: Berdner 2015. Refrigeration system control cost: DOE 2017a. Refrigeration system control savings: Zogg 2016.

SMART TECHNOLOGY BARRIERS

Retail stores that are not responsible for their own HVAC and lighting have much less opportunity to save energy than those that do. For example, Schneider Electric estimates that energy savings of only 3–10% are possible stores in shopping malls and strip malls. Individual small stores typically have control over lighting, and potentially some control over HVAC, but HVAC is most likely controlled by the landlord. This is why big box stores have a greater energy savings potential on average (20–30%)—they typically have full control of HVAC and lighting (Jamieson and Renaud 2014).

Finding the funding to invest in smart technology can be a major barrier for retailers. Larger, big box chain retailers like Kohl's often receive a set amount of funding for energy efficiency and sustainability projects and have a designated energy team. For stores with their own energy team, the biggest barrier can be convincing members of the finance department to prioritize energy efficiency projects. Kohl's found a way to bridge the gap by creating a position for a liaison who physically worked with the energy team but reported to finance. The person in this role helped foster understanding between the two departments by using tools and statistics to evaluate potential projects and communicate energy savings in financial terms (Emerson 2013).

Since big box chain retailers are able to devote more resources to energy efficiency upgrades, they are more likely to have installed an EMIS. In fact, one of their biggest problems may be figuring out how to optimize their existing control systems. Robert King, who has helped implement effective energy management and real-time data trending systems at Target stores across the country, acknowledges the company's biggest challenge now is finding the time and expertise to understand how to take advantage of all the data (R. King, lead engineer, Target Corp., pers. comm., July 11, 2017).

Conversely, a small or medium-size retailer may not have even considered a plan for energy management. These businesses usually have smaller budgets and less flexibility to absorb up-front costs than their big box counterparts. A 2016 study by the Retail Industry Leaders Association (RILA) revealed that average retailers have only begun to think about installing the most basic smart controls and technology. They will install EMIS in a newly constructed retail location, but most have not retrofit existing stores with an EMIS. Currently a little more than 70% of all retail industry floor space contains some sort of building automation system, but most retailers do not yet take advantage of some of the most advanced control features, such as real-time analytics, remote monitoring and controls, and demand response (EIA 2017b). While this lack of commitment to energy management is a barrier, there is reason to be optimistic. RILA predicts that by 2018 the average retailer will regularly retrofit existing facilities with an EMIS instead of just installing them in new construction (RILA 2016).

Related Sector: Fitness Centers

Much like a retail store, fitness centers need to provide a positive experience for customers to ensure continuous business. Smart technologies like HVAC and lighting controls can help accomplish this.

For example, rooms in a yoga studio can range from a comfortable 73°F to a balmy 90°F for "hot yoga" classes. The smart building start-up company 75F implemented a solution for YogaFit Studios that tied the studio's wireless HVAC controls to Google Calendar. The system automatically sets the HVAC system to the desired temperature during classes and then defaults back to unoccupied temperatures when the studio is not in use, thus saving energy (75F 2017).

Like other commercial building types, retail stores also face security threats from the introduction of connected devices. Smart stores may contain a network of devices, including cameras and sensors, and offer a mobile app for customers' smartphones. More devices mean greater risks to customer personal data. After the Target hack in 2013 and the Home Depot hack in 2014, which compromised millions of customers' credit card information, John Kindervag of Forrester Research suggested that retailers should view data breaches "the same way energy companies view oil spills," since they are so costly and disastrous (Gonsalves 2014).

NONENERGY BENEFITS

Improvements in technology have had a profound impact on the retail industry. The continual improvement in online shopping means that retail stores are being reduced in both number and physical size. Reed et al. (2004) have predicted that shopping in brick-and-mortar stores will shift from a necessity to a form of entertainment. Retailers will increasingly design store features that encourage customer interaction and promote their brand, rather than just filling the available space with their products.

Retail owners already consider comfort and aesthetics to be two key components of the shopping experience. A retailer may therefore focus on the aesthetic benefits of specialized lighting and controls rather than on the technology's energy efficiency benefits (Reed et al. 2004). Numerous studies support the suggestion that lighting and temperature are critical to customer experience. In one study, 87% of consumers said they perceived pleasant lighting as a very important factor for going to a store, and 75% reported that temperature was a very important factor (Gowrishankkar 2017).

Online shopping has profoundly influenced consumers' perception of the shopping experience, and these trends are starting to carry over to brick-and-mortar stores. A Korean study that explored the concept of smart stores through the lens of customer experience—rather than energy management—can provide some insights on the future of the retail industry. The study describes such technologies as the smart mirror, which through an augmented reality virtual fitting function allows the consumer to see themselves in clothing in different sizes and colors that may not be available in the store. New technologies may benefit storeowners. Indoor positioning systems like mobile device radio frequency (RF) can detect users' phones, enabling a storeowner to map and analyze customer shopping behavior The owner can use this information to optimize the store layout based on customer preference (Hwangbo, Kim, and Cha 2017).

If the future of retail stores includes technology such as augmented reality and indoor positioning systems, then these stores could very easily include smart technology that reduces energy waste. Using RF technology to detect occupancy could help curtail excess airflow or lighting. Retail buildings could display interactive building information to its customers, such as comfort information or energy efficiency performance (and goals). Consumer comfort and experience will be key considerations in the design of modern retail stores, and energy-efficient smart technology can play a key role.

DISCUSSION

Brick-and-mortar retail stores will undergo major changes over the next decade. To compete with online retailers, they will find new ways to attract and retain customers. Some of these will involve incorporating new technologies into their business model. This transition provides retailers with an opportunity to take advantage of smart technologies that can save them money on their energy bills and improve their customers' experience.

Lighting makes up a large portion of retail energy consumption. Where possible, smart lighting controls can reduce a building's energy cost and potentially provide more attractive lighting options for customers. Since the majority of retail stores use packaged rooftop unit air-conditioning systems, installing RTU controls or purchasing a new RTU with embedded smart controls can also help reduce a retailer's energy consumption. Better control over temperature and airflow can improve a customer's level of comfort. In stores with refrigerators, smart controls are also an effective method to reduce energy consumption.

Hotels

Though the larger lodging category includes buildings like motels, dormitories, and retirement homes, this section of the report focuses on hotels. We define hotels as lodging that contains rented rooms connected by interior corridors and that typically offers some level of amenities. While the hospitality sector contains 160,000 buildings, the hotel subsector consists of roughly 52,000 properties and a little more than 5 million rooms (Hotel News Resource 2016). Within the lodging sector, hotels present a prime opportunity for the installation of smart technology due to their operators' willingness to invest in technologies that enhance customer experience and gain them a competitive advantage. Figure 6 provides an overview of the hotel sector.

52,000	hotel properties
5 million	guest rooms[a]
35,000	average size (square feet)
89%	have 150 rooms or fewer
63%	considered low- to mid-scale
73	average site energy use intensity (kBtu/sq ft)
36%	rooms unoccupied on average
70%	affiliated with chains
70–86%	major hotel chain properties franchised
48%	use an energy management system
90%	have installed high-efficiency lighting

Figure 6. US hotel sector by the numbers CBECs calculations based on building floor area, not number of buildings. [a] Just as hospital beds act as a proxy for hospital size, the number of guest rooms often act as a proxy for hotel size. *Sources:* US properties, rooms, and hotels affiliated with chains: Hotel News Resource 2016. Average size and energy management system: EIA 2017b. Site energy use intensity: EPA 2016. Occupancy rate and number of rooms: AHLA 2015. Scale classifications: Statista 2017. Major hotel franchise data: ACEEE analysis of Marriott, Hilton, and InterContinental (Marriott: Cederholm 2014b; Hilton: Cederholm 2014a; InterContinental: Nielson 2014. Marriott values do not account for its 2016 acquisition of Starwood hotels). Energy management systems and high-efficiency lighting: AHLA 2016.

Large luxury hotels located in cities may be more likely to have the budget and in-house expertise to adopt smart building technologies; however the majority of hotels are not large, luxury grade, or even urban. The average hotel is 35,000 square feet and contains fewer than 150 rooms, which is considered small to medium-size (very large hotels can have more than 500 rooms) (EIA 2017b; AHLA 2015). In terms of amenities, these average hotels can be considered economy, midscale, or upper midscale (Statista 2017).

At 73 kBtu/ft^2, hotels have a higher average energy use intensity than offices and retail stores. The average hotel maintains a 64% occupancy rate, which means that 36% of hotel rooms are unoccupied, on average (AHLA 2015). This presents a great opportunity for smart technologies to save energy by tightly controlling HVAC and/or lighting in unrented hotel rooms.

Some 70% of hotels are affiliated with a chain of properties (Hotel News Resource 2016). From the available data, hotel chains appear to feature similar ownership structures, with the majority of properties franchised (70–86%) and many fewer actually owned by the organization (14–30%) (Cederholm 2014a; Cederholm 2014b; Nielson 2014). One important implication of this business model for smart building technology is that unlike, say, a major retailer such as Walmart, major hotel chains cannot mandate a new smart technology across all of their affiliated properties, since they do not own them. However chains do have a significant influence on their franchised properties. In fact, franchisees tend to look to the mother ship for support, since the central organization often negotiates for the best deals from management and procurement companies (M. Dean, senior director of engineering, Hilton Worldwide, pers. comm., June 14, 2017).

Trends show that hotels are actively embracing sustainability and energy management. Forty-eight percent have installed energy management sensors in rooms, and 90% have installed high-efficiency lighting (AHLA 2016). As a result, the hotel industry is primed to adopt smart technologies.

Hotels use most of their energy on heating, cooling, ventilation, and water heating. Additional energy is used for lighting and, in some locations, to run pool and spa equipment. We estimate that by using smart technologies, the average hotel can save 18% HVAC, 9% plug load, 15% lighting, and 30% pool pump energy, as shown in figure 7.

