GREATER THAN THE SUM OF ITS PARTS

THE CASE FOR A SYSTEMS APPROACH TO ENERGY EFFICIENCY

ALLIANCE TO SAVE ENERGY

Systems Efficiency Initiative

Year 1 Report / **May 2016**

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Acronyms and Abbreviations

AC	Alternating Current
ACEEE	American Council For an Energy-Efficient Economy
AEC	Architecture, Engineering, and Construction
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ALA	American Lighting Association
ANSI	American National Standards Institute
ASE	Annual Sunlight Exposure
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASID	American Society of Interior Designers
B2G	Building-To-Grid
BAS	Building Automation System
BEQ	Building Energy Quotient
BMS	Building Management Systems
BTU	British Thermal Unit
CBECS	Commercial Buildings Energy Consumption Survey
CBO	Congressional Budget Office
CDA	Continuous Daylight Autonomy
CEC	California Energy Commission
CEE	Consortium For Energy Efficiency
CFL	Compact Fluorescent Lamp
CIEE	California Institute For Energy and Environment
CO2	Carbon Dioxide
DC	Direct Current
DDS	Direct Digital Control
DGP	Daylight Glare Probability
DOE	U.S. Department of Energy
DSM	Demand-Side Management
EER	Energy Efficiency Ratio
EERS	Energy Efficiency Resource Standards
EIA	Energy Information Agency
EISA	Energy Independence and Security Act
EMS	Energy Management Systems
EPA	U.S. Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESPC	Energy Savings Performance Contract
EUI	Energy Use Intensity
EV	Electric Vehicle
FDD	Fault Detection and Diagnostics
FTC	Federal Trade Commission
GSA	General Services Administration
HP	Horsepower
HVAC	Heating, Ventilating, Air Conditioning
HVAC&R	Heating, Ventilating, Air Conditioning, and Refrigeration

IALD	International Association of Lighting Designers
ICC	International Code Council
IECC	International Energy Conservation Code
IEER	Integrated Energy Efficiency Ratio
IEQ	Indoor Environmental Quality
IES	Illuminating Engineering Society
IGCC	International Green Construction Code
IOT	Internet of Things
IP	Internet Protocol
IPLV	Integrated Part-Load Value
IRS	Internal Revenue Service
IT	Information Technology
LBNL	Lawrence Berkeley National Laboratory
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
MELs	Miscellaneous Electric Loads
MRI	Magnetic Resonance Imaging
NAECA	National Appliance Energy Conservation Act of 1987
NBI	New Buildings Institute
NEEP	Northeast Energy Efficiency Partnerships
NEMA	National Electrical Manufacturers Association
O&M	Operations and Maintenance
PC	Personal Computer
PD	Power Delivery
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
POE	Power Over Ethernet
PSEG	Public Service Electric & Gas
PUE	Power Usage Effectiveness
PV	Photovoltaics
RD&D	Research, Development, and Demonstration
ROI	Return on Investment
RTU	Rooftop Unit (Air Conditioner or Heat Pump)
SDA	Spatial Daylight Autonomy
SEI	Systems Efficiency Initiative
UDI	Useful Daylight Illuminance
UESC	Utility Energy Service Contract
VAV	Variable Air Volume
WWR	Window To Wall Ratio
ZNE	Zero Net Energy

*A **building system** is a combination of equipment, operations, controls, accessories, and means of interconnection that use energy to perform a specific function.*

INTRODUCTION

Programs and policies aimed at improving energy efficiency in buildings have traditionally focused on individual building components or on whole-building performance. The energy efficiency of building components (i.e., appliances and equipment) has improved substantially over the past decades due to government and industry research and development efforts, spurred by appliance and equipment minimum efficiency standards, and supported by government, utility, and industry programs (e.g., efficiency labeling and rebates). Improvements in the energy efficiency and overall performance of buildings as a whole have been driven by building energy codes and supported by various voluntary programs, such as ENERGY STAR® Buildings and Leadership in Energy and Environmental Design (LEED), which rate building energy performance based on either design features or actual energy use.

Recently, across the spectrum of individual components as well as building types, industry experts and efficiency advocates have been looking beyond these familiar energy-saving measures to consider new opportunities at the building systems level—opportunities not easily captured either by making individual devices more efficient or by emphasizing whole building performance. Other sectors, such as the industrial and wastewater treatment sectors, already have witnessed strong positive results from pursuing system-level efficiency measures. Experts agree that significant untapped opportunities also exist to increase overall energy savings in buildings by focusing on building systems; however, few attempts have been made to methodically quantify the energy savings or develop strategies to achieve these savings. To explore this potential, the Alliance to Save Energy launched the Systems Efficiency Initiative (SEI)—a collaboration of more than 50 private-sector partners, utilities, government agencies, and research organizations—in early 2015.

The goals of the SEI are to better understand opportunities for improving systems-level energy efficiency—primarily in new and renovated commercial and high-rise residential buildings— to make a compelling case for a new approach to pursuing energy efficiency and to develop a recommended plan of action for incorporating systems-level efficiency considerations in future policies and programs.

The SEI Steering Committee decided that this Initiative would first focus on new and total renovated office and multi-family buildings, because this set of buildings affords large opportunities for energy savings and relative flexibility for systemic changes. In addition, relatively speaking, more similarity of features and systems exists among office and multi-family buildings, compared with industrial buildings or single-family homes. The inclusion of multi-family buildings also offers an opportunity to begin looking at residential end-uses and systems, but in buildings with some economies of scale compared to a single-family home. The Committee agreed that it would be most feasible to focus initially on larger commercial buildings (larger than 25,000 square feet), where potential savings are the greatest—and to eventually consider adding buildings of all sizes. The emphasis on new construction and totally renovated buildings reflects the fact that these types of buildings provide the most flexibility for systems changes; the SEI thus is first exploring systems approaches for new construction and major renovations, and then will consider how these can be applied to existing building retrofits.

The members of the SEI determined that—since technical analyses are already underway by the industry—the SEI's most useful contribution would be to focus on characterizing systems opportunities in broad terms, and on market and policy barriers and strategies for overcoming them. During Year One of the Initiative, the SEI thus formed technical committees to examine opportunities, barriers, and solutions for mechanical systems, lighting systems, and multi-systems integration. This report summarizes the results of the work undertaken by these committees to characterize the energy-savings potential of a building systems approach, and to prioritize areas for technical and policy research during Year Two. These findings will provide input for recommendations on how to better incorporate systems-level efficiency into current government policies, codes and standards, utility programs, industry and professional business practices, and proposed future federal and state legislation. The report also discusses many of the non-energy benefits of systems optimization. Finally, it addresses issues that have growing impacts on building energy use—including miscellaneous electric loads (MELs), direct current (DC) power, and building-to-grid (B2G) integration opportunities—in the context of building systems energy efficiency.

The systems approach to improving building energy efficiency that is outlined in this report complements the traditional prescriptive approach that addresses individual equipment components, and the whole-building approach that is addressed through current building codes (using the performance budget path) and energy benchmarking programs. Even as individual components become more efficient over time, additional savings can be realized through creative solutions designed using an integrated systems approach to achieve the next level of efficiency in buildings.

This report identifies a variety of important issues to address during Year Two of the SEI. These include further quantification of the energy savings potential and other benefits of a systems-efficient building approach, needs and opportunities for system efficiency improvements in existing buildings, further analysis of the interactive effects of individual building systems (including the building envelope), and suggested areas for quantitative modeling of efficiency opportunities for lighting systems and heating, ventilating, air conditioning, and refrigeration (HVAC&R) systems.

1.1 Defining Building Systems Efficiency

Efficiency measures can be applied on several levels, from the individual device or component to the subsystem, system, multiple systems, whole building, and finally, the multiple-buildings scale of a campus or the utility grid itself. The term "system" is used in a variety of ways in the buildings industry. To facilitate the discussion and ensure consistency, the members of the SEI have, for the purposes of this Initiative, agreed on several definitions related to building system energy efficiency:

- A building system is a combination of equipment, operations, controls, accessories, and means of interconnection that use energy to perform a specific function. Building systems may be mechanical, such as climate control (HVAC) and water heating systems, or non-mechanical, such as lighting systems or office electronics. A building system refers to one of many systems within a building, rather than to a building as a whole.

- Building system energy efficiency is the ratio of (a) the services or functions provided by a building system to (b) the amount of energy that system consumes directly, taking into account the thermal load imposed on other building systems.
- A systems-efficient building is defined as a building in which multiple building systems (e.g., lighting, HVAC&R) are designed, installed, and operated to optimize performance collectively with one another and with energy systems outside of the building, to provide a high level of service or functionality for a given level of energy use or input.

The two major building systems addressed in this report are mechanical systems and lighting systems. Examples of systems approaches for mechanical systems include: the use (and optimized control) of variable speed drives and efficient fans and pumps to improve the overall efficiency of HVAC&R systems; the use of "demand-controlled" ventilation; heat transfer from cooling to heating zones and energy recovery from exhaust air; system enhancements, such as economizers and evaporative cooling; and optimized control of cooling towers, pumping systems, and strategic chiller sequencing to improve annual chiller system efficiency.

The SEI focuses on lighting controls as a primary strategy for achieving energy savings in lighting systems. Controls primarily are used for occupancy-based lighting, dimming (in response to daylight availability, occupant preference, and/or demand-response signals from the utility grid), and to some extent for lumen maintenance (i.e., to adjust light output for declining lamp efficacy over time while avoiding initial excess illumination). Other lighting system-oriented strategies include:

- Orientation, design and massing of a building (general shape and sizing), along with the allocation of floorspace to different uses, to allow daylight to penetrate as many spaces and serve as many occupants as possible;
- The use of glazing and light shelves (horizontal surfaces that reflect daylight deep into a building), specialized window films, or other means of projecting daylight further into a building;
- Appropriate use of task lighting;
- Integrated control of lighting and exterior blinds or other façade features; and,
- Interior design (e.g., furniture layout, use of light-colored surfaces) to maximize useful daylight, while minimizing glare and contrast.

1.2 Building Energy Use

To understand the opportunities represented by a systems efficiency approach, one must first understand building energy use. This section provides an overview of the energy use patterns and issues related to buildings, with a focus on U.S. commercial buildings.

About 40 percent of U.S. total energy is consumed by the buildings sector (U.S. DOE, 2012a). The Energy Information Agency's (EIA)'s 2012 Commercial Buildings Energy Consumption Survey (CBECS) shows that approximately 5.6 million commercial buildings exist in the United States (EIA, 2015a). Commercial buildings account for a substantial quantity of total building energy use and have very long useful lives. Over the last three decades, the rate of new construction and replacements has averaged about 500,000 buildings per year, or roughly one percent of the building stock each year (EIA, 2015d). Utilizing a systems efficiency approach during the design phase of these new buildings will ensure that decisions about installing, upgrading, or replacing major building components will take into account the efficiency of entire building systems—and will help lock in energy savings for decades, provided that the buildings are properly commissioned and maintained. Note that 50 percent of commercial buildings (representing nine percent of floorspace) are smaller than 5,000 square feet and 88 percent of buildings (36 percent of floorspace) are under 25,000 square feet (EIA, 2015d). These small commercial buildings account for roughly 33 percent of the total commercial floor space. Some key energy metrics for buildings in the United States as of 2014 are shown in Table 1.1.

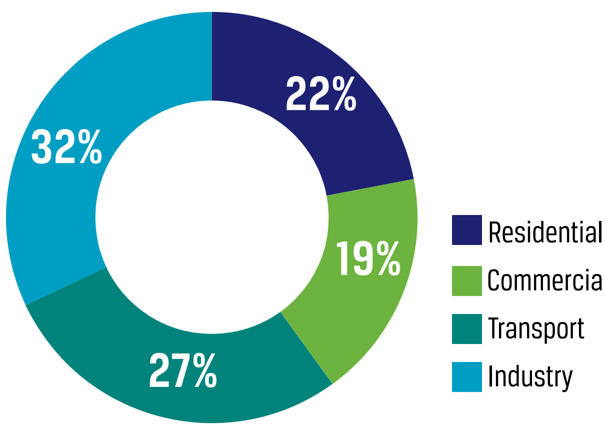
Table 1.1 – Overall USA Energy Metrics (2014)

	Primary Energy		Electricity	
End Use	TBtu (10^{12} Btu)	Percent	GWh (10^{12} kWh)	Percent
Residential	21,641	22.0%	1,403	37.7%
Commercial	18,402	18.7%	1,358	36.5%
All Buildings	*40,043*	*40.7%*	*2,761*	*74.2%*
Industry	31,279	31.8%	956	25.7%
Transportation	27,108	27.5%	8	0.2%
Adjustment	25	--	--	--
Total	98,455	100%	3,724	100%

Source: Energy Information Administration, 2015a

Figure 1.1 summarizes the distribution of energy use in the United States. This figure shows that commercial buildings use almost 19 percent of total primary energy, which includes electrical losses incurred in generating and delivering electricity to the building.

Figure 1.1 – U.S. Primary Energy by End-USe Sector, 2014

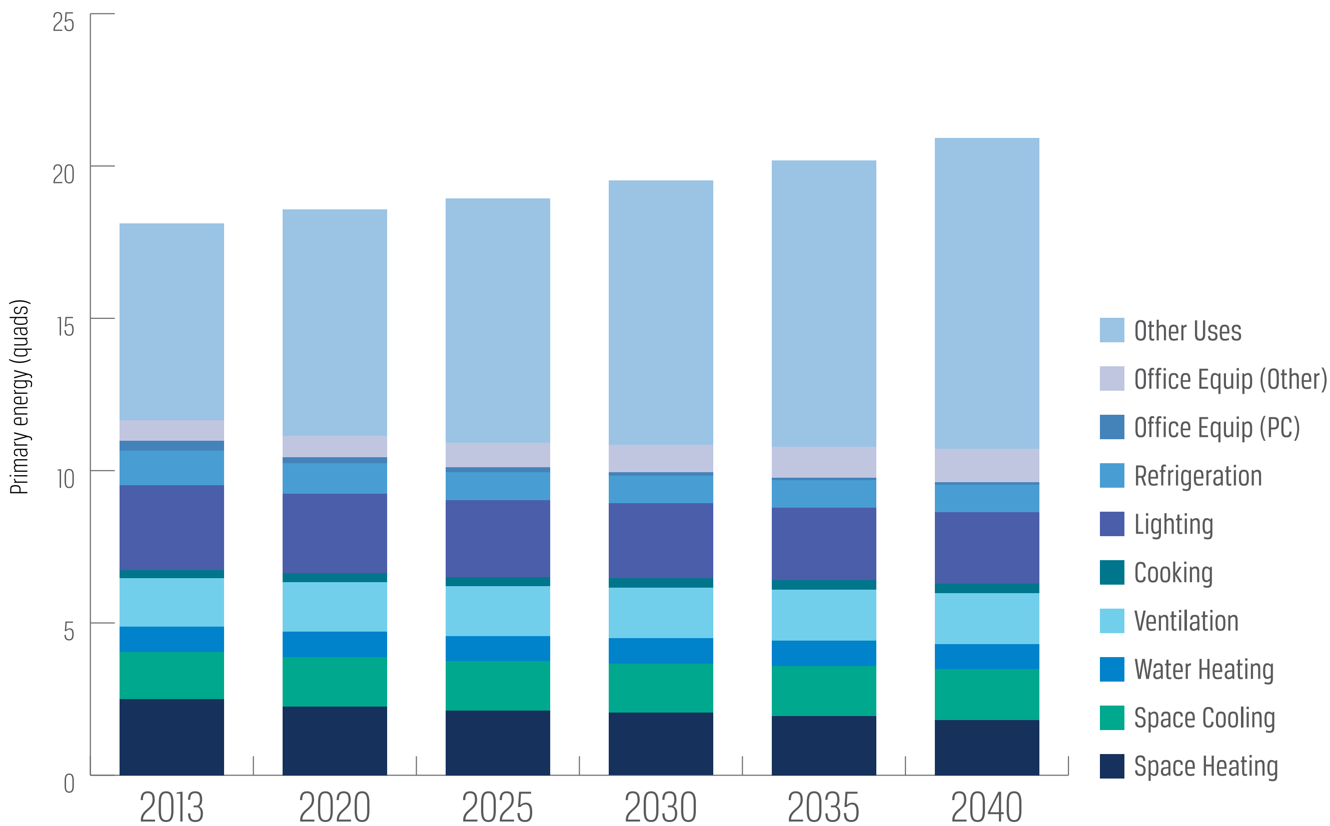


Source: Energy Information Administration, 2015b

Understanding the ways in which buildings use energy is necessary in order to design the most effective ways to save energy. The thermal loads, energy use, and operating hours of commercial buildings are different than those of residential buildings. For example, most commercial buildings are occupied during the day and unoccupied during the evening and weekends—the opposite of residential buildings.