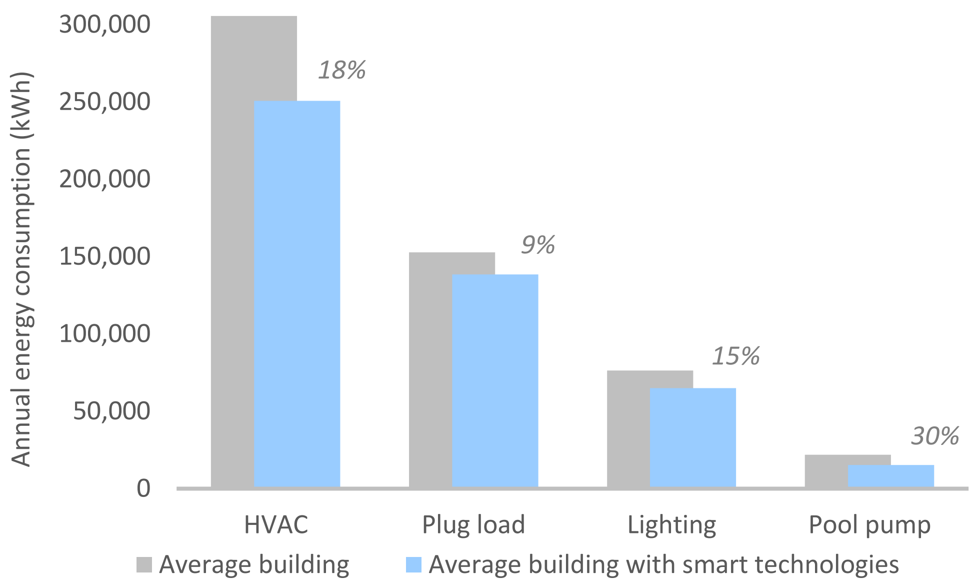

Figure 7. Average hotel energy savings with smart technology

SMART TECHNOLOGY OPPORTUNITIES

HVAC

A low-cost option to save energy in a hotel room is the installation of window and patio door contacts. These devices can be programmed to shut off the HVAC unit when doors or windows are opened, preventing the waste of energy to cool or heat air.

A higher-cost option is the installation of occupancy-based thermostats. These thermostats contain an occupancy sensor and can be programmed to set the temperature a few degrees warmer (in the summer) or colder (in the winter) when the guest leaves the room. Studies show that installing smart thermostats in hotel guest rooms can save 15–30% of HVAC energy (Pistochini, Heinemeier, and DeJean 2008). Wired thermostats can be connected directly to the room HVAC unit; wireless systems communicate with an electronic control kit (unless controls are already embedded in the HVAC system) to relay instructions to the hotel room HVAC unit, which is typically a packaged terminal air-conditioning (PTAC) unit or fan coil unit (FCU).[6] If the thermostats are networked to the check-in system, the temperatures can be set even warmer or cooler if the system determines that the guest room is unrented.

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[6] When possible, the energy manager at Hilton prefers to pair the installation of programmable thermostats with HVAC systems featuring electrically commutated motor (ECM) to fan coil units (M. Dean, senior director of engineering, Hilton Worldwide, pers. comm., June 14, 2017). Electrically commutated motors provide greater efficiency at variable speeds than traditional motors and have been shown to yield 9% energy savings in unitary air-conditioning products (Goetzler, Sutherland, and Reis 2013). As a result, they can be more effectively controlled by a programmable thermostat to ultimately achieve greater energy savings. Our review of ECM motors on Grainger.com shows that the upgrade would cost about $400–500 per room.

A hotel owner could also consider installing learning thermostats, which have greater capabilities than smart thermostats. This could be beneficial, for instance, in calculating recovery time—the time it takes for the temperature to return to its original set point after the guest enters the room. Due to added heat from sun exposure, the recovery time to cool a room to the desired level may take south-facing rooms longer than those that face the north. Over time, a learning thermostat can adjust its setback temperature and maximize guest comfort. Two vendors that specialize in learning thermostats for hotels are Verdant and Telkonet.

Other medium- to high-cost options may help control ventilation in certain parts of a hotel. Commercial kitchen exhaust hoods are frequently found in hotels with restaurants. Kitchen exhaust systems use so much energy because they remove air from the kitchen and then replace it with new, conditioned "makeup" air. Using sensors that detect steam and moisture, smart kitchen exhaust controls can help control the amount of air that is exhausted from the kitchen, reducing fan energy by as much as 60% and kitchen conditioned air loads by 20% (SPEED 2013). Since commercial kitchen exhaust-control upgrades can be costly and sometimes require the kitchen to be reconfigured, this upgrade may make the most sense during major kitchen renovations.

Over-ventilation can also be a problem in hotels with conference rooms, meeting areas, and ballrooms. In these areas, hotels may consider installing demand-controlled ventilation, which can use occupancy sensors (typically in smaller spaces) or carbon dioxide sensors (typically in larger spaces) to reduce the volume of outside air brought in the building by as much as 21%, saving approximately 10% heating and cooling energy (Seventhwave 2016).

Electronic solar film and automated shades can be applied to existing windows to control daylighting. Electronic solar film responds to the changing angle of the sun to reduce thermal gain and associated cooling energy use. Automatically controlled shading systems can respond to changes in outdoor and indoor temperatures as well as the sun's position. This has potential to reduce heating load and save 10–20% of cooling energy (Lutron 2014). Smart shading controls can also help enhance a guest experience. Some luxury hotels have programmed shades to open automatically when guests first enter their rooms, making them feel welcome.

Hilton's building analytics solution

For years, technological limitations prevented Hilton Worldwide from fully understanding its building HVAC data using a traditional building automation system. A hotel BAS can have "as many as 3,000 to 4,000 points, but the system's memory can only handle trending of maybe 300 to 400 points," says Mike Dean, senior director of engineering for Hilton. This all changed with their introduction to cloud computing around 2011.

Hilton began working with analytics company Entic to install sensors and software in several of its locations. Using wireless cloud storage, for the first time Hilton properties had the ability to trend all 4,000 data points. They could see when HVAC equipment began drifting away from set points. The software helped prioritize problems so Hilton engineers could solve them in the optimal order. This has shifted the engineering team mindset from reactive to "constant commissioning." Hilton brought in Schneider Electric to estimate savings by developing a linear regression model at six properties, which revealed potential net energy savings of $1.2 million per year. To date, Hilton has installed these systems in 20 properties, and it is considering 8 additional (M. Dean, senior director of engineering, Hilton Worldwide, pers. comm., June 14, 2017). Entic requires no up-front capital and begins collecting fees only when a property's energy savings generate a positive cash flow. This type of financing is becoming increasingly popular and can help properties overcome the initial cost hurdle.

Table 11 displays a number of low-, medium-, and high-cost technologies that can benefit hotels in guest rooms, conference areas, ballrooms, and hotel restaurants.

Table 11. Smart technologies for hotels

Technology	Cost level	Estimated cost	Savings level	Energy savings
Wireless window and patio door contacts	Medium	$25–75/contact	Low	3–5% guest room HVAC
Occupancy-based wireless thermostat	High	$150–330/ thermostat	Medium	10–30% guest room HVAC
PTAC or FCU electronic control kit	Medium	$100–200/HVAC unit	Medium	N/A
Learning thermostats	High	$250–350/thermostat	Medium	10–30% guest room HVAC
Smart kitchen hood exhaust controls (restaurant)	Medium	$1.00–2.50/cfm rated kitchen hood ventilation	Low	60% fan, 20% conditioned air
CO_2 demand-controlled ventilation package (conference rooms and ballrooms)	Low	$1–3/cfm designed outside air	Low	21% outside air, 10% heating and cooling

Technology	Cost level	Estimated cost	Savings level	Energy savings
Electronic solar film for windows	High	\$15–20/ft^2	Medium	10–20% cooling
Automated shade system	High	\$375/motorized shades	Medium	10–20% cooling

Excludes installation costs. *Sources*: Window/door contact cost: ACEEE product cost analysis from Grainger.com and Amazon.com. Window/door contact savings: ACEEE analysis. Wireless thermostat cost and savings: Pistochini, Heinemeier, and DeJean 2008. PTAC control kit costs: ACEEE product cost analysis from Grainger.com. Learning thermostat cost: ACEEE product cost analysis from Lodgemart.com. Learning thermostat savings: ACEEE analysis. Hood exhaust control cost and savings: SPEED 2013. DCV package cost and savings: Seventhwave 2016. Solar film cost: GSA 2014. Solar film savings: Lutron 2014. Automated shade system costs: Wagner 2016. Automated shade system savings: Lutron 2014.

Lighting

To control guest room lighting, all the lights in each room should be on their own single circuit. However most existing hotels were not constructed with this requirement in mind, and several rooms often share the same wall outlets and lighting circuit. As a result, it is often not feasible to retrofit an existing hotel with individual guestroom lighting controls (Touchstone 2017).

In older hotels, it may be more effective to implement strategic lighting controls, such as in guest bathrooms and conference, meeting, and ballroom areas. In addition, retrofitting outdoor lighting with smart controls can help reduce hotel energy costs. See the office section for a detailed discussion of smart lighting.

Table 12 shows hotel lighting control options, assuming that lighting controls can be applied only to bathrooms, and to conference, meeting, and ballroom areas.

Table 12. Smart lighting technologies for hotels

Technology	Cost level	Estimated cost	Savings level	Energy savings
Occupancy/vacancy/daylight sensors	High	\$20–100/sensor	Low	20–40% lighting
Smart lighting retrofit kit		\$50–200/fixture		
Wired or wireless gateway/hub		\$300–1,000/ gateway		
Exterior lighting controls	Medium	\$200–400/fixture	Low	30–50% exterior lighting

Excludes installation costs. Excludes lighting control EMIS. Exterior lighting controls include wireless control module, sensors, and gateway. *Sources*: Sensor cost: ACEEE product cost analysis from Grainger.com. Retrofit kit cost: CLTC 2015. Lighting retrofit savings: CLTC 2015 and BEEx 2015. Gateway/hub cost: C. Cook, senior systems applications engineer, Lutron Electronics, pers. comm., August 28, 2017. Exterior lighting control cost: ACEEE product cost analysis from Grainger.com. Exterior lighting savings: ACEEE analysis.