Figure 1.2 shows the distribution of primary energy (including electrical system losses) by end-use for all commercial buildings in the U.S., as estimated by the EIA through 2040 (EIA, 2015c). HVAC&R currently represents by far the largest use of energy: about 37 percent of commercial building primary energy and 34 percent of electricity. Next is lighting, with about 15 percent of primary energy and 20 percent of electricity in commercial buildings.

Figure 1.2 – Projected Commercial Building Energy by End-Use



Source: U.S DOE 2015a Annual Energy Outlook, Reference Case, Table A5

Figure 1.2 also shows the projected changes in energy end-use shares in commercial buildings over time. The projected reduction in the share of lighting energy is notable, and may even be conservative, given the rapid introduction and decrease in price of light-emitting diode (LED) lighting. The share of energy use for space heating also is expected to decrease, due to better building envelopes and increased internal plug loads and miscellaneous loads, which emit heat into the building space. The "other" (miscellaneous) category shows a significant increase and, by 2035, is projected to be the largest single energy load in buildings. Developing strategies for reducing these miscellaneous loads through increased efficiency and improved management of thermal loads is one of the key needs for a systems efficiency approach (see Section 2.3.1).

Other critical factors to consider in designing an effective systems efficiency approach are the ways in which buildings actually operate and under what conditions. The current standards to which most buildings must adhere are sometimes based on temperatures and humidity levels that reflect maximum summer and winter conditions when HVAC equipment is operating at or close to full-load conditions. Because such standards do not fully reflect the actual conditions under which most buildings operate—mostly at part-load—during much of the year, building equipment may be designed to perform best under conditions that will not actually be encountered in practice. Shifting to a systems approach provides new opportunities for building designers and operators to maximize the efficiency of whole systems—equipment, operations, controls, accessories, and interconnections—based on more realistic operating conditions.

1.3 Limitations of Traditional Efficiency Approaches

In addition to better addressing how buildings actually use energy, a systems approach also is critical for achieving energy savings that are not attained by focusing on individual components or whole-building efficiency.

1.3.1 Limits of a Component Efficiency Focus

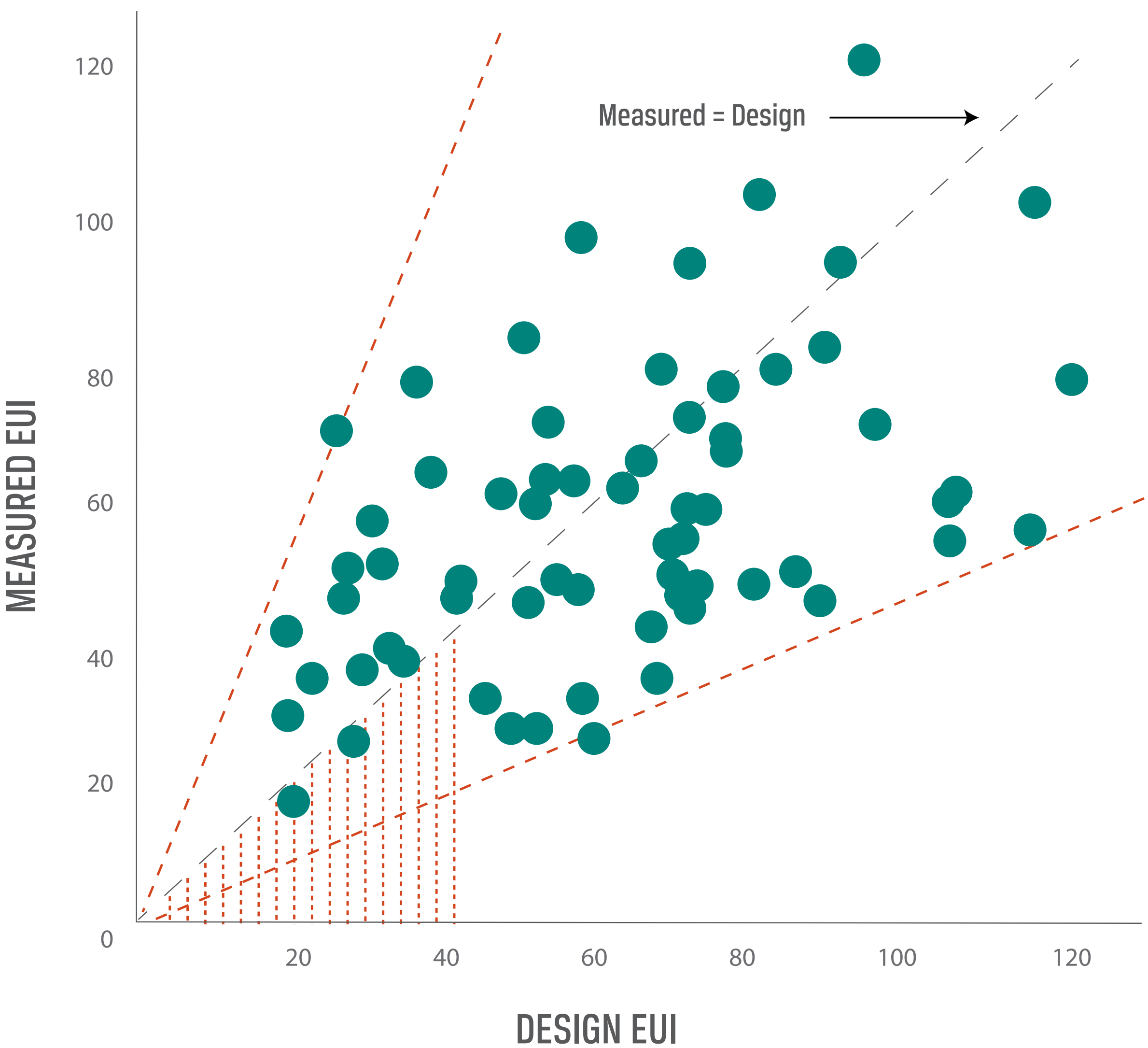
In some cases, the potential for future energy efficiency gains at the component level is decreasing, for several reasons. First, combining highly efficient individual components will not always yield an efficient building. To truly optimize building efficiency, there is a need to take into account complete building systems and their interactions with one another, the building and its occupants, and the environment. In addition, emerging opportunities for attaining significant efficiency gains—such as through the integration of smart grid and related control technologies—are optimally applied at the system, rather than at the component, level.

Another important factor is that some individual components are approaching technical and economic limitations on further efficiency improvements, as a result of technological advances over time. These advances have been driven by increasingly stringent efficiency standards, as well as market transformation efforts at the product level, including appliance energy labels, ENERGY STAR® labels, utility incentives, federal and state tax credits, government procurement preferences, and "X-prizes" for innovative emerging technologies. In many cases, further incremental energy savings are possible and, in the case of some equipment and components, significant energy efficiency opportunities remain. However, some of these efficiency gains at the component level may depend on a technology shift—as with incandescent to compact fluorescent lamps (CFLs) to LED light bulbs; single-speed to variable-speed compressors, fans, and pumps; or direct heating to air- or ground-source heat pumps—and these alternative technologies might not be applicable in all situations. In addition, for some products (e.g., many types of mechanical equipment), incremental efficiency gains will be increasingly expensive to achieve. These limitations are discussed in greater detail in Section 2.1.

1.3.2 Limits of a Whole-Building Efficiency Focus

Although building energy codes and other whole-building measures have resulted in efficiency improvements in many buildings, the whole-building approach also has limitations. One challenge with setting efficiency targets at the building level is that current modeling tools must make a variety of assumptions during the design phase about a building's future operating schedule, type of occupancy, and many other circumstances that will affect energy use, thereby introducing many areas of uncertainty. Figure 1.3 compares predicted and measured energy use intensities (EUIs) of a range of commercial buildings; the results underscore the significant challenge of predicting future performance based on design-stage modeling. Work is underway to improve the accuracy of such models and their input assumptions (e.g., through new standards such as ASHRAE Standard 205, "Standard Representation of Performance Simulation Data for HVAC&R and Other Facility Equipment.")

Figure 1.3 – Whole Building Modeled Energy Use Versus Measured Results



Source: Turner and Frankel, 2008

One common approach used in building modeling is to compare predicted performance to a baseline building and determine the results according to relative performance improvements. This is the method used for the Energy Cost Budget "performance path" in ANSI/ASHRAE/IES[1] Standard 90.1 (ASHRAE 90.1), which serves as the model energy code for commercial and high-rise residential buildings, and in the Standard 90.1 Appendix G, as well as by the LEED rating program and other building energy rating methodologies. This resource-intensive approach, however, tends to be cost-effective mainly for large, high-end buildings, which

1 ANSI: American National Standards Institute; ASHRAE: American Society of Heating, Refrigerating and Air-conditioning Engineers; IES: Illuminating Engineering Society.

account only for about 20 percent of buildings in the U.S. Given that more than one half of buildings are smaller than 5,000 square feet and almost 90 percent are under 25,000 square feet, establishing a more user-friendly method for analyzing building performance is critical. A number of organizations have worked to develop simplified energy modeling and analytical methods for small buildings, and the AirConditioning, Heating, and Refrigeration Institute (AHRI) is looking at systems approaches and associated systems metrics that might eventually be applicable to smaller as well as larger buildings.

The historical focus on regulating the efficiency of a new building based on its design and construction also has limited effectiveness as a whole-building performance approach, since it does not devote adequate attention to start-up commissioning (and periodic re-commissioning) of a building to ensure that equipment is operating as intended. Even whole-building commissioning—generally defined as commissioning of all building systems (e.g., building envelope, HVAC, electrical, plumbing)—often focuses on the performance of individual components or systems, rather than interactions among systems.

1.4 Benefits of a Systems Approach

To date, few attempts have been made to systematically quantify the potential energy savings achievable by focusing on building systems. Estimates presented at a 2014 European workshop suggest that energy savings related to both HVAC and lighting could be roughly doubled by moving beyond single devices to systems-level efficiency (ECEEE, 2014). The American Council for an Energy-Efficient Economy (ACEEE) estimates that system efficiency opportunities for energy savings "dwarf component-based efficiency improvements by an order of magnitude" (Elliott et al., 2012). Based on the concept of "intelligent efficiency," ACEEE attributes such savings mainly to enhanced performance data and control capabilities to improve the long-term operation and maintenance of systems, as well as feedback to, and engagement of, building operators and occupants.

Year Two of the SEI effort will provide opportunities—including through modeling exercises—to better quantify the potential energy savings from various systems efficiency improvements. However, the initial results presented throughout this report amply justify increased attention to better understanding, documenting, and fully exploiting the opportunities that could be achieved through systems-level energy efficiency. Example of these opportunities include:

- For mechanical systems (e.g., HVAC&R and hot water): Recently published research, development, and demonstration (RD&D) roadmaps developed for the U.S. Department of Energy (DOE) for emerging HVAC technologies, as well as for water heating systems (Goetzler et al., 2011; 2014), identified a number of systems-level technologies with the potential for significant savings if applied to commercial buildings nationwide. Examples from the 2011 study included solar-enhanced (desiccant) cooling, demand-controlled ventilation, and a dedicated outdoor air system to separately control latent and sensible cooling loads, which individually had the potential to save between 0.1 and about 1.1 Quads/year of energy.[2]
- For lighting systems: Savings estimates for energy-efficient lighting systems vary widely, depending on such factors as the types of buildings studied, lighting requirements (e.g., lighting intensity and hours of use), lighting measures included, and the baseline used for comparison (for example, pre-retrofit conditions in an existing building versus a planned lighting system in a new, code-compliant building). A recent meta-analysis of the literature on energy savings from lighting controls

2 Note, however, that these savings estimates are not strictly additive; the study did not examine the effects of various combinations of measures.

in commercial buildings looked at 240 studies, concluding that national savings from various strategies would be ". . . 24 percent for occupancy [controls], 28 percent for daylighting, 31 percent for personal tuning, 36 percent for institutional tuning, and 38 percent for combined approaches"[3] (Williams et al., 2012). A field demonstration of lighting controls in two General Services Administration (GSA) federal office buildings with updated LED lighting found measured savings of 32–33 percent of lighting energy (Wei et al., 2015). Another study of a recently built high-performance office building in New York City measured the impact of lighting controls (along with other measures) on three floors. Energy savings of 56 percent resulted from daylight dimming controls and setpoint tuning in the daylighted spaces, compared to a code-compliant (ASHRAE 90.1-2001) building with scheduled on/off controls only (Lee et al., 2013). The authors further noted that, in buildings that have LED lighting, the incremental cost of dimming controls is relatively small.

In addition to reducing energy use, a systems approach also has the potential to achieve measurable non-energy benefits, due to buildings' significant environmental impacts:

- Buildings are responsible for about 38 percent of U.S. greenhouse gas emissions and a significant amount of other air pollutants, including emissions from direct fuel use and indirect emissions from power generation and fossil fuel extraction, processing, and delivery. Commercial buildings alone account for about 18 percent of direct and indirect greenhouse gas emissions (U.S. DOE, 2012b).
- In 2003, buildings generated an estimated 170 million tons of waste from construction, renovation and demolition, with 39 percent coming from residential and 61 percent from nonresidential sources. Of the total buildings-related waste stream, 49 percent was from building demolitions, 42 percent from renovation, and 9 percent from building construction (EPA, 2009).
- Buildings account for 13 percent of potable water consumption—12 percent for commercial buildings and one percent for residential buildings (Moore, 2006).

The growing movement for green building design considers a variety of these environmental impacts from buildings, including the embedded energy in water, construction materials, and waste; and the energy used for transportation to and from the buildings.

Both energy-related and non-energy impacts can be addressed through a systems efficiency approach. For example, a systems approach can enable improvements in indoor environmental quality (IEQ) through locally optimized temperature, improved ventilation with heat or enthalpy recovery, incorporation of daylighting and controls, and improved building envelopes. Improved IEQ help boost occupant comfort, productivity, and health. More comprehensive monitoring and controls also can result in improved equipment reliability and preventive maintenance (thus extending equipment life and reducing the waste stream) as well as grid-responsive capabilities that help avoid power outages while offering a potential added revenue source to the building owner.

1.5 Other Building Systems

In addition to addressing energy efficiency opportunities related to mechanical and lighting systems, the SEI is exploring other issues

3 Savings from these individual lighting measures are not necessarily additive.

that have growing impacts on building energy use and that create opportunities that can be harnessed to improve the efficiency of building systems. These include micscellaneous electric loads (MELs), DC power, and building-to-grid integration opportunities.

1.5.1 Miscellaneous Electric Loads

Miscellaneous electric loads (MELs), including plug loads as well as larger, specialized equipment, encompass a vast array of devices in commercial buildings. They offer opportunities both for efficiency improvements when in operating mode and for energy savings in "standby" or "sleep" mode. Their diversity, along with the large number of very small devices, makes it difficult to measure energy savings from MELs except in the aggregate (at a circuit or whole-building level). Yet plug loads in the aggregate can easily account for 20-35 percent of total energy use in a commercial building and, by some estimates, can account for up to 50 percent of energy use in an otherwise efficient building (Kwatra et al., 2013; Lobato et al., 2011b; McKenney et al., 2010).

Fortunately, innovation is spurring advances in this area that could lead to new component-level and, likely, systems-level energy efficiency gains. New requirements to control plug loads, found in ASHRAE Standards 90.1 and 189.1, the International Green Conservation Code (IGCC), and state building codes, such as California Title 24, are stimulating a new generation of receptacle- and circuit-level systems for controlling such loads and verifying the savings by logging actual plug-load energy use over time.

1.5.2 Direct Current Distribution

Because the idea of using DC for building scale (or multi-building) power distribution has only recently begun to receive (or re-gain) attention, the literature on energy savings continues to evolve and estimates vary widely. In concept, DC distribution can deliver energy savings by:

- Reducing alternating current to DC (AC-DC) conversion losses and AC-AC transformer losses, both in active and "standby" modes;
- Trimming distribution losses within a building; and,
- Making it more feasible to replace AC-driven devices with "native-DC" devices for computers, telecommunications, and consumer electronics, as well as for lighting, control systems, and motors (especially those in variable-load applications).

Of these, most studies find that motors in HVAC units and refrigerated appliances offer the most significant energy savings. Other promising applications include electric vehicle (EV) charging, DC-powered lighting and ceiling fans, and data centers. In terms of potential energy efficiency gains to be attained in the context of a systems approach, DC distribution appears worthy of further analysis.

Among the significant non-energy benefits of DC distribution are the enhanced ability to use renewable energy resources (e.g., solar photovoltaics (PV) or wind energy) and to implement demand response and/or ancillary grid services, such as voltage or frequency regulation, especially when DC is combined with on-site energy storage (including EV storage) and distributed generation. Power quality in commercial buildings may be improved with the use of fewer AC-DC conversions (or just one) and with the improved control of harmonics. Installation and renovation costs might decrease, as well, due to the potential for lower maintenance costs.

1.5.3 Building-to-Grid Integration

In the past, the relationship between buildings and the electricity grid was relatively simple: a one-way flow of power from the grid to the final point of use in a building or home. The rapid rise of distributed generation (e.g., natural gas or diesel back-up generators, combined heat and power, wind or solar PV, along with recent developments in battery storage) is transforming this simple paradigm to a more complex, two-way flow of power and information between a utility and its customers. This relationship continues to evolve toward a vision of a fully-integrated system of electricity loads and resources that are continually being optimized for the potential benefit of the utility, the grid operator, and energy users.

These two-way interactions between utilities and commercial customers have a number of potential benefits. While the SEI has not yet identified definitive sources to quantify the benefits of B2G integration, this report includes an initial sampling of the literature on B2G benefits, including: 1) energy savings from improved end-use efficiency, 2) peak demand savings, and 3) other energy or non-energy benefits (notably grid reliability, energy security, and opportunities for greater use of renewable energy). Year Two of this SEI will explore this topic in greater depth.

1.6 Multi-System Integration and Controls

Documenting the incremental energy efficiency benefits of a systems-level approach over and above the efficiency gains from individual components can be difficult, both because the boundary between these two levels is not precise, and due to the limited number of field demonstrations that distinguish between component and systems-level efficiency. This challenge is exacerbated when it comes to understanding the ways in which integration among the systems in a building might add to (or offset) the benefits of optimizing individual systems.

One well-studied integration issue concerns maximizing daylight versus adding unwanted solar heat gains in a larger commercial building—or making best use of wintertime solar gains in smaller buildings. This topic has been addressed by energy modeling in some commercial buildings for which detailed modeling was included at an early stage of design (Selkowitz and Lee, 1998; Lee and Selkowitz, 1998).

Less well understood is the joint control of HVAC systems and variable-daylight façade systems (i.e., movable blinds or windows with electrochromic coatings). This is even more challenging in high-mass commercial buildings, in which the buildings themselves provide a large amount of thermal storage. One study compared the measured energy performance of a typical floor in the New York Times headquarters building—with an all glass façade and fixed exterior shading, interior automated motorized shading, dimmable lighting and underfloor air distribution—to the calculated energy of an ASHRAE 90.1 code-compliant building. The measured data showed 26 percent annual electrical energy savings, 22 percent peak electric savings, 51 percent heating energy savings, and 56 percent lighting savings (Lee et al., 2013). Another exploratory study that compared base case smart controls of window and HVAC systems with "predictive" controls (that can forecast probable weather and occupancy) in four U.S. climates found a wide range of savings from these advanced controls, from no savings (and, in a few cases, losses) up to approximately seven percent savings in lighting and cooling energy (Coffey, 2012). Researchers at Lawrence Berkeley National Laboratory (LBNL) are continuing to explore these joint optimization issues, both through modeling and through research in their

FlexLab research facility. A potentially important benefit from multi-systems integration is the opportunity to use a common set of sensors, communications links, and monitoring and control software to manage multiple systems.

Barriers to multi-systems integration include a lack of common standards and communications protocols; a preference by suppliers for proprietary rather than open-source software; and an industry structure and delivery system with little common ground among suppliers of lighting, HVAC, envelope, office electronics, plug-in equipment—and their respective sources of controls, software, installation, and maintenance services.

Even when control system providers offer multi-systems solutions (for example, control of office lighting and workstation electronics), many customers express little interest in integrated controls, either due to cost or because the timing for installing the controls for the two systems seldom coincides.[4] One study suggests that integrating systems with shared sensors and controls may not increase energy savings compared to separate, dedicated controls but could reduce costs, not only for initial installation, but also for operator training and ongoing systems maintenance and updating (Roth et al., 2005). The same report describes potential benefits of integration between energy and non-energy systems in a building, for example, "the building access system could enable or disable vertical transport systems as well as turn on or off HVAC and lighting systems, e.g., when people arrive at work in the morning instead of at a pre-set time." The integration of building systems will be examined further in the course of the SEI effort.

1.7 Systems Efficiency in Existing Buildings

As noted, during Year One, the SEI focused on new construction and major renovations. However, while recognizing the added challenges of bringing about system-level changes in existing buildings, the SEI Steering Committee fully recognizes that the majority of energy savings potential in the near term lies in the existing building stock.

Substantial analysis has been carried out on systems-oriented opportunities in existing buildings—mainly those involved with replacing or upgrading control systems. Software upgrades alone offer opportunities for energy efficiency gains from systems integration; this potential is enhanced when paired with wireless communications among sensors and control points. Major renovations of a building façade or interior spaces (including lighting system replacements, when tenants change) offer additional opportunities for system upgrades, as is the case with end-of-life replacements of major HVAC components (chillers, boilers, cooling towers, and air-handlers). In-depth "re-commissioning" of an existing building and its systems may be another important opportunity for systems-level integration and further efficiency gains.

With respect to existing commercial buildings, however, data on the incremental benefits of system efficiency compared to the efficiency of components can be difficult to obtain. In Year Two of this Initiative, the SEI members will consider additional analysis of "deep retrofits" in existing commercial buildings, based on the case study materials compiled by the New Buildings Institute (NBI) and others (NBI, 2014; Lyles et al., 2012).

4 Based on Alliance to Save Energy staff phone interviews in 2015 with suppliers of controls for both lighting and office plug loads.

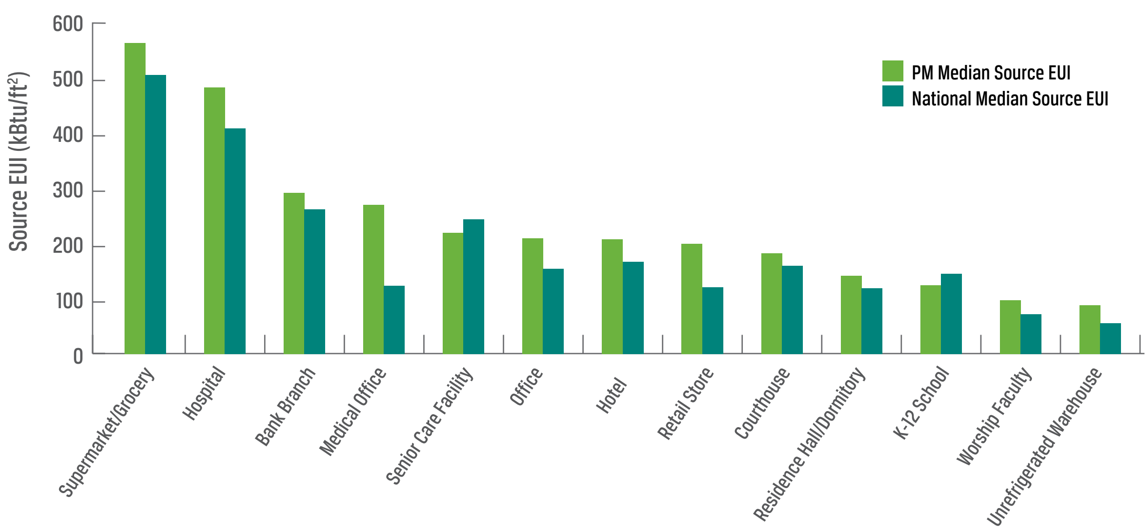
1.8 Metrics and Test Methods

A key challenge facing the systems approach is the lack of suitable metrics for measuring systems efficiency. In the case of efficiency standards for equipment and structural components (e.g., windows and wall/roof insulation), the prescriptive approach and current testing and rating methods enable relatively easy standard setting and compliance determination by manufacturers, designers, building owners, and code officials—helping to ensure that a "baseline" level of energy efficiency is installed with respect to equipment and the thermal envelope. A systems approach, however, is more complex and will require a different compliance methodology, including new system-level performance metrics and test procedures.

For example, lighting system efficiency is not a stand-alone metric. It often is defined in terms of lamp, ballast, or luminaire efficiency, which do not provide a complete picture of the overall lighting system's efficiency. Commonly-used lighting energy metrics (e.g., lumens per watt, watts per square foot) are not sufficient for a systems approach. In particular, they do not account for occupant- and task-relevant control of lighting, which affect not just light source or luminaire efficiency, and connected lighting load (watts per square foot), but also the hours of operation and the ability to dim lighting levels, all of which suggest the need for a broader energy metric, such as "lighting kilowatt-hour (kWh) per occupant-hour" (or "task-hour").

One option is to use targets or metrics aimed at energy usage (consumption), based on such factors as building design, energy availability, or energy cost targets. Such metrics typically are measured in kilowatt-hours for electrical energy or kBTUs (thousands of British Thermal Units) for total energy. One such metric, EUI, denotes total energy use per unit area of a building or kBTU/square foot. Figure 1.4 illustrates some typical EUI values for various commercial building types.[5]

Figure 1.4 – Median Source Energy Use Intensity for Buildings Benchmarked using Portfolio Manager (PM)



Some building types excluded due to inadequate data and/or EUI values beyond this range

Source: USEPA, 2012

5 Each median represents the value in the middle of a distribution, but the full range of energy use within each property type can be much larger. Source (or Primary) Energy includes the energy used on-site as well as losses from off-site generation, transmission, and distribution.

Setting such energy targets is referred to as an "outcome-based" approach, meaning the objective centers around a building's final energy performance (see Sec. 3.1.1.3). An "outcome-based" approach does not necessarily try to prescribe the design or type of equipment installed.

There is a similar lack of suitable metrics to measure the efficiency of mechanical systems. Most efficiency metrics for HVAC&R components historically have been based on an assumption that equipment runs at full load. In addition, these metrics generally have been defined at a single common rating point, which does not account for the varied temperature and humidity conditions across the U.S. As noted previously, neither of these cases is typical of actual operations of HVAC&R systems. In reality, commercial HVAC&R systems seldom run at full load and design ambient conditions. For example, outdoor temperatures and humidity differ substantially between the Southeastern and Southwestern U.S., which can dramatically affect the optimum design and operation of an air conditioning system. Similarly, the need for tight control of temperature, humidity, and air quality differ greatly among different types of buildings (e.g., between a hospital and a warehouse). Because most metrics do not address these distinctions, mechanical equipment often is designed for conditions under which it rarely operates.

A range of activities currently are underway to address the need for more representative building system energy efficiency metrics:

- The ASC-137 Lighting Systems Committee, recently formed by the National Electrical Manufacturers Association (NEMA) with broad industry and stakeholder participation, has a defined mission ". . . to develop standards and specifications for indoor and outdoor lighting systems installed in an application with consideration of human health and comfort, personal security, the physical environment, energy consumption and daylight integration. Such a system includes components (e.g., luminaires, sensors/controllers, and windows or skylights) and associated software designed to minimize energy use while maintaining lighting quality, and that may be interconnected to provide control, monitoring functions, and interface with related systems" (NEMA, 2014).
- AHRI is developing a subsystem approach and associated metrics for combinations of mechanical equipment. As an example, for a chilled water system in a large building, the chiller, cooling tower, air handler, and pumps could be considered as a system and compared with a benchmark (baseline) building in an appropriate climate zone. This would allow for the consideration of innovative solutions that increase the efficiency of the entire system rather than continuing to evaluate efficiency at a component level.
- The new industry metric for rooftop air conditioners, the integrated energy efficiency ratio (IEER), measures mechanical performance on an annualized basis and reflects the operation of the system over the full cooling load profile. The use of this metric has resulted in significant improvements in efficiency (e.g., the use of two-speed fans and multiple stages of capacity) that would not have been considered under the component full-load energy efficiency ratio (EER) metric required by DOE regulations. Industry groups also are considering revised metrics that would include the effects of economizers, demand ventilation, energy recovery, ventilation-only operation, and heating operation by climate zone.

The need remains to develop standardized methods to efficiently and accurately determine system performance for various building systems, as well as multi-system interactions and resultant efficiency at the whole-building level.

An effective systems approach will require many changes. Manufacturers will have to develop expanded ratings that can be used in systems and system analysis tools; the upcoming ASHRAE 205 Standard, targeted for public review in 2016, is being developed to address this need. Certification programs for ratings also will need to evolve to certify the complete operation map (e.g., through computerized selection tools). In addition to new rating tools, new user-friendly tools will be required to enable comparisons among baseline systems, which can be used for building design and system selection, as well as to prove compliance. Such developments also will require standards, such as ASHRAE 90.1, to define baseline systems as well as recognize a systems approach as a compliance path.

The focus on this systems-level approach enables a better understanding of the performance of mechanical equipment as it is likely to be used under realistic building loads and climate conditions and should allow for additional energy savings within the overall building.

BUILDING SYSTEMS EFFICIENCY

This section examines a range of building systems and ways in which to enhance their efficiency, including their better integration. The section focuses on mechanical and lighting systems, and explores other systems and opportunities for improving the efficiency of building systems, such as MELs, DC power, and B2G integration opportunities.

2.1 Mechanical Systems

As noted, the Systems Efficiency Initiative defines a building system as a combination of equipment, operations, controls, accessories, and means of interconnection that uses energy to perform a specific function. This section evaluates new approaches to improving the energy efficiency of commercial building mechanical systems, which include HVAC&R systems—encompassing the equipment, distribution ducts and pipes, and terminals that provide heating, potable hot water, fresh air ventilation, or cooling and humidity control to a building. The focus on this systems-level approach enables a better understanding of the performance of mechanical equipment as it is likely to be used under realistic building loads and climate conditions and should allow for additional energy savings within the overall building. It also allows for the evaluation of energy re-use and optimization of performance at a system level, rather than just at a component level.

2.1.1 Understanding Commercial Building Mechanical System Energy Use

2.1.1.1 Commercial Building Mechanical System Load Profiles and Ambient Operating Conditions

HVAC&R loads (i.e., space cooling, space heating, domestic hot water, and ventilation) are by far the largest users of energy in commercial buildings, so understanding the way in which commercial buildings operate under real-world conditions is an important aspect of a mechanical systems efficiency approach. Commercial buildings seldom, if ever, run at full load or at the design ambient conditions. Instead, loads vary significantly based on occupancy patterns, time of day, season, and climate region. The ASHRAE 90.1 Committee, with the assistance of the Pacific Northwest National Laboratory (PNNL), developed 16 benchmark buildings that can be used to evaluate the load profiles of commercial buildings. Examining the load profiles of these prototype buildings is helpful to understand issues related to maximizing energy efficiency and opportunities for increased efficiency offered by adopting a systems approach for mechanical systems.