Combined HVAC and Lighting

In a hotel setting, some sensors commonly serve a dual purpose: to reduce both HVAC and lighting energy use. To monitor occupancy, occupancy sensors are much more prevalent in the United States than the keycard occupancy systems found commonly in Asia and Europe. Infrared occupancy sensors are estimated to save 12–24% of HVAC energy and 16–22% of lighting energy in guest rooms (DOE 2016b). Unlike a motion detector, these systems can detect occupancy even if someone is sleeping, so they will not make the mistake of reducing or increasing the temperature when the guest is still in the room. However some luxury hotels install pressure sensors in beds to avoid any potential occupancy sensor misreads.

One of the main drawbacks of traditional wireless systems is that they require batteries, which have a limited life span. A large hotel with many guest rooms could require as many as 30 battery changes every day, costing material and labor (Martin 2015). An alternative to traditional sensors and controls is wireless and batteryless technologies (switches, sensors, and so on). Germany-based EnOcean GmbH manufactures and supplies self-powered modules to companies like Siemens, Osram, and Distech Controls. These devices charge themselves through kinetic motion (literally the motion of pushing a button or flipping a switch), photovoltaic energy (both sunlight and indoor light), and other methods that can generate small amounts of energy (DOE 2016b). Although these devices are not estimated to save any more energy than traditional ones, their additional benefits may make them attractive to some hotels. The technology was developed and has been adopted at a greater scale in Europe than in the United States, where it still appears to be in the early stages of adoption.

Table 13 shows two technologies can be used to achieve both HVAC and lighting savings.

Table 13. Combined smart HVAC and lighting technologies for hotels

Technology	Cost level	Estimated cost	Savings level	Energy savings
Wireless passive infrared ceiling occupancy sensors	Medium	$50–150/guest room	Medium	12–24% guest room HVAC, 16–22% guest room lighting
Wireless/batteryless infrared ceiling occupancy sensor	Medium	$100–200/guest room	Medium	12–24% guest room HVAC, 16–22% guest room lighting

Excludes installation costs. *Sources:* Wireless occupancy sensor costs: ACEEE product cost analysis from Grainger.com and Mysecurityparts.com. Battery-free occupancy sensor cost: ACEEE analysis and Powercast Corporation 2011. Wireless and batteryless occupancy sensor savings: DOE 2016b.

Energy Management and Information Systems

Some hotel chains are starting to implement cloud-based energy management and information systems (EMISs) and sensors to help analyze data and identify areas needing improvement. These systems often follow the software-as-a-service business model, which may require little to no up-front investment but does require a monthly service fee. By using real-time analytics to identify inefficient operations and equipment faults, an EMIS has the potential to save as much as 5–15% of whole building energy (Gilliland 2016). Larger hotels with high variation in occupancy can take advantage of analytics to group rented rooms and then significantly set back temperatures in unrented hotel blocks or wings. An EMIS is not fully automated, however, and requires an analyst to interpret the data and make the necessary adjustments to the energy systems to achieve the greatest benefit. EMIS vendors serving hotels include Schneider Electric and Entic. In addition, Verdant and Telkonet, which both manufacture smart thermostats, also offer hotel energy management and information systems.

Though it is included for reference, the cost of retrofitting an existing hotel with a hardwired networked system to centrally control the HVAC and lighting will usually be prohibitive as well as extremely disruptive to guests. Hotel retrofits will likely achieve a greater return on investment using smart thermostats and an EMIS that can be wirelessly controlled, along with occupancy-based lighting controls in places like conference rooms and back-of-house areas. However a wired option may be feasible during a major hotel renovation project. Wired controls provide guests with a greater level of security than a wireless system, which can be more easily hacked.

Table 14 covers EMIS for hotels.

Table 14. Smart EMIS technologies for hotels

Technology	Cost level	Estimated cost	Savings level	Energy savings
Wireless cloud-based EMIS	Varies	Initial: <$0.01–0.40/ft^2 Monthly: <$0.01–0.10/ft^2	High	5–15% whole building
Wired networked guest room building automation system	High	$500–1,000/guest room	Medium	15–30% guest room HVAC, 20–25% guest room lighting

Sources: Cloud-based EMIS cost, excluding installation: Granderson, Lin, and Piette 2013; E. Feeny, director of sales, BuildPulse, pers. comm., July 20, 2017. Wireless cloud-based EMIS savings: Gilliland 2016. Wired networked automation system cost, including installation: ACEEE analysis and E Source 2009. Wired networked automation system savings: ACEEE analysis.

Other

Hotels may also consider installing smart plugs, which can be controlled remotely to shut off devices in unrented rooms, saving 50–60%in plug load where connected (BOSS 2016). Although it does not make sense to control guest electronics like cell phones and laptops remotely, hotels could reduce energy by shutting off TV systems and cable boxes when the guest room is unrented. In addition, controls can save 20–25% of vending machine plug load energy (Bert 2013).

For the many hotels that have swimming pools, smart pool pump controls can be a relatively inexpensive way to reduce pool pump energy by 25–40% (KSI 2017). These controls can also be applied to spa pumps.

It is worth noting that water heating uses a large amount of energy in hotels, roughly 20% of whole-building energy consumption, according to the 2012 CBECS. As a result, we investigated smart control options for hotel water-heating and boiler systems. Unfortunately, currently the primary market for smart water-heating controls is residential and multifamily buildings, and we were unable to locate valid options for a large hotel system.

Table 15 presents miscellaneous smart technologies that could save energy in a hotel.

Table 15. Other smart technologies for hotels

Technology	Cost level	Estimated cost	Savings level	Energy savings
Smart plugs	Low	$100/120v plug	Low	50–60% plug load
Vending machine controls	Low	$100–200/vending machine	Low	20–25% vending machine electricity
Smart pool pump controls	Low	$300–500/pump	Low	25–40% pump electricity

Excludes installation costs. *Sources:* Smart plug cost: ACEEE product cost analysis from Amazon.com. Smart plug savings: Boss 2016. Vending machine control cost: Morton 2012. Vending machine control savings: Bert 2013. Pool pump control cost: ACEEE product cost analysis from INYOPools.com. Pool pump control savings: KSI 2017.

SMART TECHNOLOGY BARRIERS

Hotel chains are committed to presenting the best possible experience to their guests. A survey of upscale hotel managers revealed that one of the biggest barriers for smart hotel technology is the perception that smart devices, like in-room sensors or demand-response controls, could cause occupants' inconvenience or discomfort (Baloglu and Jones 2015). It is true that guests dislike mistakes such as lights automatically switching off when the guest is still in the room. However hotels like the Potawatomi Hotel in Milwaukee, Wisconsin, which installed the Telkonet in-room energy management system, claim to have increased guest satisfaction while saving money and energy (Gregory 2015).

Another major barrier is the tendency for managers to view efficiency technology from a short-term investment perspective, rather than focusing on long-term benefits. Building managers strongly prefer technologies with a simple payback of three years or less to those with longer paybacks that could potentially show much greater energy savings and improved guest comfort (Baloglu and Jones 2015).

Older hotels tend to face more challenges in installing smart technology than do newer hotels. For instance, hotels constructed with concrete and rebar have a difficult time installing Wi-Fi for guests, much less connecting a network of smart devices. These hotels also often use insufficient cabling and require a costly and disruptive re-cabling process (Wroten 2016). These hotels were not built to handle today's technology, and as a result it can cost more to install.

Additionally, hotels face the challenge of ensuring cybersecurity for their guests. In 2012, the Federal Trade Commission (FTC) sued Wyndham Hotels for its security standards that led to multiple data breaches (Lecher 2015). In 2013, a security consultant found that he could easily take control of the thermostats, lights, TVs, and window blinds in more than 250 rooms in a luxury hotel in Hong Kong. It was fortunate that this was more or less an academic exercise (he reported his findings to the hotel), but this security vulnerability could have just as easily been discovered by a hacker with devious intentions (Zetter 2014). Cybersecurity breaches undermine the benefits of smart technologies and pose a serious threat to their cultural acceptance. Fortunately, there are readily available best practices to dramatically reduce the chances of such problems, such as on the FTC's website (FTC 2015). Still, as hotels comes to rely more heavily on technology, it makes sense for the entire hotel industry to work together to solve this problem.

Some hotels owners have been burned by bad investments in technology and may be skeptical in investing in more. For example, hotels spent millions of dollars over the past few years installing tablet kiosks for guest check-in. The tablets went largely unused in favor of traditional face-to-face check-ins and were eventually leapfrogged by mobile app check-ins. The result was that hotels wasted a large investment on a technology that their customers did not embrace (Deloitte 2017).

Despite the current barriers, some experts believe that the groundwork has been laid for the success of smart building technologies in hotels. They suggest that the success of linen reuse programs, which reduce energy and water use associated with washing towels and bedsheets, could translate to success for smart technologies (Baloglu and Jones 2015). Alerting guests to technology like in-room sensors or programs like demand response and educating them about how the hotel is managing its energy use can help obtain their buy-in. Sample table tents can be found in Appendix D (Baloglu and Jones 2015).

NONENERGY BENEFITS

Hotels invest in technology primarily to improve guest experience, not to save energy. However many energy-saving technologies can also improve user experience. For instance, in addition to saving energy through temperature setbacks, learning thermostats can reduce the time it takes a temperature to return to its original set point. And lighting that automatically turns on when a guest arrives in the room can feel like a welcoming experience.