An analysis of the load profiles and potential systems-focused efficiency improvements for two types of buildings—a large office building and a large hospital—is provided in Appendix 1 (Figures A1.3 and A1.4). As these figures show, HVAC&R loads are highly dependent on ambient conditions, and both the building load and ambient profiles change significantly as a function of the building type and climate zone. Building mechanical equipment is usually selected at the 0.4 percent cooling and heating design points for the location of the building, meaning that 99.6 percent of the ambient temperatures will be within this temperature range (for sizing and selection of cooling and heating equipment). The building load and heating or cooling equipment efficiency are highly influenced by ambient conditions, and efficiency of most equipment varies significantly between full- and part-load operation. Oversizing equipment to allow for unanticipated loads in a building also is common practice. In fact, ASHRAE 90.1, Appendix G, which is the industry standard for modeling buildings, requires that the baseline building model assume 15 percent oversizing in cooling and 25 percent in heating.[6] Recognizing the extent to which design loads typically exceed actual loads provides opportunities for significant energy savings in the design and operation of mechanical systems, including consideration of hybrid technologies, such as outdoor-air economizers and energy recovery technologies. The fact that many commercial buildings operate in a cooling mode even when it is cold outside offers other opportunities for saving energy (e.g., by shutting off compressors and using "air and water economizers" that use water or outdoor air for cooling).

To help evaluate the impacts of ambient operating conditions on the performance of building systems, ASHRAE, in its Standard 169, defines 19 standardized U.S. domestic and global climate zones. The discussion in Appendix 1 characterizes the effects of these climate zones on the buildings analyzed, and illustrates opportunities to design systems approaches for saving energy in ways that consider typical building load profiles and regional climate conditions.

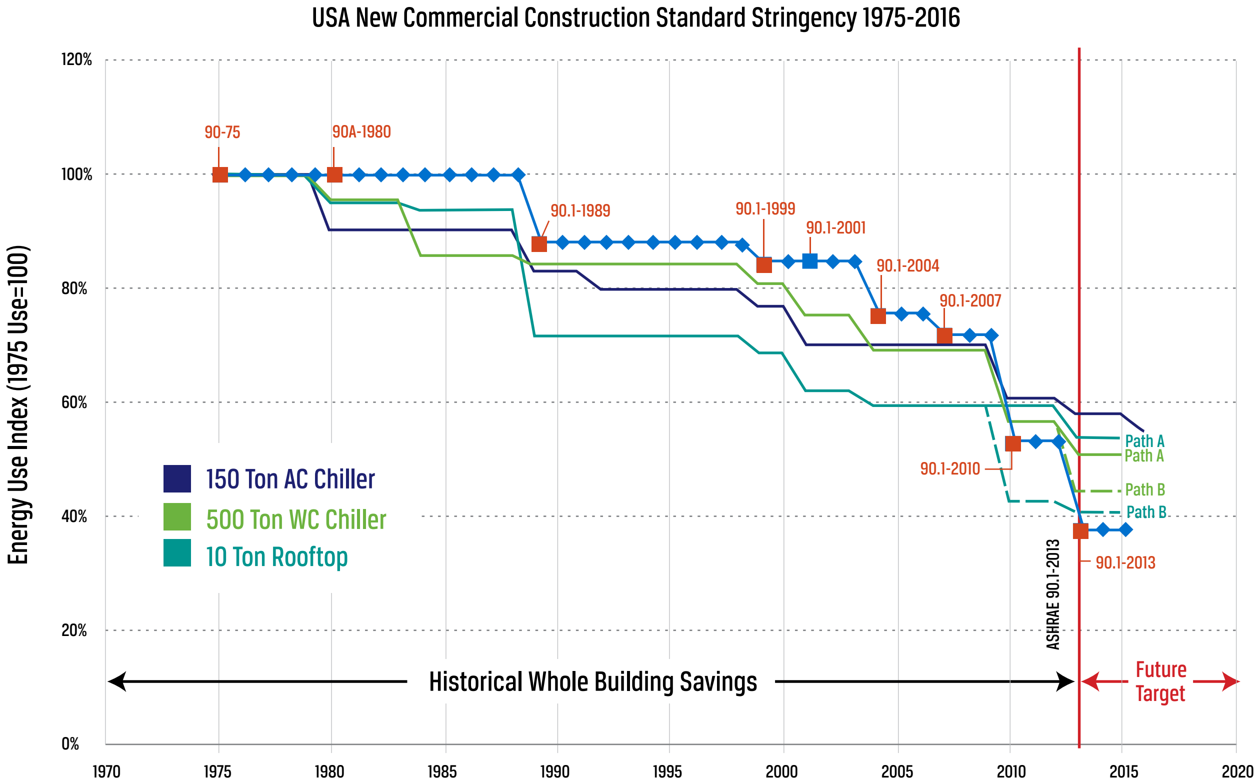
2.1.1.2 Historical Approach to Mechanical Systems Efficiency

Since efficiency regulations were initiated in the 1970s, the approach to mechanical systems efficiency—in the United States as well as in other countries—has focused on defining minimum efficiency requirements at a component level, combined with some prescriptive design requirements for hardware (e.g., economizers, fan speed control, and operational controls). As noted above, the majority of efficiency metrics for mechanical compontents are defined at some common design standard (i.e., a certain temperature and humidity) and at full-load design conditions.

Over recent decades, significant progress has been made in increasing equipment component efficiency, as measured by these metrics. Improvements in mechanical system component efficiencies have, in turn, contributed significantly to increasing building energy efficiency. One major driver for this trend in the U.S. has been government- and industry-led efficiency standards; for commercial equipment, these are primarily standards proposed as part of ASHRAE Standard 90.1 and then adopted by DOE as federal efficiency requirements. Performance-path requirements in model building codes, both ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC), also have encouraged improvements in equipment efficiency (see Appendix 3 for a full discussion of efficiency standards). Figure 2.1 highlights the improvement in ASHRAE Standard 90.1 minimum efficiency levels over time for some common commercial mechanical cooling components, along with trends in the overall stringency of the Standard (which addresses the efficiency of mechanical equipment, lighting, building envelope, controls, and other provisions).

6 Oversizing to account for industry typical practices is defined in ASHRAE 90.1-2013 in Section G3.1.2.2.

Figure 2.1 – ASHRAE Standard 90.1 Efficiency Improvements for Cooling Components



Source: Prepared by Richard Lord based on PNNL Determination Studies and ASHRAE 90.1 Minimum Product Efficiencies

However, the focus on individual component efficiency for some mechanical equipment may not be as effective at reducing total energy use in buildings in the future as it was in the past. This is due to several factors.

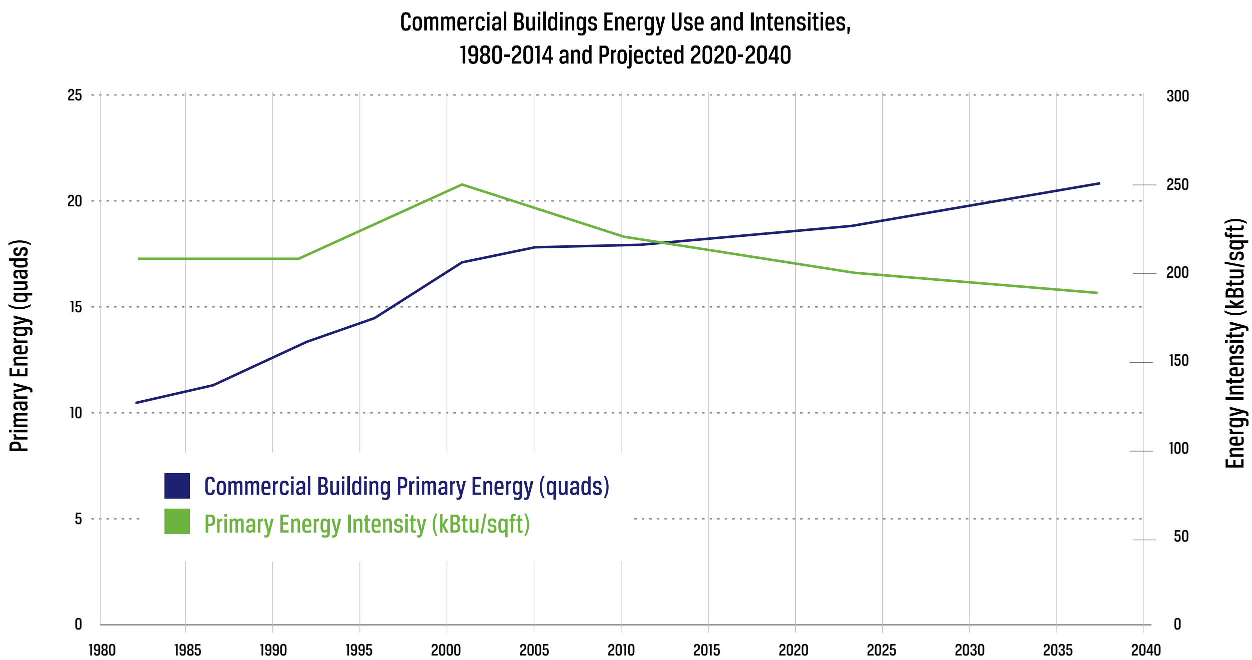
First, it is not always the case that highly efficient components will yield an efficient building. For example, despite growing attention by manufacturers and their customers to part-load performance, some equipment is still designed for optimal effiency at full load. In these instances, differences between rated and actual performance arise. Examining a system in a holistic manner—including the interactions among components and with the building and environmental conditions—is vital to truly optimize building efficiency.

Second, some individual system components are approaching technical and economic limitations on further efficiency gains. Further incremental energy savings might be possible, especially in situations in which alternative technologies may emerge (as in the case of fluorescent lighting replacing incandescent lighting and, in turn, being eclipsed by solid-state (LED) lighting); in other instances, however, substantial additional efficiency gains might be unlikely or increasingly expensive to achieve. These limitations are discussed further in the next two subsections.

Third, emerging opportunities for attaining significant efficiency gains—such as through the integration of smart grid and related control technologies—optimally are applied at the system, rather than the component, level. These types of opportunities also are discussed in the subsections below.

Fourth, even with the increasing stringency of minimum efficiency standards for building equipment, the energy intensity (energy use per floor area) for the commercial building stock has not decreased significantly over the past several decades and EIA projections show only a modest decline in the future, even as total commercial building energy continues to grow with increased floor space (Figure 2.2). The relatively stable energy intensity is largely due to envelope and equipment efficiency gains being offset by growth in plug and miscellaneous loads as a result of the growing use of electronics and other electrical and fossil fuel-powered equipment, which not only add directly to a building's energy use but also create added cooling loads for mechanical systems. Another factor is that efficiency requirements typically are defined for new buildings and equipment (including replacement equipment), but the significant population of existing buildings and equipment remains largely unaddressed by these requirements.

Figure 2.2 – Trends in Commercial Building Energy Use (per floor area and overall)



Source: EIA, 2016

Finally, most current regulations pertain to the efficiency of equipment and buildings, as designed, but generally do not address the commissioning and maintenance of mechanical systems. As discussed in the sections below, new systems-based diagnostic tools, energy dashboards, and other new systems-level tools could support improvements in the performance of mechanical systems over the long term.

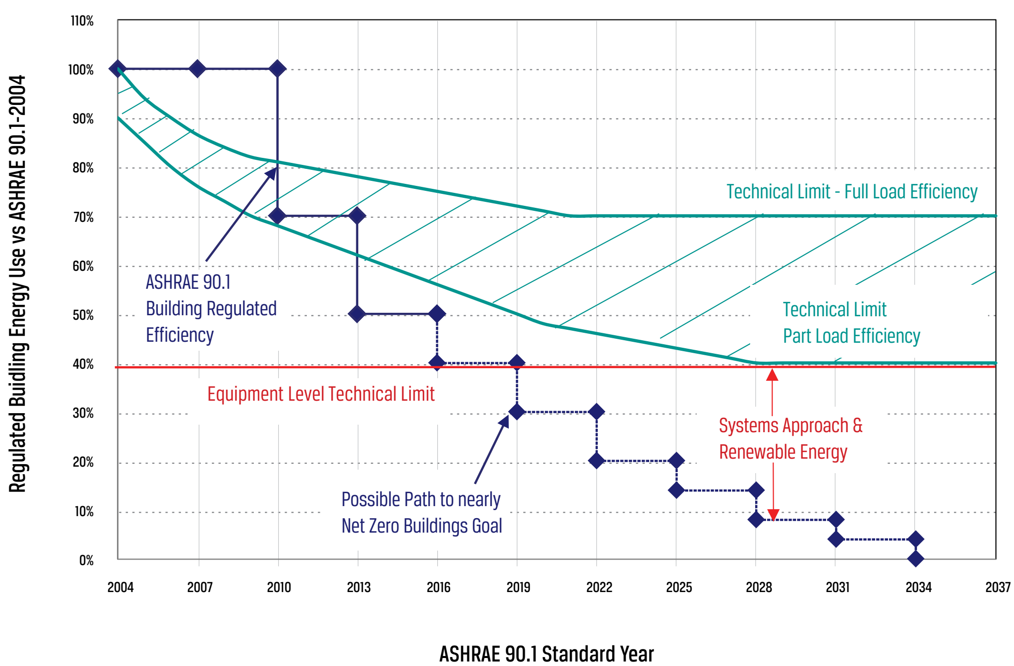
2.1.1.3 Technical Limits to Component Efficiency

As the efficiency of a given component continues to improve, further performance improvements will increasingly be limited by thermodynamic boundaries. The First and Second Laws of Thermodynamics, for example, will preclude motors from operating at greater than 100 percent efficiency, and will prevent heat exchangers and refrigeration systems from performing better than the Carnot cycle.[7]

However, variable-speed technologies, innovative refrigerant technologies, and improved controls can all contribute to better equipment performance—especially when implemented in a systems context. By enabling creative strategies to optimize energy use and consider the interaction of the components, system approaches will continue to offer more opportunities for savings past the point at which individual components bump up against technical and economic limitations.

Figure 2.3, which was created to support the work of the AHRI System Steering Committee, illustrates conceptually how HVAC equipment technical limits are approached in both full- and part-load situations. The upper green line represents the conventional full load metrics and suggests that technical limits will be reached sooner at full load when trying to optimize around a single-design, full-load capacity rating point. Shifting to part load and annualized system efficiency metrics (which the industry has been starting to explore) will allow deeper savings. The amount of savings will depend on the product and the scope of the part-load and annualized system metric; this is further discussed later in this report. Also conveyed in Figure 2.3 is the importance of this type of approach for meeting future aggressive building-level goals (e.g., net zero energy buildings) that are being discussed by efficiency advocates, policy makers, and the industry.

Figure 2.3 – HVAC Equipment Technical Limits



Source: Prepared by Richard Lord for the AHRI Systems Initiative"Focus on System Efficiency" brochure

7 An ideal, reversible, closed thermodynamic cycle.

Not all equipment is approaching its technical limits; some components still have significant potential for improvement under the current component standards approach—either through innovative developments in existing technologies or by shifting to inherently more efficient technologies (e.g., switching from an air-source heat pump to a water- or ground-source system). In addition, opportunities exist to further improve efficiency by introducing part-load and annualized metrics (and further refining the metrics themselves); this approach is discussed further in Sections 2.1.1.3 and 2.1.4.1. That said, individual components are closer to their theoretical limits than they were 30 years ago, and it will be increasingly important to strike an appropriate balance between focusing on individual component improvements and systems efficiency improvements.

2.1.1.4 Cost-Effectiveness Limits to Mechanical Component Efficiency

As technical efficiency limits are approached for some components, costs to achieve incremental improvements may increase substantially, which also would increasingly limit the feasibility of additional improvements. A recent analysis for ASHRAE Standard 90.1-2013, "Chiller Efficiency Improvement Addendum Justification," illustrates the cost-effectiveness limits of chiller efficiency at the component level. The ASHRAE analysis shows that average U.S. payback periods for selected chiller efficiency improvements would approach 6.3 years, but that payback periods would be as high as 46 years in some climate zones. Although 6.3 years is acceptable given the long life of the product, many customers look for payback periods of less than four years. Long payback times can negatively affect efficiency, as some owners might simply delay replacing equipment until it fails while continuing to use old, inefficient equipment. On the other hand, some manufacturers believe that further gains in chiller efficiency may be feasible and that they will have the option to offer their customers these "above-standards" models.