Virgin Hotels created an app that allows guests not only to control their room temperature, but also to order room service, control the TV, and make dinner reservations (Deloitte 2017). Apps like this are likely the first step in achieving a more advanced hotel experience driven by the Internet of Things, in which part of the experience is more interaction with HVAC and lighting. It is possible that in the future, sensors will identify a guest by her smartphone, unlock the door as she approaches, and adjust the lighting, temperature, and entertainment settings to her preference (Deloitte 2017).

Related Sector: Dormitories

Many recommended smart hotel technologies can also save energy in dormitories and enhance student experience.

Installing smart or learning thermostats in dormitory rooms can help enhance student comfort. Occupancy sensors can help reduce HVAC and lighting loads in dorm rooms and common areas when students are at class. Equipping students with smart plugs or advanced power strips can help reduce plug load energy consumption.

In an education setting, smart technology doubles as a teaching tool. Educating the students about using smart equipment to save energy can help prepare them to save energy when they live in their own home or apartment.

DISCUSSION

Hotels constantly seek to improve customer experience, and some energy-saving smart technologies can also help achieve this goal. Within a guest room, smart thermostats, smart lighting, and smart window shade controls all give a guest greater ability to personalize his environment. Some hotels even offer some of these benefits through an app on the customer's phone. Tying these technologies to the guest check-in system allows the hotel to set back or completely shut off lighting and air-conditioning in unrented rooms. Though the greatest energy savings are typically achieved through guest room upgrades, smart technologies can reduce energy consumption in other parts of the hotel as well, with such equipment as demand-controlled ventilation in conference areas and smart pool pump controls for the pool and spa.

Nonteaching Hospitals

While the hospital sector has far fewer buildings than the other sectors in this report, hospitals are much larger and much more energy intensive. At 250,000 square feet, the average hospital is 7 times bigger than the average hotel and 20 times bigger than the average retail building (EIA 2017b). Its average energy use intensity of 197 kBtu/ft^2 is nearly triple that of the average office (EPA 2016). Figure 8 provides an overview of the nonteaching hospital sector.

9,579	hospital buildings
274 million	beds[a]
250,000	average square feet per hospital
197	average site energy use intensity (kBtu/sq ft)
69%	have a building automation system
77%	nonteaching

Figure 8. US hospital sector by the numbers. CBECs calculations based on building floor area, not number of buildings. [a] Beds calculated on the basis of 0.5 beds per 1,000 sq ft (EPA 2015).*Sources:* Number of hospitals and average square feet: EIA 2017b. Site energy use intensity: EPA 2016. Beds: EPA 2015; EIA 2017b. Nonteaching hospitals: Shahian et al. 2012.

The hospital industry has embraced technology, with 69% of hospitals having installed a building automation system (EIA 2017b). This means that hospitals are well positioned to adopt other smart energy-saving technologies.

This section of the report focuses on nonteaching hospitals rather than university teaching hospitals. Nonteaching hospitals tend to be medium size and may have more regional locations. Teaching hospitals tend to receive better funding and are more likely to have already embraced smart technology. In addition, our research shows that the majority of hospitals, 77%, are nonteaching (Shahian et al. 2012). As a result, nonteaching hospitals represent the greatest energy-saving opportunity in the sector.

Hospitals use a significant amount of energy for heating, cooling, and ventilating, often within very tight parameters. In addition, hospitals need a significant amount of energy for water heating, which is used in a number of hospital processes. Lighting also contributes a major portion of a hospital's overall energy consumption profile. We estimate that smart technologies can help the average hospital save 28% on HVAC energy, 20% on water heating, and 30% on lighting energy, as shown in figure 9.

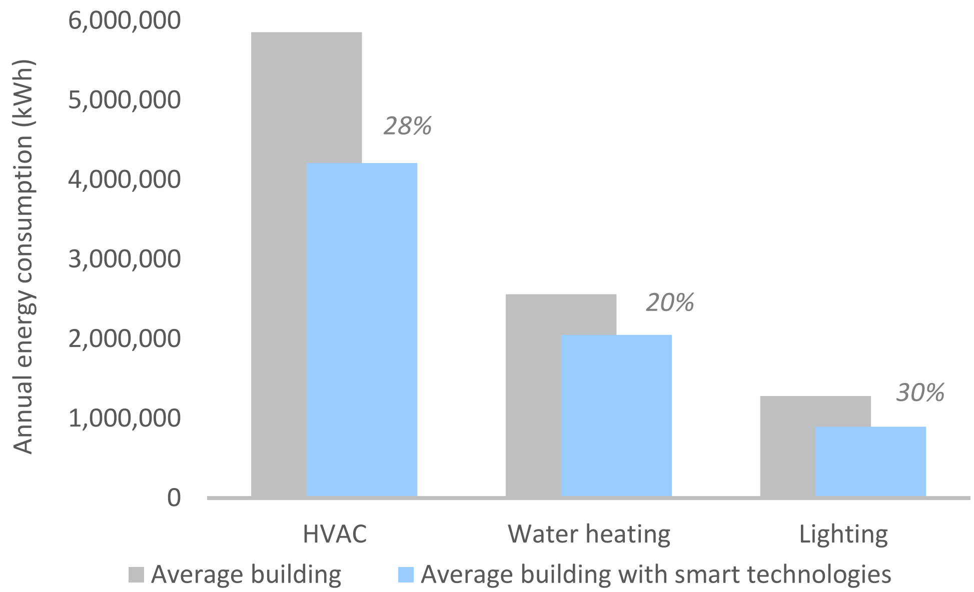

Figure 9. Average hospital energy savings with smart technology

SMART TECHNOLOGY OPPORTUNITIES

HVAC

Because of their typically near-constant operation, it can be difficult to achieve a scale of savings in hospitals similar to the savings possible in other building types. The same strategies that, for instance, an office might use to cut back HVAC operation during off hours will not apply to hospitals that are in operation 24-7.[7]

Hospitals frequently use steam, generated either by their own plant or by a district system.[8] The steam is used primarily for heat, hot water, and humidity control, but it can also be used for medical purposes, such as instrument sterilization. Steam traps, an integral part of a steam system, are used to discharge built-up condensate and other gases from the steam line when necessary. DOE estimates that 15–30% of steam traps are likely to fail in steam systems that have not been maintained for three to five years (DOE 2012). Steam traps are designed to release small amounts of condensate; when one of them fails to open, it allows too much steam to escape. Installing a wireless steam trap monitoring system can help

[7] However these strategies may still be effective in ancillary areas such as offices and meeting rooms.

[8] Steam is often a hospital's most expensive utility.

minimize these energy losses. Such systems are available from vendors such as Cypress Envirosystems, Emerson, and Armstrong.

Like hotels, hospitals also frequently contain kitchens. Installing range hood exhaust controls can save an estimated 60% of fan energy and 20% of conditioned air energy, from reductions in hood fan usage and makeup supply air, respectively (SPEED 2013).

In addition, of the four sectors analyzed in this study, hospitals are the most likely to contain a central HVAC plant. If an existing building automation system is not already gathering efficiency information about the plant's equipment, including chillers, cooling towers, boilers, and pumps, then building owners may consider installing submeters on the equipment. This will enable them to use the submetered data to make important efficiency decisions, such as the optimal way to run multiple chillers, or even to perform continuous monitoring-based commissioning. The cost of these submeters can range anywhere from $400 to $3,000, depending on level of accuracy, hardwired versus wireless design, and other criteria (NSTC 2011).

Additionally, many hospitals may still use outdated pneumatic (compressed air) controls to modulate heating and cooling. These can be converted to a smart electronic system, typically called a direct digital control (DDC) system. The cost difference between pneumatic and electronic controls is stark, however. Pneumatic actuators can range in cost from $15 to $250 each, while an upgrade to a DDC system with electric actuators ranges from $800 to $3,000 per actuator (Greenfield 2012). Because the initial cost of replacement is high, due to all the mechanical, electronic, and control components, upgrading to DDC is recommended only if the pneumatic controls are at the end of their useful lives or if major building renovations are being undertaken. Recently the falling cost of wireless CO_2 sensors has made DDC slightly more affordable. Even so, the energy savings from installing DDC are rarely enough by themselves to justify the investment (Hydeman 2004). Decision makers would also have to value the ancillary benefits, such as the ability to control HVAC zones remotely and generate data for trending and fault detection.

An alternative to full DDC is wireless pneumatic thermostats. These systems mimic DDC operation by using electronics to control a pneumatic system. These systems are much less expensive than DDC, typically ranging in price from $0.60 to $1.10 per square foot, including installation (Howett and Bhandari 2015). When these devices are in place and programmed to operate efficiently, they can cut HVAC energy use by 5–15% (Pollard 2012).

Automated shades and switchable window film can help reduce cooling energy. In addition, both can be regulated remotely, which can provide patients with a greater level of control over their comfort. Table 16 shows the smart HVAC and water-heating options that can be installed in a hospital.

Table 16. Smart HVAC and water-heating technologies for health care

Technology	Cost level	Estimated cost	Savings level	Energy savings
Wireless steam trap monitoring	Medium	$650/steam trap	High	15–25% steam energy
Smart kitchen hood exhaust controls (restaurant)	Low	$1.00–2.50/cfm-rated kitchen hood ventilation	Low	60% fan, 20% conditioned air
Networked central plant submeters	Low	$400–3,000/meter	High	5–45% per piece of HVAC equipment
Upgrade from pneumatic to electronic controls	High	$800–3,000/actuator (incremental)	High	10–20% HVAC
Wireless pneumatic thermostats	High	$0.60–1.10/ft²	Medium	5–15% HVAC
Automated shade system	High	$375/shade	Low	10–20% cooling
Electronic solar film for windows	High	$15–20/ft²	Low	10–20% cooling

Excludes installation costs. *Sources:* Wireless stream trap monitoring cost and savings: Cypress Envirosystems 2010. Hood exhaust control cost and savings: SPEED 2013. Networked central plant submeter cost and savings: GSA 2013; NSTC 2011. Upgrade from pneumatic to electronic control cost: Greenfield 2012. Upgrade from pneumatic to electronic control savings: ACEEE analysis. Wireless pneumatic thermostat cost: Howett and Bhandari 2015. Wireless pneumatic thermostat savings: Pollard 2012. Automated shade system cost: Wagner 2016. Solar film cost: GSA 2014, Solar film and shade system savings: Lutron 2014.

Lighting

Hospitals may consider lighting retrofits in areas like patient rooms, hallways, and common spaces. In hallways and common spaces, daylighting sensors and dimming controls can be installed in locations where they can take advantage of natural daylighting.

Many hospitals are starting to enable greater user control in patient room lighting. This can extend to smart lighting retrofits that let patients adjust lighting levels and colors. These retrofits include the installation of sensors, fixture components, and wireless gateways, which can save 20–40% of lighting energy (CLTC 2015; BEEx 2015). DOE-sponsored research showed that health care lighting can impact patient well-being and recovery as well as health care employee performance, from surgeons to administrative assistants (Joseph, Davis, and Wilkerson 2016). It is important to ensure that any lighting projects meant to reduce energy consumption still serve these goals.

Like most commercial buildings, hospitals can use smart exterior lighting controls to schedule or dim lighting to save energy. An ideal time to install exterior lighting controls is during a retrofit to LED lamps, although LED lamps are so energy efficient that the controls will show less energy savings than they would with inefficient lighting such as metal halide or high pressure sodium. Refer to the office section of this report for a more detailed discussion of smart lighting.

VacaValley Hospital networked adaptive exterior lighting

NorthBay VacaValley Hospital's exterior lighting project showcases how much energy can be saved by combining LEDs and networked lighting control upgrades. This hospital in Vacaville, California, decided to retrofit its inefficient exterior lighting (induction, high-pressure sodium, and metal halide) with efficient LED lights and also decided to add controls. These included motion sensors and a smart lighting control network. The network provided users the ability to adjust lighting schedules, monitor light levels, and even detect when the luminaires required maintenance. The LED upgrade reduced exterior lighting energy consumption by 34%, and the addition of the networked controls system increased the savings to 49% (Goesmann and Graeber 2014).

Another technology to consider in a hospital is cabling, which can be used to control lighting as well as other small devices. Category 6A cables can transfer up to 10 times as much data as the traditional category 6 cables. More important, cat-6A cables allow for Power over Ethernet (PoE), by which certain devices can be controlled directly through the data cables rather than through power cords, allowing for a higher level of control and data analysis. While PoE is still a developing technology and can currently support only small devices like light bulbs and laptops, some predict that it will be able to provide much more power and control a wider range of devices in the near future. Costing 25% more than cat-6 cabling, this measure may make the most sense if a hospital is already considering installing new cabling, such as to accommodate a new health care IT system (Belden 2012; Schneider Electric 2016).

Table 17 lists possible smart lighting options for a hospital.

Table 17. Smart lighting technologies for hospitals

Technology	Cost level	Estimated cost	Savings level	Energy savings
Occupancy/vacancy/daylight sensors	High	$20–100/sensor	Low	20–40% lighting
Smart lighting retrofit kit		$50–200/fixture		
Wired or wireless gateway/hub		$300–1,000/ gateway		
Exterior lighting controls	Medium	$200–400/fixture	Low	30–50% exterior lighting
Cat-6A cabling (to enable Power over Ethernet)	High	25% more than cat-6 cabling (incremental)	Low	20% lighting

Excludes installation costs and lighting control EMIS. Exterior lighting controls include wireless control module, sensors, and gateway. *Sources:* Sensor cost: ACEEE product cost analysis from Grainger.com. Retrofit kit cost: CLTC 2015. Gateway/hub cost: C. Cook, senior systems applications engineer, Lutron Electronics, pers. comm., August 28, 2017. Lighting retrofit savings including sensors, retrofit hardware, and gateways: CLTC 2015; BEEx 2015. Exterior lighting control cost: ACEEE product cost analysis from Grainger.com. Exterior lighting savings: ACEEE analysis. Cat-6A cable incremental cost: Schneider Electric 2016. Cat-6A cable savings: Belden 2012.

Energy Management and Information Systems

As a method of collecting data and performing trending and fault detection, a hospital can benefit from installing an energy management and information system. As previously mentioned, hospitals have fewer opportunities to reduce HVAC operation during unoccupied hours because many parts of a hospital are never unoccupied. However one way in which a hospital EMIS can be particularly effective is in identifying equipment faults. If an air-handling unit breaks down, it could adversely impact patient health. An EMIS can also help identify simultaneous cooling and heating from variable air volume (VAV) boxes in the ceiling, a common fault in hospitals.

Table 18 provides information for a hospital EMIS.

Table 18. Smart EMIS technologies for hospitals

Technology	Cost level	Estimated cost	Savings level	Energy savings
Cloud- or edge-based EMIS[a]	Varies	Initial: <$0.01–0.40/ft^2 Monthly: <$0.01–0.10/ft^2	High	5–15% whole building

Excludes installation costs. [a] Edge system control processes are performed close to the device rather than from a central location.
Sources: Cloud-based EMIS cost: Granderson, Lin, and Piette 2013; E. Feeny, director of sales, BuildPulse, pers. comm., July 20, 2017. Cloud-based EMIS savings: Gilliland 2016.

Other

Advanced power strips can save energy in a hospital's office areas when connected to computer workstations. In addition, some hospital equipment can be programmed to reduce energy consumption. For instance, hospital imaging equipment, including MRI machines and CT scanners, represent larger plug load users in hospitals. Where possible, equipment should include smart controls like low-power sleep mode (but should still be able to power up quickly when needed).[9] These energy-saving controls should be enabled whenever possible during work hours. For little cost, controls on vending machines can also help save a small amount of energy.

Since hospital campuses use a significant amount of energy, they are more likely than other commercial building types to install distributed energy resources. A renewable energy source like solar photovoltaic panels is one type of DER common to hospitals. Another is combined heat and power (CHP), also called cogeneration, which uses the waste heat from power generation to supplement building air and water heating. In addition to DERs, hospitals may also use energy storage systems, like lithium-ion batteries or fuel cells, to provide emergency backup power. For any of these technologies, it is important to include a distributed energy smart inverter, which allows a two-way connection between the utility and the DER.

[9] We were unable to obtain information on the incremental cost or energy savings for purchasing hospital equipment equipped with smart controls.

Hospitals may also have refrigeration equipment in kitchen areas, labs, and pharmacies. Controls may save 15–30% of energy (Zogg 2016). However smart refrigeration should be viewed as a long-term investment, as it pays off relatively slowly. See the retail section of this report for a more detailed explanation of refrigeration controls.

Table 19 displays information on smart technologies that could be installed in a hospital.

Table 19. Other smart technologies for hospitals

Technology	Cost level	Estimated cost	Savings level	Energy savings
Tier 1 or Tier 2 advanced power strips (offices)[a]	Low	$25–100/strip	Low	26–65% per connected plug load
Vending machine controls	Low	$180/vending machine	Low	20–25% vending machine electricity
Distributed energy smart inverter	High	$0.16/watt	Medium	12% electricity
Refrigeration system controls	Low	$800–900/unit	Low	15–30% refrigeration electricity

Excludes installation costs. [a] In a hospital setting, advanced power strips may not meet medical-grade equipment standards, even if they are used on nonmedical devices. *Sources:* Advanced power strip cost: ACEEE product cost analysis from Amazon.com. Advanced power strip savings: Boss 2016. Vending machine control cost: Morton 2012. Vending machine control savings: Bert 2013. Distributed energy smart inverter cost: Fu et al. 2016. Distributed energy smart inverter savings: Berdner 2015. Refrigeration system control cost: DOE 2017a. Refrigeration system control savings: Zogg 2016.

SMART TECHNOLOGY BARRIERS

To achieve safe and comfortable air quality, hospitals are required to ventilate more than other building types and may use 100% outside air. High ventilation rates, as measured in air changes per hour (ACH), are necessary to prevent the spread of airborne diseases like tuberculosis, protect the safety of immunocompromised patients, and reduce risk of infection in operating rooms (English 2016). Although conditioning fresh outside air is one of the biggest energy users in hospitals, they have much less flexibility than office or hotels to cut energy costs by reducing ventilation.

One consistent problem in health care is the difficulty in prioritizing investment in energy-efficient technology. Smart controls and equipment are often trumped by clinical expenditures on medical equipment and the like. Some larger hospital systems, like the University of Pittsburgh Medical Center (UPMC), address the issue by creating a separate energy department and allocating it a set amount of funding each year for energy efficiency projects (DOE 2017b). In addition, some hospitals deposit energy savings from projects into revolving funds, to support new investments each year. This system has been used successfully by the Spectrum Health Sustainability Fund (Karas and Chartier 2015). However a medium-size regional hospital with a smaller budget and staff will obviously have a smaller fund and fewer opportunities.

One issue is that doctors reign supreme in a hospital. They have enough influence to veto projects that they do not like. To avoid potential problems, they should be consulted before any major smart technology purchases are made.

When installing an EMIS for a hospital, the consequences of a cybersecurity breach must be considered. If the lighting system is hacked and lights are shut off during surgery, for instance, the result could be deadly. If hospital management wants a simple energy information system that has no control over building operation, then a cloud-based system is usually sufficient. However if management want the system to be able to control lighting, HVAC, or plug loads, it is preferable to use a decentralized edge network, which is less vulnerable to attacks than a centralized cloud system. The control processes in edge systems are performed close to the device (i.e., at the edge of the network), rather than from a central location (W. Stoppelmoor, industry standards manager—energy efficiency, Schneider Electric, pers. comm., August 2, 2017).