Looking at the chiller system as a whole can offer more cost-effective options for improving efficiency through the strategic selection of cooling towers, pumping systems, controls, and physical arrangements for chiller sequencing. As an example, most buildings use multiple chillers, and simply operating the chillers in series using a counter flow arrangement can improve annual efficiency by approximately six percent over a parallel configuration; these savings would not be recognized by current chiller efficiency metrics, which only rate the energy use of single chiller components.

In summary, by focusing on component efficiency in isolation, operating under hypothetical loads and conditions that rarely are encountered, technical and cost effectiveness limits will necessarily be approached. A systems approach that takes into account more realistic loads and conditions, and the interaction of various components with each other and with other building systems, provides an additional pathway to increased efficiency and energy savings.

2.1.1.5 Limitations of Current Metrics

As noted above, another limitation of the component approach to mechanical system efficiency improvements is related to the metrics used to measure them. To date, many (but not all) efficiency metrics are based on an assumption that the equipment is running at 100 percent load. The metrics also generally have been defined at a common industry rating point (i.e, at one national peak design temperature).

Neither of these cases is typical of actual operation of HVAC&R systems. The actual conditions under which they operate vary widely: For example, temperatures and humidity, which are substantially different in the Southeastern and Southwestern U.S., can dramatically affect how an air conditioning system is most efficiently designed and operated, and can influence the best type of equipment to use. In addition, HVAC needs differ depending on the type of building (e.g., hospitals and warehouses have very different heating and cooling needs). When metrics fail to consider these distinctions, mechanical equipment may not be optimally designed for the conditions under which it operates. Appendix 1 includes a discussion of the importance of regional weather and building load profiles for developing metrics more reflective of actual operating characteristics.

The limitations of current metrics are, at least in part, a result of the assumptions used to define them. For example, an HVAC&R unit that operates efficiently at full load will not necessariliy be proportionally more efficient at partial load. To accurately reflect the energy use of mechanical systems, it is important to take into account part-load efficiency and understand the operation of the equipment on an annualized basis, as is factoring in seasonal changes in building loads using a typical building load profile and regional weather data. Also key is recognizing system-level energy savings resulting from the use of system features, such as economizers, and implementing more efficient strategies, such as energy and heat recovery.

Metrics that take these factors into account can allow for creativity in increasing efficiency. For example, in 2010, AHRI developed a new efficiency metric called an Integrated Energy Efficiency Ratio (IEER) for the mechanical refrigeration section of a rooftop air conditioner.[8] Unlike full-load metrics, this metric was developed to represent the annualized performance of an average building, including full and part loads, based on building load profiles. However, this metric still represents a U.S. average and only the performance of the mechanical cooling system rather than the full HVAC system. DOE and several end-users of this equipment established the "Rooftop Challenge" for the industry, aimed at boosting performance to 18 IEER, which represented a 60 percent improvement over the standard at that time. This aggressive goal encouraged the industry to develop creative efficiency solutions that included fan speed control and alternate approaches to capacity modulation. Manufacturers were able to meet (and in some cases exceed) the target within a few years using modifications to existing equipment platforms. This approach resulted in significantly greater energy savings than would have been obtained using incremental, full-load efficiency metrics. The challenge has resulted in changes to the ways in which the industry designs rooftop air conditioning units as well as to the ways in which standards approach efficiency improvements for these types of products (i.e., by including more of the HVAC system). DOE has approved the use of the IEER as its regulated metric from 2018 onward.

Other new system metrics are beginning to incorporate part-load and annualized performance for an average "bin"-weighted load profile but, again, using a common industry national average set of full and part-load rating conditions. It will be important to consider ways in which to use part-load and annualized metrics to foster new opportunities to further improve efficiency. This is one of the many systems approaches discussed below as a more effective way to obtain energy savings.

8 IEER is a measure of annualized efficiency for commercial unitary air conditioning and heat pump equipment on the basis of weighted operation at various part- and full-load capacities.

2.1.2 Systems Efficiency Approach for Mechanical Systems

As the discussion above indicates, a clear need exists to explore opportunities for mechanical systems efficiency improvements at the systems level. More and greater options for efficiency improvements and creative solutions are available when such systems-oriented approaches are considered.

Consider a building that contains significant refrigeration equipment. It is common for such equipment to reject (or "emit") waste heat back into occupied spaces of the building. Although the refrigeration equipment itself may be quite efficient, the system as a whole may significantly increase a building's overall cooling load, thereby requiring larger space conditioning equipment. A systems approach to efficiency could enable the consideration of alternative concepts, such as the use of remote condensing units that reject heat outdoors, or recovering the "waste" heat for water heating, or ventilation air pre-heating. Similar opportunities exist for larger thermal loads, such as data centers[9] or commercial cooking equipment.

Another example pertains to hot water needs for a large office building. The conventional approach is to use a central hot water boiler and a circulating loop(s) to serve rest rooms, convenience kitchens, and possibly also first-floor retail spaces. Using this type of approach can result in delivered efficiency being quite low, due to heat losses from the piping, the loads served being small, and the delivered water temperature requirement being relatively modest. One systems-level alternative approach would be to use small, locally-clustered heat pump water heaters installed in distribution transformer closets (using the rejected transformer heat as a source to heat the hot water). Another option would be to use small electrical resistance tanks or tankless water heaters.

In addition, a systems approach is critical for optimizing HVAC&R systems and ensuring efficient solutions as we move toward the use of more renewable energy, site-recovered energy, and energy storage. Designers and operators increasingly will need to examine the ways in which equipment and systems interface with buildings and the electric grid. The use of energy management systems and "smart zoning" will enable different building zones and systems to be managed separately. For example, these capabilities would enable a cooling system to be turned on early in the day, so that it begins to pre-cool the thermal mass of a building during times of the day when ambient temperatures and grid demand are lower. This could result in significant energy savings, peak demand reductions, and improvements in grid efficiency—all at minimal cost (including helping to avoid peak demand charges that otherwise would be incurred).

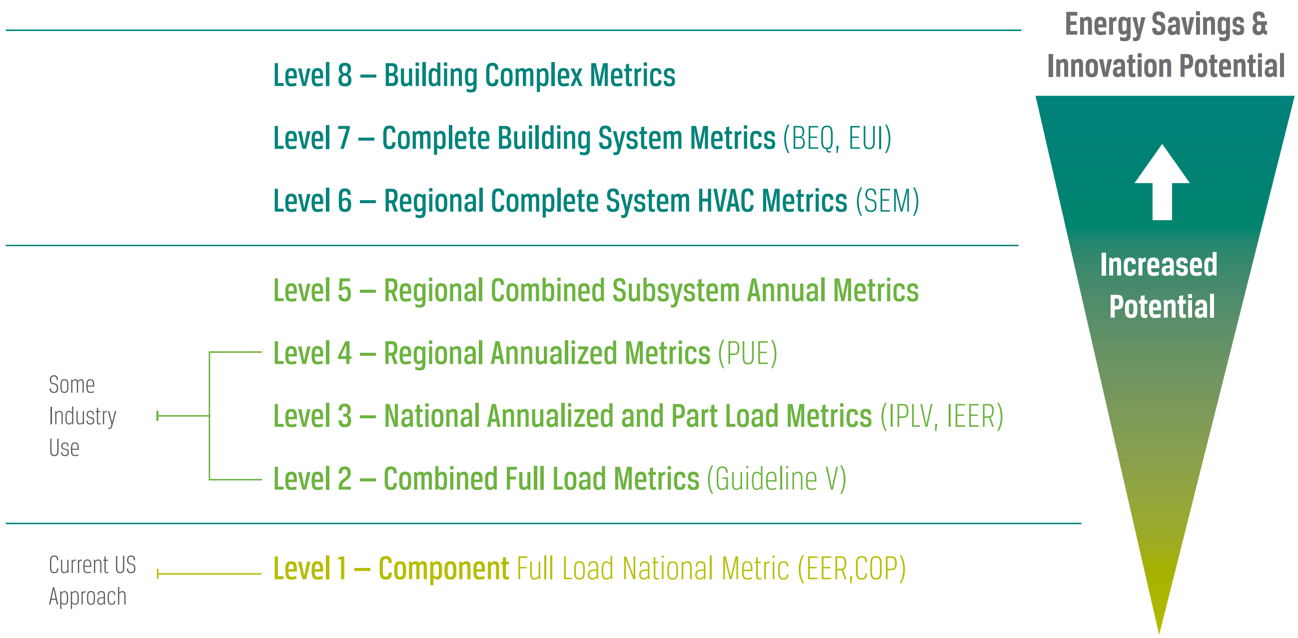
2.1.2.1 Mechanical Systems Efficiency Framework

Because of the complexity of HVAC&R and other mechanical systems, the industry has been developing a variety of approaches to increase mechanical system efficiency. These include entire mechanical systems, as previously discussed, as well as parts of these systems (or subsystems). To better reflect these efforts, this subsection includes a discussion of mechanical system as well as subsystem approaches.

9 See, for example, http://www.seattletimes.com/business/real-estate/amazon-towers-will-be-heated-by-neighbors-excess-energy/.

Figure 2.4 shows the way in which this approach can be used to increase the scope of analysis beyond the component level. Each level of analysis expands in scope to capture more elements—starting with components, then incorporating subsystems, systems, buildings and, finally, multiple buildings. As the scope expands from one level to the next, different opportunities for energy savings emerge.

Figure 2.4 - Building Mechanical System and Subsystems Structure



Source: Prepared by Richard Lord. It is a proposed structure under consideration by AHRI.

1. Level 1 corresponds to the component approach to energy efficiency that uses full load efficiency metrics at a common national rating condition. This is the current approach used for most mechanical system components and other individual components in a building.

2. Level 2 begins to move away from the "lab conditions" method found in the traditional component approach and into "real-world" situations that equipment is more likely to experience. It combines full load efficiencies of two technologies. Only one such approach is in use today, and involves the combination of a rooftop "packaged" air conditioner or heat pump and an exhaust air energy recovery device.

3. Level 3 includes part load and/or annualized metrics (e.g., integrated part-load value (IPLV))—that also take into account the operation of equipment on an annualized basis, as well as using a typical building load profile and average weather data. This concept is only used in about 16 industry metrics, but could be expanded to other products, considering that commercial units rarely run at full load or at design ambient conditions.

4. Level 4 evaluates systems at a higher level and on an annualized basis. An example of a relevant metric for this type of analysis is the power usage effectiveness (PUE) metric that is used for data centers. PUE is defined as the ratio of the total amount of energy used by a data center to the energy used for information technology (IT) equipment. A data center system

that does not require any cooling power would have a PUE closer to 1, although some energy would still be used for lighting, ventilation, and other purposes. (Note that the PUE metric does not directly address efficiency or effective utilization of the data processing equipment itself.) ASHRAE Standard 90.1 has defined maximum PUE levels for each of the 19 climate zones in the U.S. Similar metrics could be developed for any system in which the annualized energy use could be compared to a baseline standard for a system. In the future, such standards could be based on a percentage improvement relative to the baseline system. This would have the advantage of not being overly prescriptive and would encourage the use of creative solutions, such as one being proposed for data centers (i.e., raising the ambient temperature, which reduces cooling, but also enables cooling to occur by bringing air into the circulation/HVAC system from the outside).

5. Level 5 is similar to Level 2 in that it uses combined full load metrics, but would be applied at a climate-region level, and on an annualized basis.

6. Level 6 would be a full subsystem approach (like the full chilled water system option 3 shown in Example 1 of Appendix 2, Figure A2.1). It would be used at a regional level and the likely approach would be to compare it to a baseline system for an appropriate benchmark building.

7. Level 7 would entail the use of full building metrics such as the ASHRAE Building Energy Quotient (bEQ) metric.

8. Level 8 consists of an analysis involving multiple buildings (e.g., a campus or complex). As building efficiency moves toward more ambitious targets such as "Net Zero Energy," such building complexes may be able to obtain greater efficiencies and energy savings by sharing systems and resources, such as renewable energy and energy storage.

2.1.2.2 Benefits of a Mechanical Systems Efficiency Approach

The literature on HVAC energy efficiency includes some assessments of the potential for energy savings resulting from systems-focused measures. In a recent study for DOE, Navigant reviewed 182 possible HVAC efficiency measures, some at the system or whole-building level, others at the component level, and some at the sub-component level (Goetzler, et al. 2011). Of these, 57 were selected for more detailed analysis, and potential nationwide energy savings were estimated for 17 measures. The detailed analyses included three measures involving air distribution ducts and another five involving two or more HVAC system components. A longer list of HVAC efficiency measures included more than 30 that can be considered systems-level opportunities. The study estimated savings for each of these systems-related measures, ranging widely from about 0.05 Quads to about 1.0 Quad (in the case of HVAC system commissioning and recommissioning), while emphasizing that savings for each measure are generally interactive and should not simply be added.

Recently published RD&D roadmaps developed for DOE for emerging HVAC technologies, as well as for water heating systems (Goetzler et al., 2011; 2014), included a number of systems-level technology options, such as:

- DC-powered HVAC equipment, which has the potential to save 1-1.9 Quads of energy in 2030, as well as DC-powered HVAC equipment integrated both with the electric grid and with on-site solar photovoltaic (PV) generation;
- Technology to separately control latent and "sensible" cooling loads, which could save 0.7-1.1 Quads of energy in 2030;

- Seasonal energy storage systems;
- Low-cost sensors and controls;
- Open-source software platforms that enable transaction-based connectivity among building systems, and between the building and the grid; and,
- "Smart" water heating controls integrated with other building controls.

A report by the Institute for Building Efficiency, an Initiative of Johnson Controls, evaluated energy savings and cost-effectiveness for several dozen "intelligent efficiency" measures applied to a typical office building in the Washington, D.C. area (Ruiz et al., 2014). For most of the HVAC measures, savings estimates ranged from less than one percent to about three percent of a building's overall energy usage. However, this study did not evaluate the combined or interactive effects of multiple measures.

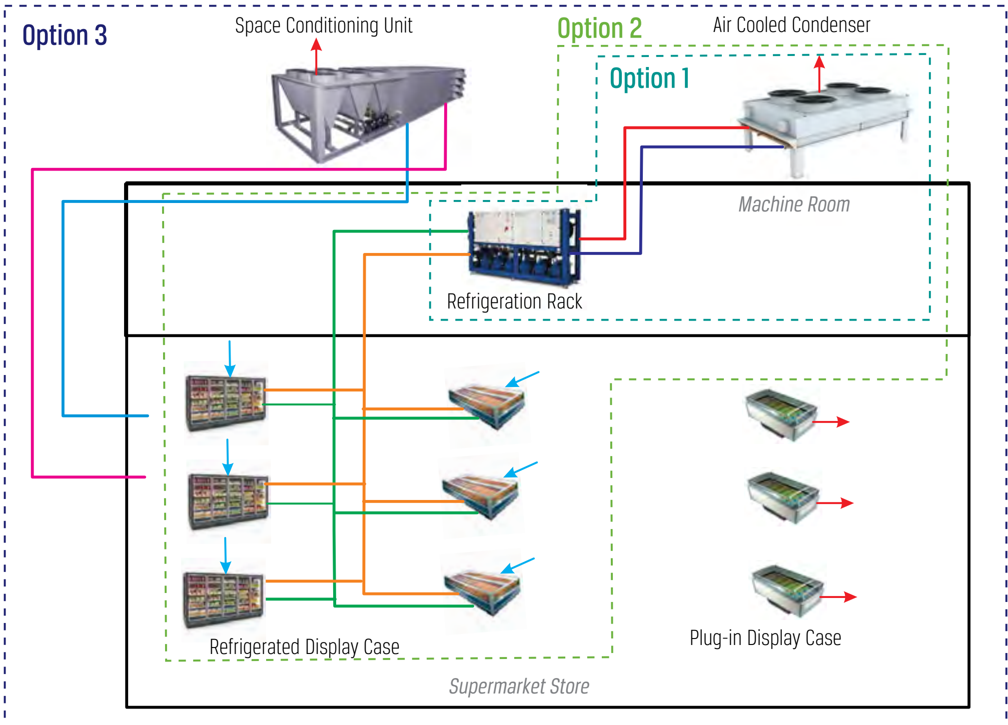
The following are brief examples of other benefits of a mechanical systems approach:

- Improved economic payback for efficiency improvements: The current efficiency requirement for a four-pole, 30 horsepower (HP) motor is 94.1 percent as defined in ASHRAE 90.1-2013. While it may be possible to increase the efficiency of these motors by a few percentage points, doing so would be very expensive for manufacturers, because they would have to develop all new motors and qualify them in thousands of applications. On the other hand, combinations of advancements in variable speed devices, fans, pumps, and controls of such devices can result in system savings of 30-50 percent for HVAC systems (ABB, 2014). Such a systems approach could lead to a much better economic payback. These types of advances, however, are not considered by current efficiency regulations when evaluating motor efficiency improvements.
- Ability to address ventilation air issues: Systems approaches can be used to address the re-heating of ventilation air in variable air volume (VAV) systems, for example, by re-directing air into relevant zones of an occupied building, and by implementing energy management methods, such as "demand-controlled ventilation" (automatic adjustment of ventilation equipment according to occupant choice). Additional options include transferring heat from cooling to heating zones, when appropriate, and recovering energy from exhaust systems. These factors are not reflected in the efficiency metrics that are used today for HVAC&R equipment, but are aspects that could be included in a systems approach to efficiency.
- Opportunities to save energy in various types of commercial buildings, based on their specific energy load profiles: Such opportunities include using system enhancements, such as free cooling economizers, energy recovery, evaporative cooling, and other hybrid system approaches that are not incorporated into current minimum efficiency standards or metrics.
- Opportunities to factor in "intelligent" controls and/or other technologies or capabilities, such as demand ventilation, variable speed fans, supply air reset, static pressure reset, and variable water flow, which also are not reflected in current efficiency metrics.