Additionally, while it is clear that smart technologies can play a role in saving energy in the larger health care IT ecosystem, interoperability among health care devices lags behind other industries. The research organization Frost & Sullivan compares the state of health care IT standards to Internet standards back in 2000, when IT vendors "publicly touted collaborative efforts toward building standards but tended to tweak specifications at the back end just enough to ensure each protected its share of the IT pie" (Ruppar et al. 2017). In other words, many health care devices and IT systems do not play nice with other manufacturers' devices—yet.

Related Sector: Laboratories

Both laboratories and hospitals use substantial energy to ensure adequate air quality. Although the safety of building occupants is the top priority for both buildings, there is still an opportunity to save energy.

Just as exhaust hoods might be found in a hospital kitchen, laboratories often contain fume exhaust hoods. Smart exhaust hood controls can help improve the efficiency of these notorious energy wasters. Additionally, laboratories can install smart HVAC control systems and sensors to detect levels of toxins and contaminants. This ensures that the building is being safely ventilated, but also that energy is not being wasted by over-ventilation.

However the industry is slowly moving toward a more uniform set of interoperability standards. For instance, in 2016 the industry adopted Fast Healthcare Interoperability Resources (FHIR) standards and the Carequality–CommonWell partnership was announced; both moves promote open data sharing and interoperability (Ruppar et al. 2017). As with other industries, it does not appear to be a matter of *whether* the health care industry will solve its interoperability problems, but rather a matter of *when*.

NONENERGY BENEFITS

In a hospital, smart technology can be used not only to save energy, but also to improve patient health. This is important because the patient is the most important stakeholder in a hospital. "All our upgrades are patient-centric," says Richie Stever of the University of Maryland Medical Center. Richie's team decided not to install low-flow sink aerators because they would have increased the risk of patients contracting legionella (R. Stever, director of operations and maintenance, University of Maryland Medical Center, pers. comm., July 27, 2017). However hospitals also purchase smart technologies in order to improve patient health. Sensors and controls can help maintain hospital temperatures, air pressure, and humidity to ensure that conditions are safe and comfortable for patients.

Another way to improve patient health is through lighting. Preliminary research suggests that lighting may have an important impact on sleep and circadian rhythm (i.e., the 24-hour cycle). For instance, one study of an intensive care unit showed that patients preferred an environment in which the lighting cycled with natural daylight; those in rooms with traditional lighting were more likely to experience a disrupted circadian rhythm and even experienced nightmares (Engwall et al. 2015). Some hospitals are even starting to experiment with entire smart hospital rooms, as in IBM's collaboration with Jefferson Health System, which gives patients control of room lighting and temperature through a device that looks like a clock radio (Bengfort 2017).

Maintaining patient satisfaction benefits the hospital, since it earns good survey reviews, gets higher rankings among peers, and stays in business. The senior researcher of a firm that administers one such patient survey, the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS), claims, "Many hospital executives feel their investment in interactive systems . . . is justified as long as it can be measured against patient satisfaction through HCAHPS scores" (Bengfort 2017).

Additionally, some medical equipment can be considered smart and has benefits beyond energy savings. Take a modern, connected magnetic resonance imaging (MRI) machine. The machine collects valuable data about patients. It also uses sensors to collect useful information about its own performance. Modern machines can diagnose whether they need replacement parts or are about to break down, which improves the efficiency and effectiveness of the doctor (Newkirk 2016). This equipment is part of a rapidly expanding hospital ecosystem of smart, connected devices.

Finally, some smart equipment could also help improve hospital security. Since PoE systems are typically supported by an uninterruptable power supply (UPS), security cameras could remain powered by the system during a power outage (Binnie 2014).

DISCUSSION

The health care industry is rapidly changing. Ten years from now most physicians think they will spend more time using data from apps and wearables and less time giving in-person care (PwC 2016). Hospitals typically have complex energy systems and already have EMISs, which provide greater opportunity for smart controls. In the near future, it is entirely possible that through the Internet of Things, the EMIS will coordinate with the surgical schedule to ensure that room conditions are appropriate for a given procedure and to save energy when the room is vacant. Although controls provide a great opportunity for energy savings, hospitals also face greater restrictions on the way they use them, to ensure safety.

In recent years, hospitals have embraced technology more rapidly than any other sector in this report. Federal initiatives like the Health Information Technology for Economic and Clinical Health (HITECH) Act of 2009 have helped expedite this process. For instance, in 2009, the year the economic stimulus package passed, only 12.2% of hospitals had even a basic electronic health record (EHR), but by 2015, 96% had an EHR tested and certified for the government's incentive program (Henry et al. 2016). Hospitals are already using mobile technologies and data analytics to enhance their ability to treat patients, and it is reasonable to assume that they are primed to adopt other technologies to manage energy consumption.

Hospitals represent the most complex building type in this report. This being the case, a variety of smart technologies can be beneficial in reducing a hospital's energy load. However, since hospitals are more stable than the other commercial building types, they may be more willing to invest in smart building equipment with a longer-term payback. Installing monitoring devices like central plant submeters and wireless steam trap monitoring helps the hospital track its equipment and detect faults to avoid wasting energy. An energy information system will help monitor this equipment from a central location. Older hospitals may have pneumatic controls, which can be either replaced with electronic devices or, for a cheaper option, upgraded with wireless pneumatic controls. Smart lighting controls will save energy and may have the added benefit of creating a more comfortable environment for patients.

Conclusions

Table 20 shows some of the estimated smart technology savings and costs detailed throughout this report.

Table 20. Smart technologies costs and savings

Technology	Office		Retail		Hotel		Hospital	
	Cost	Savings	Cost	Savings	Cost	Savings	Cost	Savings
HVAC								
Occupancy-based wireless thermostats	M	H	L	H	H	M	---	---
Learning thermostats	M	H	L	H	H	M	---	---
Submeters (tenant/end-use)	M	M	---	---	---	---	L	H
Advanced rooftop controller	M	H	M	H	---	---	---	---
CO_2 demand-controlled ventilation package	M	H	M	M	L	L	---	---
Electronic window solar film	H	L	H	L	H	L	L	L
Wireless window and patio door contacts	---	---	---	---	M	L	---	---
PTAC or FCU electronic control kit	---	---	---	---	M	M	---	---
Smart kitchen hood exhaust controls	---	---	---	---	M	L	L	L
Automated shade system	---	---	---	---	H	L	L	L
Wireless steam trap monitoring	---	---	---	---	---	---	M	H
Upgrade from pneumatic to electronic controls	---	---	---	---	---	---	H	H
Wireless pneumatic thermostats	---	---	---	---	---	---	H	M

Technology	Office		Retail		Hotel		Hospital	
	Cost	Savings	Cost	Savings	Cost	Savings	Cost	Savings
Combined HVAC and lighting								
Wireless passive infrared ceiling occupancy sensors	---	---	---	---	M	M	---	---
Wireless/batteryless infrared ceiling occupancy sensors	---	---	---	---	M	M	---	---
Lighting								
Smart lighting controls (sensors, retrofit kit, wireless gateway)	H	M	H	H	H	L	H	L
Exterior lighting controls	L	L	L	L	M	L	L	L
Cat-6A cabling	---	---	---	---	---	---	H	L
EMIS								
Cloud-based EMIS	Varies	H	Varies	H	Varies	H	Varies	H
Tenant comfort feedback system	N/A	H	---	---	---	---	---	---
Networked guest room building automation system	---	---	---	---	H	M	---	---
Other								
Tier 1 advanced power strips	L	M	L	L	---	---	L	L
Tier 2 advanced power strips	M	H	L	L	---	---	L	L
Smart plugs	L	L	L	L	L	L	L	L
Vending machine controls	L	L	L	L	L	L	L	L
Distributed energy smart inverter	---	---	H	H	---	---	H	M
Refrigeration system controls	---	---	M	M	---	---	L	L
Smart pool pump controls	---	---	---	---	L	L	---	---

L = low, M = medium, H = high. See Appendix A for cost and savings calculation methodology.

Estimating smart technology energy savings has proved challenging for many in the industry. For example, installing a Wi-Fi–enabled thermostat does not instantly and automatically generate the kind of energy savings that we immediately see when we replace an incandescent lamp with an LED. A smart thermostat enables us to save energy but requires an extra step in the process: human intervention.

To avoid hype and overselling, we had to approach smart technologies with some skepticism. Are they worth the investment? Do they achieve the savings manufacturers claim? After our literature review, case study analyses, and expert interviews, we have developed several overarching conclusions about smart buildings in the commercial space.

Most smart technologies do not directly save energy, but indirectly enable energy savings. It is more difficult to quantify energy savings from smart technologies than from traditional energy efficiency measures like upgrading lighting or HVAC equipment. However, when installed and used correctly, smart technologies do tend to result in energy savings. Often the savings are enough to justify the cost of the technology within a desirable time frame, with paybacks of 2–3 years or less.

Energy savings from smart technologies have a range of uncertainty. Because smart technology energy savings can vary depending on many factors, efficiency program administrators must either include them in custom programs (including pay for performance) or rely on energy savings estimates from case studies to incorporate them in prescriptive programs. This is a major impediment to transforming the smart building market. However the large quantities of data collected by smart technologies may be the key to overcoming this problem.

All building types can invest in smart technologies. All buildings, not just large and well-funded properties, can benefit from smart technologies. Small and medium-size buildings may consider purchasing smart components incrementally, anticipating that smart systems to eventually tie all the components together will continue to fall in price. These smaller buildings can also take advantage of some cloud-based products and services. As another way to save, smart technology upgrades may be most cost effective at major transition points, such as during renovation, when a building is bought/sold, or when a major piece of equipment fails and must be replaced. Smart technology financing options like leasing, performance contracting, and as-a-service businesses can help reduce up-front costs.

Nonenergy benefits of smart buildings can be some of their best selling points. Not all customers are interested in purchasing smart technologies because of the energy they might save. Some care more about the nonenergy benefits. Smart lighting controls can provide a better customer experience. Improved ventilation controls can make hospital patients safer. An energy management and information system increases the value of a property. Understanding how to message about smart technologies can help transform the market.