2.1.2.3 Real-World Examples of a Mechanical Systems Efficiency Approach

The benefits of a mechanical systems approach can be analyzed using a real-world example—in this case, a supermarket refrigeration system—to understand potential energy savings opportunities. Such systems can be very complex, as shown in Figure 2.5, which is a simplified schematic of the refrigeration equipment and space conditioning unit. Current metrics only are defined for display cases and walk-in coolers, along with some prescriptive requirements.

Figure 2.5 – Commercial Supermarket Refrigeration System



Source: Prepared by Richard Lord using common industry knowledge of the configuration of a typical supermarket. The figure is the property of Carrier and has been shared with AHRI and the SEI.

The simplest subsystem approach is defined above as Option 1 and would entail evaluation of the combination of the refrigeration rack and the condenser section. This would be carried out using a normalized load profile, based on a prototype supermarket and on benchmark city weather data.

Expanding the boundary of the analysis, Option 2 includes the directly-connected refrigerated display cases. Although the space conditioning unit is not included, a method could be developed to use a default energy model to account for the cooling and/or heating resulting from the plug-in display cases that reject, or emit, their heat back into the occupied space.

Option 3 would encompass the full commercial supermarket refrigeration system, including the space conditioning unit. This could be an effective approach for supermarkets, since it would factor in the heat that is rejected from equipment that otherwise would create a need for additional cooling in the summer; this approach also would help reduce the heat load in the winter. Such an approach would provide the opportunity to factor in heat that is reclaimed from the rack system to enhance the total performance of the system, as well. This analytical method also demonstrates the cost-effectiveness of including additional system options, such as evaporatively-cooled condensers, dedicated outside air units, and system level controls, that would not be considered in a component-level analysis.

Implementing Options 2 and 3 will require the development of tools that are capable of analyzing a system as well as its components. Work is underway at ASHRAE to develop equipment models (using the new ASHRAE Standard 205 that establishes common formats for input data). The AHRI System Steering Committee also is considering ways to develop systems-oriented analytic tools.

To establish minimum efficiency targets, one possible approach is to use benchmark buildings and cities to define a baseline system for a building type (and location). This baseline system would be based on current minimum efficiency performance standards as well as on applicable prescriptive requirements, where they are defined, or on industry best practices, in cases in which standards are not defined. A newly-proposed system would be required to use less energy than the baseline, when run through a simulation tool to demonstrate compliance.

A recent internal system-level study conducted by one manufacturer using a typical European supermarket found that the refrigeration systems never run at the extreme conditions defined by the prevailing Standards (EN/ISO 23953).[10] Adjusting for this discrepancy resulted in a reduction of 34 percent below the energy use indicated by the rating metrics and standards. The study also found that optimization at the system level (e.g., adjusting fan speeds and defrost settings) would yield a 22 percent savings in energy.

Two additional examples of a systems approach—for a chilled water system and commercial rooftop air conditioning system—are provided in Appendix 2. AHRI is in the process of conducting studies on these types of systems.

2.1.3 Barriers to Implementation

2.1.3.1 Technical Barriers and Opportunities

As noted earlier, computerized tools will be required to model various types of mechanical systems and demonstrate compliance. An important part of this effort will be to develop accurate models for mechanical systems operating at both full and partial loads over the entire operating range. Current models do not always show acceptable correlations for new, optimized part-load systems that operate with multiple stages and/or at variable speeds, and work will need to be done to improve the modeling equations or approaches used in programs such as EnergyPlus. ASHRAE and AHRI are working to address parts of this challenge, as further described in the "Recommendations" for this section.

One of the goals of the AHRI Systems Committee is to prove the concept of a systems approach, and for this they have selected three benchmark systems to evaluate in 2016:

1. A water-cooled, chilled water system, with the chiller(s), cooling tower, and pumps;

2. An air-cooled, rooftop air conditioning system, with the economizer, energy recovery, evaporative cooling, and other hybrid systems; and,

3. A supermarket refrigeration system, including the refrigeration rack system, condensers, and refrigerated display cases.

10 Proprietary manufacturer data shared with SEI on February 14, 2016.

This approach will compare system performance results against a baseline system to normalize any uncertainties in the calculation tools. Work already is underway in the industry to develop some of these tools and make them "user friendly," to increase the percentage of systems modeled from an estimated 20 percent to 80 percent or more. The choice of benchmark buildings used to establish ratings and baselines also will heavily influence the protocol. The benchmark buildings developed by ASHRAE Standard 90.1 and PNNL need to be updated to reflect the new ASHRAE Standard 169 and expanded to cover additional buildings. Some proposals have been generated to conduct this work.

A systems approach also will need to address the use of controls. Controls can provide significant efficiency improvements at part-load and off-peak usage, but their impact is difficult to capture using current building modeling tools.

Finally, an effective systems approach will need to account for, as well as help facilitate and ensure, the proper installation and maintenance of mechanical systems, and to include improvements in commissioning as well as diagnostics and prognostics, use of the "smart grid," and equipment monitoring (e.g., through visual dashboards to interface with users).

2.1.3.2 Policy and Market Barriers

Truly optimizing building efficiency will require addressing systems as a whole, and their interactions with other building systems (e.g., lighting, envelope, interior space planning) and with the environment. In the case of large chilled water systems, for example, efficiency requirements exist for the chiller at full- and part-load power and for the cooling tower with full-load fan power, but requirements do not exist for the tower approach temperature, which can have a significant impact on the system's overall efficiency. In the case of air distribution motors and fans, even if standards specify the use of high-efficiency models, the designed ductwork might have problems (e.g., be undersized, contain leaks, or be poorly insulated) that could prevent a large percentage of the heating and cooling capacity from actually reaching the occupied space.

In recent years, efficiency standards have attempted to address some of these issues through requirements for these "secondary" efficiency attributes, but the requirements generally are prescriptive and do not allow for innovative approaches that could yield greater savings and lower incremental costs.

In addition, successful implementation of a systems approach will require acceptance by the following organizations and groups as a viable alternate path in the short term, and as the preferred compliance path in the long term:

- DOE, for "covered" products subject to national efficiency standards;
- ASHRAE and the International Code Council (ICC), in their efficiency standards and code compliance requirements;
- Equipment manufacturers;
- State and local (e.g., city, county) officials, including building code enforcement personnel; and,
- DOE and the U.S. Environmental Protection Agency (EPA), for their voluntary programs such as ENERGY STAR®; the U.S. Green Building Council (e.g., LEED); and incentive-focused organizations, such as the Consortium for Energy Efficiency (CEE). (The work being done by AHRI to validate proofs-of-concept for a systems approach will help achieve acceptance by voluntary rebate programs.)

Change is difficult. Preliminary efforts to adopt some systems-oriented approaches through CEE are underway but have been slow to progress. Utilities have expressed concern about the degree to which promised savings actually will be achieved. Equipment manufacturers also have expressed concern that a systems-oriented approach will be added to current prescriptive approaches and could increase their regulatory burden. However, an underlying goal of this approach is to avoid such increased burdens by setting efficiency goals in a way that allows creative solutions to be developed that are not considered under current approaches.

2.1.4 Achieving the Potential

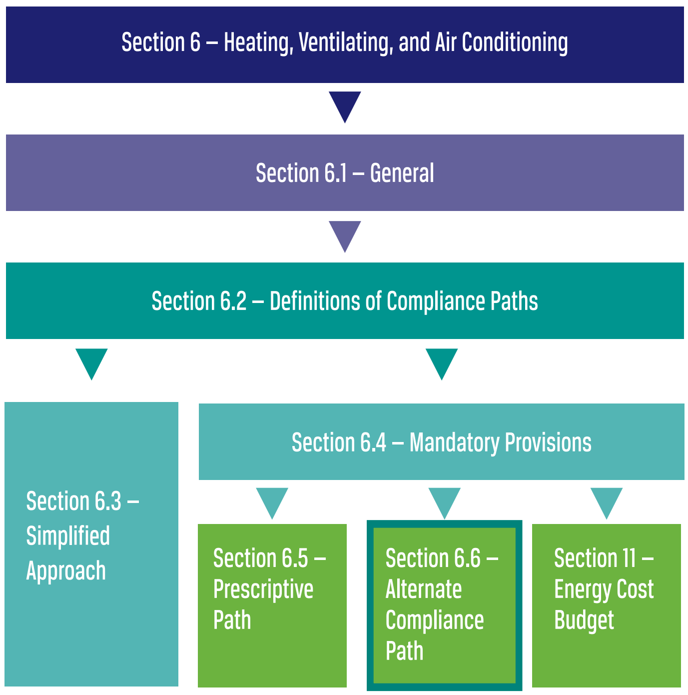
Achieving the potential of systems efficiency will require an approach that expands beyond individual components to optimize system interactions relative to a building's actual load and ambient profile. This will require the development of ratings that are compatible with updated models, as well as expanded ratings that can be used in system-level analytic tools.

For example, work has been underway for several years through the ASHRAE 205 Standard, which is expected to be released for public review in 2016. ASHRAE Standard 205 is intended to offer a standardized approach to data inputs for modeling and information-exchanges among systems. This will be useful in developing performance ratings based on a complete "operating map" over a likely range of ambient conditions and loads—an approach that subsequently could be used in simulation tools, such as EnergyPlus, and in systems-level tools developed by AHRI or others.

The industry will need new tools that can quickly and accurately model systems, based on ambient temperatures and average and/or more realistic load profiles of a proposed building. Progress has been made by the ASHRAE Standard 90.1 Committee and PNNL to develop standardized baseline building models that cover about 80 percent of the market. A new proposal also is being developed to expand building models to address approximately 90 percent of the commercial building market.

To pursue a systems-oriented approach, both minimum energy standards (e.g., ASHRAE 90.1, IECC) and voluntary approaches (e.g., ASHRAE 189.1, LEED, EnergyStar®, CEE) would need to be modified to include systems-level protocols for compliance with minimum efficiency levels, as well as with higher performance certifications required for utility rebates and other incentives. ASHRAE Standard 90.1 already has an alternate compliance path (in its Section 6.6) that has been used with data centers. Section 6.6 uses the PUE metric and defines efficiency levels based on climate zones (without defining prescriptive requirements). This approach is promising for use with other mechanical systems as well. Figure 2.6 shows the ASHRAE 90.1 compliance paths and the Section 6.6 alternate compliance path used for the PUE. The PUE efficiency targets are shown in Table 2.1. This concept also could be expanded and revised as the systems concept is further developed and adopted.

Figure 2.6 - ASHRAE Standard 90.1 System Alternate Compliance Path



Source: ASHRAE 90.1-2013[11]

Table 2.1 - Data Center PUE Efficiency Requirements

Climate Zone	PUE*
1A	1.61
2A	1.49
3A	1.41
4A	1.36
5A	1.36
6A	1.34
1B	1.53
2B	1.45
3B	1.42
4B	1.38
5B	1.33
6B	1.33
3C	1.39
4C	1.38
5C	1.36
7	1.32
8	1.30

*PUE_0 and PUE_1 shall not include energy for battery charging.
Source: ASHRAE 90.1-2013

An important part of a systems approach involves commissioning, monitoring and conducting diagnostics, and providing proper maintenance over the life of a system to ensure that it operates and performs at a high level on an ongoing basis. This aspect of lifetime performance is not addressed by the current component efficiency approach or by most building standards and codes. Newer, state-of-the-art controls incorporated into a systems approach can monitor the health of the equipment and help ensure these types of needs are met.

11 Figure 2.6 is based on ASHRAE 90.1-2013 Standard, but corrected for the missing Section 6.6.

2.1.4.1 Potential New Metrics and Implementation

Implementing a systems approach will require the development and use of metrics that can account for systems-level efficiency improvements. As discussed, instead of setting national efficiency metrics and prescriptive design requirements, system metrics in the future should be designed to define an annualized minimum efficiency target. This type of change would enable the development of creative solutions—including those involving the implementation of controls—that are not recognized by current industry metrics. New part-load and annualized metrics, combined with the use of "smart" technologies and capabilities at a system level, will offer opportunities for energy savings past the point at which individual components meet technical limitations.

One early step would be to continue to expand existing part-load and annualized metrics, such as IPLV and IEER; for example, the IEER metric applied to rooftop air conditioning units could be expanded to include ventilation fan operations, economizer operations, and even heating. Today, only about seven percent of products have an associated annualized metric, but work is underway to improve existing metrics and to expand them to cover additional products. These metrics likely will have to take regional climate conditions into consideration and should be expanded to encompass more aspects of a system (e.g., economizers on rooftops and ventilation fan power). Heating is one area for which very few annualized metrics exist and for which they will need to be developed.

Implementation efforts also should consider the expansion of combined hybrid metrics, such as AHRI Guideline V, the only existing combined metric for a hybrid system, and which is applicable for a rooftop air-conditioner and an exhaust energy recovery device. Guideline V is currently limited in that it is based on full load, but work is underway at AHRI to expand it into an annualized metric.

Shifting to the use of systems-level metrics likely will take many years. Starting with the lower level subsystems and/or systems approaches and demonstrating successes will help facilitate the transition to a more comprehensive systems-oriented approach.

2.1.4.2 Potential Changes to Standards and Regulations

The mechanical systems in commercial buildings are highly regulated and require substantial engineering and industry resources to comply with and maintain certifications. Moving to new, systems-level metrics will require changes to federal as well as industry-led equipment efficiency standards and ratings. In the long term, if the proof-of-concept evaluations and implementation pilot tests succeed, changes to existing regulations and/or related policies might be required.

2.1.4.3 Role of Utilities and Utility Programs

In recent years, utilities increasingly have offered rebates for efficient appliances, as they have worked to meet state-mandated energy efficiency targets and manage their own demand and infrastructure growth. A good starting point for the integration of systems metrics may be to consider whether such metrics can be factored into utility rebate programs. Entities such as Pacific Gas and Electric (PG&E) and CEE have shown interest in pilot programs to explore possible implementation approaches.

2.1.5 Next Steps and Recommendations

2.1.5.1 Research, Technical Support, and Market-Based Needs

Many new technologies, market and regulatory reforms, and innovative policy approaches are needed to make a systems approach viable. Some are underway; for example, ASHRAE Standard 90.1 and ASHRAE Standard 169 completed an update to their "benchmark cities" to align with new ASHRAE Standard 169 climate zones. Additional elements that need to be developed include:

- Part-load and/or annualized metrics, such as IPLV and IEER, should be expanded to cover additional products. In addition, metrics will be needed to accommodate hybrid technologies within a given building system.
- AHRI and other organizations likely will need to modify testing procedures and ratings standards to accommodate these changes in metrics.
- ASHRAE Standard 205 – A standardized approach for formatting data inputs to (and outputs from) modeling equipment performance should be completed and adopted for widespread use. Related to this is a need for standard means by which to confidentially and securely transfer data on equipment and system performance ratings.
- Standardized Building Models – Expansion is needed of the 16 benchmark buildings to add a laboratory, supermarket, and public assembly building, with the goal of reaching 90 percent market coverage.
- More accurate models and/or other computer tools are needed to analyze mechanical systems at full and partial loads, over an entire operating range, as well as to better reflect ambient temperatures and more realistic load profiles of proposed buildings. Models also should incorporate the use of controls and intelligence to a greater extent.
- Alternative simulation tools and approaches should be developed. Updating benchmark buildings and cities will help establish better baselines against which to measure systems approaches.
- Results of "proof-of-concept" work will be useful to demonstrate potential systems-related efficiency savings, and for education and outreach.
- Commissioning and proper maintenance should be conducted over the life of a building system.

2.1.5.2 Training and Certification

Training for design engineers, operating personnel, and code officials (among others) in the use and application of systems-oriented approaches—including building inspection and code enforcement procedures—will be critical. Current AHRI and other certification programs will be particularly important.

2.1.5.3 Recommendations for SEI Year Two Efforts

The following activities are recommended as areas of focus for Year Two of this SEI and for other mechanical systems initiatives (e.g., in AHRI and ASHRAE):

- Address plans for training and certification using systems-level approaches and metrics.

- Focus on validating these systems-oriented concepts and the amounts of energy that can be saved in selected building types (i.e., large office building and high-rise (multi-family) residential building), as well as in other building types.
- Coordinate efforts closely with the AHRI Systems Steering Committee, which has selected three benchmark systems for evaluation.
- Further examine miscellaneous loads and ways in which to reduce their impacts on mechanical building systems (see Section 2.3.2 of this report).
- Identify opportunities for mechanical system improvements, and for testing new tools and metrics, for the subset of small buildings.
- Examine the potential for commissioning and continuous commissioning of mechanical building systems.
- Examine whether systems metrics can be factored into utility rebate programs. PG&E and CEE have shown interest in working on pilot programs to explore possible implementation approaches.
- Explore the potential to increase the efficiency of hybrid systems, in which multiple technologies are combined into one system. These can include integrated energy recovery, evaporative cooling for hot and dry climates, thermal storage, renewable energy, and internal heat pump and heat reclaim systems.
- Explore opportunities for efficiency improvements through the use of connected equipment at a system level, including:
    - Use of diagnostic and prognostic approaches;
    - Connection of all equipment in a system to a system-level control mechanism;
    - Connection of the system to the "smart grid" and use of the smart grid to optimize system operations; and,
    - Development of common dashboards for system monitoring and management.
- Review and analyze on an ongoing basis systems efficiency efforts being carried out globally, with a specific focus on the European Second Energy Directive, work in Vancouver and other parts of Canada, and the work underway in Singapore, and incorporate lessons learned.

2.2 Lighting

ASHRAE Standard 90.1 defines a lighting system as "a group of luminaires circuited or controlled to perform a specific function." The "C-137 Committee," which was recently formed by NEMA and other partners, and whose scope is lighting systems, has defined an optimal lighting system as "a collection of luminaires and related lighting equipment installed in an application to provide the right amount of light where and when needed, with consideration of human comfort, visibility, safety and security, the physical environment, and daylight integration." Based on this definition and for the purpose of this SEI, optimal lighting systems comprise multiple components, including luminaires and other hardware (fixtures, sensors, and controls), software (scheduling, control algorithms, networking with each other and with other building sub-systems), interior design (surfaces, furniture/partition layouts, colors and textures), and windows or skylights designed and operated to minimize energy use while maintaining lighting quality.

Energy used for lighting is one of the largest single contributors to the total energy consumed by commercial buildings, historically representing about 20 percent of commercial building electricity use in the United States (EIA, 2009). While significant improvements have been made in the efficiency of individual lighting components in the past decades, the lighting industry and its professional associations believe that more energy savings can be obtained in new and existing U.S. buildings by focusing on lighting systems. Lighting professionals also are keenly aware that existing building lighting—both public and private—is not being upgraded at a rate that keeps pace with technological development.

The primary forces shaping minimum requirements for lighting systems in commercial buildings in the U.S. are the ICC's International Energy Conservation Code, California's Building Energy Efficiency Standards (Title 24, Part 6), and the National Standard, ASHRAE/IES Standard 90.1. Each features requirements for indoor lighting systems and applies to new construction, major renovations, and retrofits. While California's Title 24 only applies to that state, its continuous development and refinement have encouraged advocates to press for similar changes to be adopted into ASHRAE Standard 90.1 and the IECC.

This section highlights some of the ways to optimize the efficiency of lighting systems, as well as the benefits of doing so, and discusses technical, market, and policy barriers to achieving such improvements. The section also provides preliminary recommendations for an effective systems-based approach to lighting, addressing the areas of data collection, daylighting, controls, "smart" products, legislation, and policy.

2.2.1 Optimal Lighting Systems

A systems approach to lighting combines efficiency goals with lighting quality to meet the needs of the occupants and users of a space. Given the above definition of an optimal lighting system, the process of optimizing a lighting system incorporates a concept that has been labeled the "four rights." To this end, an optimal system delivers:

- The right **amount** of light,
- At the right **place**,
- At the right **time**,
- Using the right **equipment** (Raynham, 2012).

Optimizing a lighting system thus means meeting quality goals (the right amount of light at the right place), while also consuming the least possible amount of electrical energy (light at the right time and using the right equipment).

Designing and structuring an optimal lighting system is a subtle and complex goal. Strategies for achieving the goal will vary, depending on the uses and functions for which a space is designed (e.g., commercial office space, retail sales, hospitality, or manufacturing) as well as on other design goals. In addition, the terms "right amount" and "right place" are subjective. Thus, it is important to identify and more clearly define the key elements of lighting quality that must be considered in optimizing a lighting system. Key elements of lighting quality include:

- Vision;
- Comfort;
- Modeling;
- Composition;
- Color; and,
- Health (IALD/ALA/IES, 2010).

The box below provides definitions of each of these terms and the ways in which each applies to an optimized lighting system.

"Right time" and "right equipment" also are subjective terms. In practice, they mean that electrically- powered lighting is turned off when not needed, and that light in a space is provided by the combination of daylight, electric light, and controls that minimize electrical energy use, while still providing the "right" amount of light at the "right" place—that is, achieving lighting quality goals.

A systems approach offers many opportunities for optimizing lighting systems by ensuring flexible, real-time availability of lighting, including through the use of occupancy sensors, light-level sensors, and other equipment. Systems-level strategies for lighting are discussed in more detail throughout this section.

KEY COMPONENTS OF AN OPTIMIZED LIGHTING SYSTEM

LIGHT + VISION

Lighting exists to enable us to see; higher or lower light levels affect the visibility of what we see. The more visible tasks are, the more efficiently, accurately, and safely we perform them. For this reason, selection of light levels is critical to health, safety, and welfare.

LIGHT + COMFORT

Good lighting provides sufficient light levels without glare, which can be irritating or even impair vision. Just as older people need more light to see clearly, they are also more sensitive to glare, making vision and glare critical issues for America's aging population.

LIGHT + MODELING

Light and shadow are tools that lighting designers use to make faces, objects and spaces more visible or more attractive.

LIGHT + COMPOSITION

Within spaces, patterns of light and appearance of lighting equipment itself convey vital information to people such as scale, function, and way finding while emphasizing points of interest such as artwork. Light patterning can articulate architecture and reinforce mood and atmosphere.

LIGHT + COLOR

Visible white light is comprised of colors; the spectral composition of a light source, whether is it "cool" or "neutral" or "warm" in color appearance, can affect how we perceive the colors of faces, objects, and surfaces.

LIGHT + HEALTH

Poor lighting may negatively impact health and well-being by producing glare, eyestrain, flicker, tension, and interfere with the body's circadian rhythms. It can also produce unsafe conditions by failing to properly illuminate hazards such as curbs, stair edges— even labels on cleaning products.

Source: IALD, ALA, IES, 2010

One of the most challenging, yet rewarding, aspects of optimizing lighting is the incorporation of daylight into lighting systems. Daylight is free, non-electric, and recognized as a high-quality light source. In fact, recurring exposure to daylight is vital for people to thrive. At the same time, controlling daylight to optimize elements of lighting quality, such as glare and other aspects of visual comfort (e.g., contrast, shadow), requires additional equipment, careful system design and integration, and an overall understanding of how the four "rights" will be achieved in any given space or building.

The remainder of this section addresses ways in which to optimize lighting systems, with particular attention to lighting controls, the integration of lighting systems with other building systems ("boundaries"), incorporating daylighting as part of such a systems approach, and technical and policy barriers in the U.S. that work against truly optimizing lighting and other building systems.

An additional area that could contribute to increased lighting system efficiency is that of the emerging technology of DC power. While DC power has been around since the dawn of the electric lighting era, alternating current (AC) has been the preferred method of supplying power to buildings since the early twentieth century. With the recent advances in PV panels in terms both of performance and cost, renewed interest exists in DC power (the "direct" output of PV panels is in the form of direct current). This DC power could be used directly, without having to convert it to AC power, if the powered devices in a building were able to take a DC input directly.

The lighting market's transformation and conversion to LED lighting is quite timely. LEDs inherently are DC devices. They now are powered by "drivers" (power supplies) that convert the AC line voltage to the DC required by an LED. If a building could take advantage of renewable energy in the form of PV panels and supply DC power to the lighting system, the design of LED drivers could be somewhat simplified and their cost could be relatively lower. This situation currently is being discussed by various industry organizations and could be a viable option in the near future, if it is determined to be technologically and economically feasible.

2.2.2 Lighting Controls

Lighting controls are the central nervous system of a lighting system. Lighting control components, such as occupancy sensors, light level sensors, and daylight sensors, take inputs from the external environment, process those inputs, and send the outputs to smart controllers, ballasts, or drivers that make decisions regarding how to operate the lighting system. The wiring infrastructure and communications backbone link all of the lighting system components to enable them to operate in a manner that optimizes lighting usage in individual spaces and throughout a building.

Lighting system controls help eliminate the use of excess or wasted energy by automatically turning lights off, or dimming them, when spaces are not being used and by using daylight, when available, in lieu of electric lighting. Reducing lighting system electrical use also can reduce space cooling loads, which can enable HVAC equipment to be downsized. In addition, advanced lighting control systems can provide real-time information on energy use and illuminaton levels that can facilitate energy management, reporting, and monitoring. As a further (non-energy) benefit, lighting system controls also help enhance occupant comfort and satisfaction by enabling occupants to customize light levels to their unique needs.

To optimize the use of lighting controls as part of an optimal lighting system, their design and layout must allow for the separate control of daylight and non-daylight zones. Automatic daylight-responsive control enables lights to be dimmed, based on the amount of useful daylight. Various schemes may be employed to accommodate the required level of control, according to the type of space and occupancy characteristics. Controls can be used to perform the following types of tasks:

- Switch on/off or dim lights (step or continuous dimming);
- Set the amount of dimming before switching off luminaires;
- Integrate dimming control with any active fenestration (i.e., window) systems and attachments (e.g., shades, external louvers, electrochromic windows);
- Set the extent and method of occupant override capability;
- Ensure the proper placement of photo-sensors to maximize reading capabilities, due to lighting conditions, and to minimize or prevent interference from unwanted environmental or office layout effects; and,
- Integrate electric lighting system responses and daylighting into the overall building management system programming.

The effective use of lighting controls to optimize lighting systems can result in measurable energy savings. A lighting controls study in two GSA federal office buildings with updated LED lighting resulted in measured savings of 32–33 percent of lighting energy (Wei et al., 2015).

An article posted on the Lighting Control Association's website summarized the range of estimated or measured savings from lighting controls as follows in Table 2.2, based on a review of the literature (DiLouie, 2013).

Table 2.2 – Sampling of Industry Research Indicating Demonstrated, Estimated, or Potential Lighting Energy Savings for Various Control Strategies and Environments

Space Type	Controls Type	Lighting Energy Savings Demonstrated in Research or Estimated as Potential	Study Reference
Private Office	Occupancy sensor	38%	*An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems,* Lighting Research Center/EPA, August 2000.
	Multilevel switching	22%	*Lighting Controls Effectiveness Assessment,* ADM Associates for Heschong Mahone Group, May 2002.
	Manual dimming	6-9%	*Occupant Use of Manual Lighting Controls in Private Offices,* IESNA Paper #34, Lighting Research Center.
	Daylight harvesting (sidelighting)	50% (manual blinds) to 70% (optimally used manual blinds or automatic shading system)	"Effect of interior design on the daylight availability in open plan offices", by Reinhart, CF, National Research Council of Canada, Internal Report NRCC-45374, 2002.
Open Office	Occupancy sensors	35%	National Research Council study on integrated lighting controls in open office, 2007.
	Multilevel switching	16%	*Lighting Controls Effectiveness Assessment*, ADM Associates for Heschong Mahone Group, May 2002.
	Daylight harvesting (sidelighting)	40%	"Effect of interior design on the daylight availability in open plan offices", by Reinhart, CF, National Research Council of Canada, Internal Report NRCC-45374, 2002.
	Personal dimming control	11%	National Research Council study on integrated lighting controls in open office, 2007.
Classroom	Occupancy sensor	55%	*An Analysis of the Energy and Cost Savings Potential of Occupancy Sensors for Commercial Lighting Systems,* Lighting Research Center/EPA, August 2000.
	Multilevel switching	8%	*Lighting Controls Effectiveness Assessment,* ADM Associates for Heschong Mahone Group, May 2002.
	Daylight harvesting (sidelighting)	50%	*Sidelighting Photocontrols Field Study,* Heschong Mahone Group, 2003.

Source: Lighting Control Association

One industry source estimates stand-alone commercial lighting energy savings of 20–60 percent, using occupancy sensing, and 10–20 percent from personal dimming controls, as well as other savings, as documented in Table 2.3.

Table 2.3 – Stand-Alone Commercial Lighting Energy Savings from Controls and Other Measures

Solutions	Single Space Energy Savings
Occupancy/Vacancy sensing	20-60% lighting
High-end trim	10-30% lighting
Daylight harvesting	25-60% lighting
Personal dimming control	10-20% lighting
Plug load control	15-50% controlled loads

Source: Lutron, 2016

2.2.3 Lighting System Boundaries and Integration with Other Building Systems

Defining metrics, specifications, and goals for a system can be fundamentally more challenging than doing the same for an individual component or device. A system comprises multiple devices and system performance often is dependent on more than just device characteristics. Interactions among devices can positively or negatively affect performance and, in turn, the performance of a system. Prior to defining metrics, specifications, and goals for a system, one must first define the system. What devices comprise it? How do they interact with one another?