In terms of capability, smart buildings are still in their infancy. Due to budget constraints and the perception of uncertain energy savings, it is a mistake to think that most commercial buildings will jump at the chance to be early adopters of smart technology. However this report provides guidance on different components of smart office, retail, hotel, and health care buildings that do make sense to install now. These buildings can begin laying the foundation with smart components that ultimately can be phased into smarter systems as the building technology market continues to improve. Future smart buildings, grids, and cities will be connected in ways we cannot currently even imagine and will include more autonomous technology. For the United States to continue to be a leader in this space, utilities, government, and industry must work together to overcome barriers and encourage innovation.

Recommendations

ENERGY EFFICIENCY PROGRAMS

Traditionally, program administrators have a few options in developing incentive programs for energy-efficient equipment. They can create brand-new programs to incentivize the purchase and ongoing use of an energy management and information system. Or they can find a way to incorporate smart components into existing programs.

Most program administrators would like to find ways to incorporate smart technologies into their prescriptive programs. One of their barriers is finding ways to claim energy savings from smart technologies, which typically involve a wide range of uncertainty. As discussed in King and Perry (2017), NYSERDA's Real Time Energy Management (RTEM) program represents an approach that addresses both the up-front system installation costs and the ongoing service contract.

Early reports from NYSERDA on its Commercial RTEM program are promising. In a year and a half, the program has attracted a number of showcase buildings to take advantage of the incentives it offers for energy management systems. The list of approved real-time energy management service providers has grown to around 50, and there are at least another 50 applicants. NYSERDA now reports its biggest challenge is figuring out how to "scale downward" and reach beyond early adopters, such as Class A offices, to buildings with tighter budgets (C. Corcoran, team lead: products, NYSERDA, pers. comm., September 13, 2017).

To move a smart technology from a custom incentive program to a prescriptive program, commercial program administrators could choose to use the residential smart thermostat as the model of success. This requires sufficient modeling, field studies, and demonstration projects to give the program administrator some level of confidence of energy savings.

Because of their high potential for energy savings, some of the smart components discussed in this report that program administrators could consider incorporating into existing programs are:

- Submeters (tenant and end-use)
- Occupancy sensors
- Smart thermostats[10]
- Lighting controls
- Advanced rooftop controls[11]
- Energy management and information systems
- Smart plugs and advanced power strips
- Smart inverters (for distributed energy resources)
- Electronic control upgrade (from pneumatic) or wireless pneumatic thermostats
- Wireless steam trap monitoring systems

[10] Some program administrators include smart thermostats in residential programs. For example, programs from National Grid and San Diego Gas and Electric have begun including smart thermostats in their prescriptive rebate programs (Mizolek et al. 2017). In addition, the ENERGY STAR® program developed criteria and recently started certifying connected thermostats based on lab and field studies. There are currently seven ENERGY STAR–certified models (Mackovyak et al. 2017). This certification gives efficiency program administrators an additional set of criteria to consider when developing incentives.

[11] Some programs, like Mass Save, have experience with advanced rooftop unit control programs going as far back as 2011. These have met with limited success. For many units, retrofitting with advanced controls was cost prohibitive (A. Kulkarni, engineering supervisor, Eversource, pers. comm., July 24, 2017). However, with smart components continuing to fall in price, advanced controls may become tenable for more and more RTUs.

Some program administrators are already incorporating these technologies into their program portfolios. For instance, Hawai'i Energy offers up-front money for submetering used for tenant billing, as well as hotel guest room energy management systems (Hawai'i Energy 2017).

However most program administrators currently incentivize smart equipment and systems through custom programs. These programs are typically structured as pay-for-performance, offering a fixed sum per kWh saved. On the surface, this may seem like a better option than a prescriptive program; however the uptake is higher on prescriptive programs. The money from custom programs is usually contingent on achieving positive results after a period of measurement and verification. This means that a customer is unsure whether he will receive any money until well after the technology has been purchased and installed.

An improved smart technology custom program could include at least a portion of the incentive up front, to help offset initial costs. In addition, programs could consider basing payments in part on the project or subscription cost, rather than only on energy savings, to provide certainty that the customer or contractor will receive some money. This simple adjustment has benefited participants in NYSERDA's RTEM program.

In marketing programs, administrators may also consider targeting the specific nonenergy benefits identified as most important to each sector in this report. For instance, a program designed for offices might reference data on increased employee productivity. Retail and hotel programs could mention improvements in customer experience, sales, and occupancy rates. Programs for hospitals could provide information on the potential for improved patient comfort and health or even draw a connection between the installation of smart technologies and a hospital's ranking among its peers.

However there is reason to believe that progress could be slow if we continue using the same methods to develop incentive programs: running pilots, performing case studies, and building a business case, making changes primarily as a result of program filings that occur only annually or as rarely as every three years. Technologies are developing much faster than the programs we create to promote them, and at a minimum, we need to speed up the pace, reviewing and revising programs at least annually, if not more often at times. In addition, we should consider new approaches to address this disparity, as we discuss in the next section.

LEVERAGING DATA

Throughout this report, we have attempted to highlight the value of leveraging technology in ways that commercial buildings are already adopting. For example, if a hospital is upgrading its network infrastructure to accommodate a new health care IT system, perhaps the hospital could also upgrade its cabling to enable Power-over-Ethernet for lighting and some devices. Using smart technology, there may be a way to help leverage data for efficiency program administrators.

Currently it is difficult for programs to estimate energy savings from many smart products because, as mentioned in King and Perry (2017), "they do not directly save energy but rather help identify opportunities to do so." Often, evidence that smart technology saves energy comes from energy models, case studies, and claims from the manufacturer. Though helpful, these do not give consumers much certainty. For instance, a case study showing X% energy savings in a Manhattan high-rise office building does not necessarily translate to a mid-rise office in suburban Minneapolis.

However there may be a way to take advantage of the data from all the smart equipment that is already being installed. Aggregating and analyzing results collected across many smart building applications would produce a greater level of confidence in energy savings and return on investment than case studies and demonstration projects. For example, an analysis of data from 1,000, 5,000, or 10,000 buildings over multiple years could be much more persuasive than a case study in one building for a three- to six-month period. Access to this kind of data could catalyze the market by reducing the perceived investment risk of smart technologies and providing program administrators data to substantiate savings claims.

When speaking to chief financial officers (CFOs), Wendell Brase, vice chancellor at the University of California, Irvine, recommends proposing "projects with a track record of consistent, assured savings in comparable climates, organizations, and facilities" (Brase 2013). Instead of providing the CFO with assured savings, the smart-technology industry typically gives potential buyers a range of possible savings (as this report has generally done), for instance claiming that a technology can "reduce energy costs between 10% and 30%" or "save as much as 50% of your energy bill." These vague promises of energy savings may not help overcome the barriers of building operators consistently undervaluing energy efficiency. Large-scale monitoring can help the industry overcome this problem. Where it previously was not feasible, smart buildings make it possible.

Achieving this goal will likely require standardization. A party or parties, such as utilities, DOE, or a group of industry experts, could be responsible for developing standards requiring smart technologies to report anonymized data. The connected lighting industry has made the first strides in this area. The ANSI-C137 standard's energy reporting working group is exploring different methods of reporting on such metrics as energy performance verification and failure diagnosis (Arnold 2017). A recently completed study for the Design Lights Consortium demonstrated how this reporting might be used by analyzing detailed energy monitoring data from 114 buildings at the zone or fixture level (Kisch et al. 2017).

One challenge that we will face in leveraging data is finding (or training) building data experts. Buildings data analysis is still an emerging field. Millennials may be able to write software code but unable to differentiate a chiller from a boiler, while the opposite is more likely to be true of baby boomers. Analyzing smart building data requires deep understanding of both technology and building operations, which is why a limited workforce may be one of the biggest barriers to leveraging smart building data on a greater scale. Multidisciplinary apprenticeship programs are one potential solution.

One successful example, the University of Maryland Medical Center's state-approved apprenticeship program, allows apprentices to train on-site to learn building operations and in the classroom to learn about computer programming and technology. This particular program has existed for a year and a half and serves as a model for other workforce development programs (R. Stever, director of operations and maintenance, University of Maryland Medical Center, pers. comm., October 30, 2017).

GOVERNMENT, INDUSTRY, AND PROGRAM ADMINISTRATOR COLLABORATION

Most experts predict that smart buildings will have a defining impact on the future of the economy, from GDP to jobs. Government, industry, and energy program administrators will need to work together to encourage innovation. Administrators can help identify the key smart technology data points they need to help shape their smart building programs. All three stakeholders can ensure that any data collection initiatives protect manufacturers' proprietary information (for example, by anonymizing data). Attempts to leverage performance data should not put any manufacturer at a disadvantage.

Growth will require continued funding for government research and development programs in areas where the private sector is hesitant to invest. ARPA-E, the Advanced Research Project Agency—Energy, was created with the mission to develop advanced energy technologies. One area that ARPA-E is currently exploring is novel sensor ideas. Its SENSOR program is pursuing different low-cost methods of determining occupancy, ranging from sensors that detect the phone in your pocket to those that depend on sound (Gerbi 2017). For sensors and other smart equipment, perhaps including adaptive and fault-tolerant controls, government programs can advance technologies that private markets will not address on their own. Once these innovations are at a certain point of development, the private sector can turn this research into marketable smart building products and businesses.

The high up-front cost of submetering tenants, which can range from $300 to $4,000, discourages many offices from investing in the technology (NSTC 2011). To incentivize a low-cost solution, DOE recently completed its successful "Low-Cost Wireless Metering Challenge," in which the agency recognized one company (out of 30 original participants) for devising a wireless submeter costing less than $100 (DOE 2017f).

Government may also be able to help eliminate some of the other barriers to entry for smart building technologies. For instance, a bipartisan group of senators introduced legislation to attempt to tighten the security of Internet-of-Things devices (Volz 2017). Although this bill applies only to devices sold to the government, regulations could help secure an industry that, from a cybersecurity perspective, is still the Wild West. Government, efficiency program administrators, and the private sector must also work together to overcome the barriers of interoperability and workforce training. In addition, the industry would benefit greatly from collaboration among organizations such as the National Electric Manufacturers Association (NEMA), Consortium for Energy Efficiency (CEE), and Edison Electric Institute (EEI) to develop a common definition of smart buildings and create a framework for the evolution of standards.

Last Word

Equipment we use daily, from cell phones to cars, contains an increasing number of smart sensors and microprocessors. The commercial building industry is following, and this trend promises to continue to grow over time. Smart components and controls can reduce wasted lighting, HVAC, and plug load energy. A central energy management and information system can analyze the data these devices collect and provide reports and recommendations to improve a building's operations. Subsectors like offices, retail stores, hotels, and hospitals are all prime candidates for smart technologies. However it is imperative that efficiency program administrators working on smart building programs address the limitations of and motivations for investing in new technologies. For those involved in the industry, a critical next step is figuring out a way to move beyond case studies and demonstration projects, to take advantage of the massive quantities of data collected by smart technologies. These data could be the key to legitimizing energy savings claims and expanding the market. Accomplishing this will likely require collaboration among key stakeholders, including manufacturers, utilities, and government. The sooner the average commercial building becomes smart, the sooner smart buildings can develop into smart cities connected to a smart grid, adding value to our lives and revolutionizing US energy efficiency in the process.

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Appendix A. High, Medium, and Low Cost and Savings Assumptions

Throughout this paper, we designate the cost and savings for different technologies as high, medium, or low. We developed these designations through a set of calculations and assumptions. We estimated the actual cost and energy savings for the prototype buildings referenced in Appendix C (a 16,000-square-foot office building, 18,000-square-foot retail store, 35,000-square-foot hotel, and 250,000-square-foot hospital).

Although we provided a range of possible costs and savings in the report, we used conservative figures to characterize savings as H, M, or L. For instance, we estimated wireless thermostats to save 10–30% of HVAC energy, but we used an estimate of 15% in our savings characterization. The 15% is higher than the lowest end of the estimate (10%), but not quite the average (20%). We based these summary values on our experience with commercial building technology and a desire to err on the side of underestimating rather than overestimating energy savings.

We also developed our own assumptions about building use, using published resources where available, such as the percentage of plug loads in an office that are workstations. Measures that saved up to 3% of whole-building energy consumption were considered *low*, measures equal to or greater than 3% and below 6% were considered *medium*, and 6% energy savings or greater were considered *high*.

Similarly, to characterize costs where the report provides a range, we used the medium to high end of the range. To determine the relative cost for each building type, we divided the cost of each smart technology measure by the building's estimated total annual energy consumption. We multiplied the 2012 CBECS average annual energy consumption by a blended average energy rate of $0.11 per kWh.

For office, retail, and hotel, if a project cost less than 10% of the total energy budget, then it was considered low; 10% or above but below 40%, medium; and equal to or greater than 40% was high. Because hospitals have such high energy costs, we used a slightly different metric for hospitals: up to 3% for low, equal to or greater than 3% but below 7% for medium, and equal to or greater than 7% for high.

Appendix B. EMIS Cost Methodology

Well-established companies like Johnson Controls, Schneider Electric, and Intel, as well as newer start-ups, are all currently competing in the smart buildings space. Between 2008 and 2016, more than 250 smart building companies were founded (Memoori 2017). With so many available vendors and technologies, it can be overwhelming for a facility manager or operator to understand the best fit for his or her building. In addition, it can be difficult to understand what a smart building system costs, since prices are rarely advertised on a company's website.

King and Perry (2017) indicated an up-front cost range of \$0.01–0.77/ft^2 based on Granderson, Lin, and Piette (2013). Since that report, we have conferred with practitioners in the industry and have revised the number to more specific ranges: an initial cost of \$0.01–0.40/ft^2 and an ongoing cost of less than \$0.01–0.10/ft^2 per month. A vendor indicated that since the 2013 estimate, the original upper end of the range, \$0.77, had fallen due to competition among vendors.

The lower end of the cost range applies most often to large buildings or portfolios of buildings, due to economies of scale, or buildings with existing state-of-the-art systems. The cheapest systems to install typically require little to no hardware installation. However these options also tend to offer none of the benefits of control or automation. For a large building with relatively new HVAC equipment, it is possible to install a software-only cloud-based EIS package for zero up-front and less than \$0.01 per square foot on an ongoing monthly basis. The main benefits of this system will be to provide trending of the building equipment and automated fault detection and diagnostics.

The upper end of this range, around \$0.40/ft^2 initially and \$0.10/ft^2 per month, requires the installation of both hardware (e.g., sensors and controls) and software. Often, in buildings with older, legacy equipment, the smart building consultant will need to spend more time connecting to the equipment, and this will increase the cost. These more expensive options can provide real-time analytics and fault detection and can integrate with an existing BAS to automate building HVAC and lighting. Solutions that provide automation may be too expensive for a budget-constrained building; however they can be justified in certain situations, as in very large buildings with inconsistent occupancy, or large portfolios of buildings that do not have building operators.

Most EMIS technologies will fall in between these extremes, using some combination of hardware and software to provide varying degrees of analytics and controllability. Some vendors specialize in different building sectors, and each will offer a different type of smart building solution. When it comes to purchasing an EMIS, we recommend focusing on the perceived return on investment more than on cost.

Appendix C. Sector Energy Savings Assumptions

We used the following assumptions to determine our estimated average energy savings per building, for both the whole-building energy savings estimates in table 2 and the individual end use estimates in figures 3, 5, 7, and 9. Just as we did with the high, medium, and low energy savings assumptions, we used the conservative end of ranges for cost savings. We used 2012 CBECS data to calculate average building size and portion of end-use energy consumption.

OFFICE

Using an average 16,000-square-foot office building that uses about 400,000 kWh of energy per year, we estimated that four smart building upgrades can achieve 21% energy savings, equivalent to 80,000 kWh per year. Submetering of tenants saves 3% of whole-building energy. Smart thermostats save 15% of total HVAC energy, which is 52% of the building's energy consumption. Additionally, a smart lighting retrofit saves 30% of the building's lighting energy use, which is 12% of the total energy use. Finally, advanced power strips and smart plugs will reduce plug load energy consumption by 20%, and plug loads represent 16% of the building's energy use.

RETAIL

We used an average retail building of 18,000 square feet, which uses about 500,000 kWh of energy per year. We calculated smart technologies can save 22% of its annual energy consumption, equal to almost 120,000 kWh. Since it is a small retail store, we went with smart thermostats over a whole building EMIS. Smart thermostats are estimated to save 15% of the building's HVAC energy consumption, which is 45% of its energy use. In our assumption, lighting represents 20% of the retail store's energy use and achieves 30% energy savings from a smart lighting retrofit. Finally, advanced power strips and smart plugs reduce energy use from plug loads (like point-of sale equipment and other electronics) by 25%. Plug loads are estimated to represent 5% of energy consumption.

HOTEL

We calculate that at an average size of 35,000 square feet and an energy usage of 1 million kWh, a hotel can save about 8% of its energy, equivalent to nearly 90,000 kWh. Guest room thermostats and sensors can save 20% of HVAC energy, which is 28% of the building's energy use. We assume the hotel to be 75% guest rooms and 25% common areas and conference space. A smart lighting retrofit can save 30% of lighting energy, which is 7% of a hotel's energy use. However we also estimate that the average hotel can save lighting energy only in common areas, conference areas, and guest/public bathrooms, which is only 50% of the building's lighting. Smart plugs can save 25% of plug load energy in unrented guest rooms. Guest room plug loads represent about 11% of the building's energy use, but only 50% will be reduced by plug load controls. In addition, smart pool pump controls save 30% of the pump energy, and pumps use 2% of the building's total energy.

HOSPITAL

We estimate that the average hospital of 250,000 square feet that uses 18 million kWh per year can save 17% of its energy use, equivalent to 3 million kWh. A smart lighting retrofit can save 30% of the building's lighting energy, which is 7% of the building's energy use. In addition, the combination of central plant submetering, steam trap monitoring, and a central EMIS reduce air heating and water heating by 20% and cooling by 15%. In our assumptions, heating represents 30% of energy use, cooling represents 12%, and water heating is 14%.

Appendix D. Sample Hotel Room Notices

Your room is equipped with an occupancy sensor. Eight minutes after you leave your room the temperature in the room will increase by approximately six degrees in the summer, and will decrease by six degrees in the winter. However, immediately upon your return, the sensor will recognize your presence and will return the temperature of the room to whatever you have set within just a few minutes. This feature allows us to save valuable energy for heating and cooling when it is not being demanded by the guest. The room's temperature will not rise to the point of being uncomfortable for an extended period of time in the summer, nor will it be lowered to an uncomfortable temperature for an extended period of time in the winter. If you have any concerns with the temperature of your room, please call the engineering department at (number) for assistance. Thank you.

Figure D1. Sample table tent for guestroom occupancy sensors. ***Source:*** **Baloglu and Jones 2015.**

You may have noticed that certain lights have been turned off, such as the outdoor sign in the daytime, or perhaps a bank of lights in the hallway. This is due to a peak load shaving system that turns off some of the electrical functions in the hotel while other electrical functions start up. This prevents us from demanding too much electricity from the power company at critical demand times thus ensuring that our community will not face a brownout or blackout. We thank you for your patience and we hope this will not be an inconvenience to you. If you have any concerns, please call our engineering department at (number). Thank you.

Figure D2. Sample table tent for peak load control systems. ***Source:*** **Baloglu and Jones 2015.**