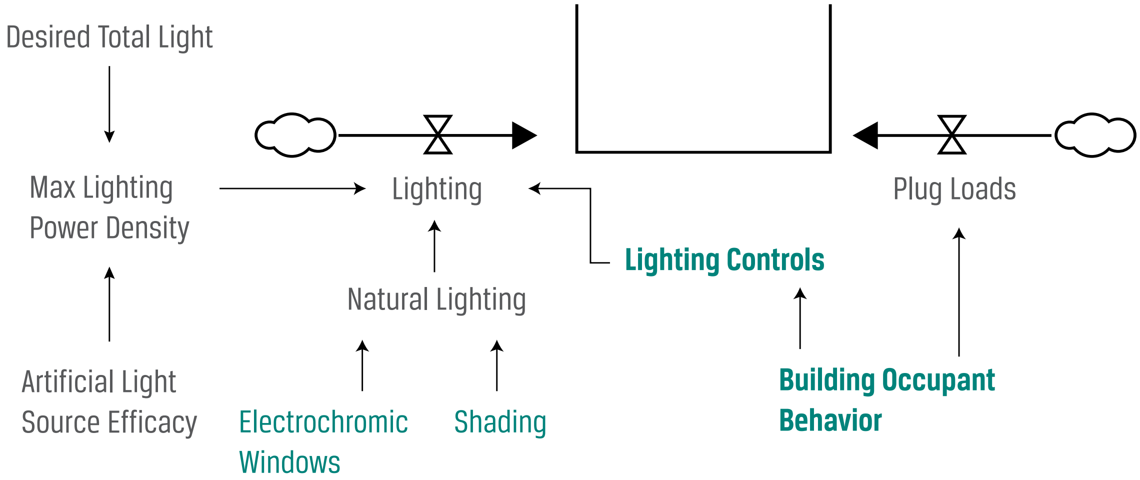
In addition, to determine the potential efficiency gains of a systems-oriented approach for lighting—as well as the feasibility, costs, and other benefits—defining the boundaries of what are considered component parts of a lighting "system" is important, as is understanding the inter-relationship between the lighting system and other building systems, such as the HVAC&R system or the building envelope.

This subsection is focused on addressing the following two questions:

- Where are the boundaries between the lighting system and other systems?
- How does the lighting system interact with other systems?

This report makes certain assumptions regarding the "boundaries" of a lighting system for analytic purposes. While recognizing that the term "boundary" suggests a hard line of distinction between where the lighting system ends and another building system begins, it may be more accurate to think in terms of "interfaces," or the points at which lighting interacts with artificial lighting, natural lighting (i.e., windows or other sources of daylighting), controls, and other building systems. In one sense, the devices that produce light from electricity are the only purely lighting-related devices in a lighting system. Therefore, focusing on the defined interfaces where electric lighting devices and systems interact with these other components and systems is important. Figure 2.7 illustrates the interactions among lighting systems and other systems.

Figure 2.7 – Interactions Among Lighting Systems and Other Systems and Factors



Source: Lutron

Devices that interact with more than one system (e.g., electrochromic window controls and occupancy sensors may interact with lighting and/or HVAC systems) might conceptually be considered part of both systems, as comprising their own system, or as part of one system or another, based on a particular criterion. For example, devices might be considered to belong to a system if they directly interface with the communication network like other devices in that system. Alternatively, devices that are interconnected by their own communication network may be considered a stand-alone system.

Controls of all types function increasingly on a distributed basis, rather than on a centralized basis; that is, we expect the portion of building lighting that relates to a particular subset of occupants to respond to those occupants' needs rather than to a central control module that is running every space in a building on a pre-determined schedule. In recent years, technology trends in the industry have resulted in devices becoming increasingly "intelligent"—enabling them to make "decisions" about their own operation and enabling relevant building systems to leverage distributed intelligence rather than relying solely on centralized intelligence.

From a practical standpoint, therefore, treatment of a lighting system and its boundaries should take into account the following:

- Performance measurement and prediction;
- Design, installation, configuration, and operation of the lighting system;
- Lighting system interfaces with other devices and systems; and,
- Codes and regulations that must be met, or adopted, to address changing technologies, practices, and responsibilities.

2.2.4 Daylighting

As noted, one key consideration in defining lighting system boundaries is the interface of lighting devices and controls with daylighting. The interaction between a building's lighting system and the building's envelope is particularly important in any effort to maximize the benefits of daylight and daylight management systems.

Effective use of daylighting is critical to systems-oriented energy efficiency. Introducing certain amounts of daylight into indoor spaces can greatly reduce lighting energy consumption. Two steps must be taken to achieve a good daylighting design. First, daylighting should be a major consideration during the design phase. Building orientation is important; daylighting should be brought into play as a design element in siting buildings. In addition, building façades and interiors should be designed with the goal of introducing sufficient daylight deeper into interior spaces (e.g., through the use of skylights or narrow building footprints).

Second, in the operational phase, lighting control systems should be designed to ensure that available daylight is used as effectively as possible. Controls should automatically dim the electric lights based on daylight levels; research has shown that using such daylight "harvesting" systems in commercial buildings can save 25–60 percent of lighting electricity consumption (Reinhart, 2002). However, it is worth noting that excessive daylight can have a negative impact on HVAC energy consumption. That is, solar heat gain from direct sunlight can greatly increase a building's cooling load. This heat gain can be controlled or minimized when exterior shading devices or dynamic glazing are used in the building design. Exterior shading devices may be static, such as projections above or to the side of windows, or dynamic as in the case of manually-controlled or motorized exterior louvers. Automatically-controlled interior or exterior shading devices also can be used to control or minimize heat gain. Dynamic systems should be considered, especially in northern climate zones, where a significant part of the year is spent in heating mode: Making use of solar heat gain during those times might be desirable. Finally, building orientation also can be planned to control or minimize heat gain.

Examples of the benefits of effective daylighting include the following:

- The combination of dynamically-controlled exterior glazing with dimmable lighting controls was examined in a monitored commercial building retrofit project in Washington, D.C. Automated electrochromic windows and light dimming controls in a west-facing conference room were monitored for 15 months, and yielded weekday lighting energy savings of 91 percent compared to the previous lighting system, along with a 35 percent reduction in peak demand for lighting. Savings on an annual basis (including weekends and evenings) ranged from 39 percent to 48 percent (Lee et al., 2012).
- An estimate of the potential nationwide savings from dynamically controlled glazing in commercial buildings suggests that such advanced glazing could increase the savings from daylighting controls by as much as 85 percent (Shehabi et al., 2013).[12]

2.2.4.1 Non-Energy Benefits of Daylighting

When designed properly, a daylighting system can help increase the health and well-being, satisfaction, and productivity of occupants of a built environment without compromising their visual and thermal comfort (Bouberki, 2014; California Energy Commission, 2003). However, to provide these benefits, daylighting systems must be carefully designed and properly controlled: Too much glare and thermal discomfort from excessive daylight (e.g., excessive glare or insufficient or inaccurate daylight control) can dilute the positive impacts of providing daylight and outside views.

12 Note that this number refers to a percentage increase in savings, not to the percent of energy savings per se.

Indeed, if a daylighting system is not designed to adequately deal with occupant comfort, because of either poor design or improper system control, occupants likely will circumvent the daylighting system to make themselves comfortable. For example, occupants may react to excessive daylighting by closing manual blinds indefinitely, thereby negating the potential daylighting benefits. Subsection 2.2.4.2 introduces the metrics that typically are used in industry and academia to quantify daylight performance, and Subsection 2.2.4.3 introduces some design guidelines for façade, interior, and skylight systems.

2.2.4.2 Metrics for Quantifying Daylighting Performance

Metrics commonly used to quantify daylighting performance generally address non-energy benefits of daylighting, including:

- ***Daylight sufficiency:*** Provision of sufficient daylight spaces to reduce lighting energy consumption, as well as provide the occupants with the daylight they need to entrain their circadian rhythms. Metrics include spatial daylight autonomy (sDA), continuous daylight autonomy (cDA), and useful daylight illuminance (UDI).
- ***Glare control:*** Provision of active systems to ensure that glare levels are below a certain, acceptable threshold. Metrics include daylight glare probability (DGP) and annual sunlight exposure (ASE).
- ***Quality view:*** Giving occupants a connection to the natural outdoor environment by providing quality views. For example, guidelines provided by LEED v4, for new construction, core and shell, schools, retail and hospitality buildings, and data centers specify provision of a direct line of sight to the outdoors via vision glazing for 75 percent of all regularly occupied floor area (UGBC, 2015). View glazing in the contributing area must provide a clear image of the exterior, not obstructed by fibers, patterned glazing, added tints that could distort color balance, or other factors. In addition, 75 percent of all regularly-occupied floor area must have at least two of the following kinds of views:
  - Multiple lines of sight to vision glazing in different directions that are at least 90 degrees apart;
  - Views that include at least two of the following: (1) flora, fauna, or sky; (2) movement; and (3) objects at least 25 feet (7.5 meters) from the exterior of the glazing;
  - Unobstructed views located within a distance equal to three times the head height of the vision glazing; and,
  - Views with a "view factor" of 3 or greater, as defined in "Windows and Offices: A Study of Office Worker Performance and the Indoor Environment."

Any permanent interior obstructions should be included in the calculations. Movable furniture and partitions may be excluded. Finally, views into interior atria may be used to meet up to 30 percent of the required area (USGBC 2015). More details are available in LEED v4 EQ-Quality Views.

2.2.4.3 Design Considerations for Effective Daylighting

As noted, effective use of daylighting requires its consideration during the design phase, both in the building façade and interior design. Some useful design guidelines for both are provided below.

Façade Design

Four factors involved in the design of a building's façade have impacts on a building's lighting systems and their energy efficiency.

First, there is the window-to-wall ratio (WWR). Energy codes typically limit WWRs to 30 or 40 percent in their prescriptive paths (ASHRAE, 2013 – see Section 2.2.4.3). This is based on the assumption that the fenestration system is passive and that the lighting control in the daylight zone is not continuous-dimming-to-off, based on daylight availability and consistent with code requirements. When high performance fenestration systems, which are designed to optimally control solar heat gain and glare, are used with continuous-dimming-to-off lighting controls, the optimal WWR has been demonstrated to be very different and larger than the current energy code allowance (Carmody et al., 2004).

Second is window placement and design. Daylight effectiveness increases when windows are placed high on the wall and when the view portion and daylight portion of a window are separated and glass and shades or blinds are individually controlled. (Energy codes are silent on the placement and design of windows along exterior walls.)

The third factor pertains to dynamic fenestration (i.e., windows or window systems that move). Dynamic fenestration systems, such as interior and exterior automated roller shades, blinds, louvers, and electrochromic glass, help improve energy efficiency both for lighting and HVAC systems. Fenestration with dynamic solar control and a low "U-factor" (defined as the rate at which a window, door, or skylight conducts non-solar heat flow), integrated with continually-dimmable lighting controls, has been demonstrated by DOE to be a component of a net zero energy envelope solution (Curcija, 2014). Dynamic fenestration systems often are more effective than their passive counterparts at providing occupant visual and thermal comfort.

The fourth factor pertains to whether a building can accommodate daylight redirecting systems. Light shelves, though not required by code, are helpful in increasing daylight penetration (DiLaura, 2011). Although light shelves do not increase the amount of light in a room, they do help to spread it into the space. Typically, the term "light shelf" refers only to interior systems, although many would refer to an exterior sunshade that directs light towards interior ceilings as a light shelf, as well (Carmody et al., 2004). Tubular daylighting devices and other daylight redirecting systems also can be used for a variety of space types.

Interior Design

Interior design elements are extremely important to the effectiveness of daylighting designs. For example:

Highly-reflecting surfaces help ensure that light reaches further back into the interior of a building. The Illuminating Engineering Society (IES) has recommended reflectance on interior surfaces of 50 percent for walls and 80 percent for ceilings to help increase daylight penetration and uniformity (DiLaura et al., 2011).

Low partition heights increase daylight effectiveness by allowing a greater penetration of light into the core of a building.

Using transparent walls for perimeter offices and conference rooms or locating private offices to the inside of a building helps increase daylight penetration, thus sharing daylight with a greater portion of a building's footprint and increasing lighting system effectiveness.

These key parts of daylighting design are typically considered to be outside the scope of energy codes. Only in ASHRAE Standard 189.1 (green codes) are interior surface reflections mandated.

Coordination with the American Society of Interior Designers (ASID) to determine how best to integrate interior and lighting design into building design guidelines and potentially into codes is a promising area for exploration during Phase 2 of the SEI.

Skylight Design

While they are architecture- and site-sensitive, skylights and *clerestories*[13] also should be considered for inclusion in any lighting system (DiLaura, 2011).

Clerestory use in an office environment

Source: *National Park Service*

Incorporation of a skylight into an office space

Source: Mono Ad Agency, 2011

13 Windows positioned above eye height or above an adjacent roof.

ASHRAE Standards 90.1 and 189.1 do not mandate the use of skylights and clerestories. However, when these features are included in a building's architecture, the ASHRAE Standards provide guidelines for the design and utilization of skylights and clerestories in combination with the lighting system and interior design of a space. New requirements currently are being discussed in the Standard 189.1 Daylight Task Force for inclusion in the next version of the Standard.

2.2.5 Technical, Market, and Policy Barriers

Some of the barriers to improving system-level efficiency with respect to lighting are regulatory in nature; others are market- and policy-oriented. Still other types of barriers include issues of compatibility, security, and measurement of the energy performance of a lighting system (including controls).

Regulatory issues: One challenge to improving the efficiency of lighting systems is related to compliance with building energy codes. Currently, energy codes favor prescriptive approaches to compliance, which "prescribe" maximum energy use or connected load, or specific characteristics of each building component to realize savings. This method is relatively straightforward and manageable for code and compliance officials; however, as it relates to regulating allowed lighting power density (LPD, expressed as connecting lighting watts per square foot), this approach does not address the amount of time that lighting systems are used.

In ASHRAE Standard 90.1, for example, each type of space in a building (e.g., open office space, conference room, private office, cafeteria) is assigned an LPD, which is the maximum lighting power (in watts) per square foot allowed in that space. This metric represents the installed watts of lighting in the space. LPD also is a power-based metric, basically limiting the fixture wattages and number of fixtures that may be used in a particular space.[14] (For more discussion of codes and standards, see Appendices 3 and 4.) The dilemma is that the prescriptive LPD approach, while having provisions and credits for employing the use of lighting controls, does not mandate their use. Therefore, the possibility still exists that the lighting equipment could be used for an excessive amount of time, wasting energy even when a space is unoccupied or adequate daylight is available. Several options exist to mitigate this problem; these can be applied individually or in combination with one another, as follows:

- Using controls more extensively, with limits on overrides;
- Implementing automated lighting control systems;
- Monitoring energy use via metering (or sub-metering) of a lighting system; or,
- Employing a different type of metric, such as an energy-based metric.

The first two options can be effective, but require a more complex design and are more expensive for building owners. Well-trained facility management personnel also are required to ensure proper operation and maintenance.

The last two options recognize the need to more directly account for actual energy use. Targets or metrics aimed at energy usage

14 At this point, LPD values are determined independent of any system efficiency gains. Also note that: energy is defined as power demand (e.g., kilowatt) over a defined period of time (e.g., kilowatt-hour). (Energy = Power x Time (i.e., Kilowatts x hours = kilowatt-hours, or kWh.) The amount of energy used by a lighting system is dependent on the amount of time the equipment is in use during a monthly billing cycle.

(consumption) could be set, based on such factors as building design, energy availability, or energy cost targets. Such metrics typically are measured in kilowatt-hours for electrical energy or kBTUs (thousands of British Thermal Units) for total energy. For example, the EUI metric (discussed in Section 1.8 of this report) denotes total energy use per unit area of a building or kBTU/square foot, and can be used for such an "outcome based approach," focused around a building's final energy performance (see Sec. 3.1.1.3).

Market and policy barriers: One policy-related barrier to implementing an outcome-based approach involves the way in which government is organized and managed at the local and state levels. The agencies responsible for code compliance are almost never the same as those responsible for safety (or other relevant factors), after a building has an occupancy permit. In addition, the objectives for complying with building codes might be at odds with those for meeting safety requirements, or one agency might impose one set of requirements without necessarily bearing mind other requirements with which a building must comply.

An additional barrier is that financial incentives for lighting equipment are driven by specifications from energy-efficiency programs. The product specifications tend to promote very efficient lighting products, but provide no assurance that glare control, optical optimization, and/or dimming performance have been addressed.

Compatibility issues: A variety of platforms have been designed and tested to ensure control devices are compatible with luminaires. Various protocols (e.g., Zhaga, NEMA SSL7A and 7B) to facilitate such compatibility exist, but have not yet been widely adopted.

Security: As lighting moves toward a more "intelligent" paradigm, with more potential infiltration points through various devices (e.g., controls), cybersecurity becomes a greater concern for both wired and wireless systems. To the greatest extent feasible, lighting system designs will need to be able to prevent hacking and alteration of devices that make systems vulnerable to unauthorized access.

In reality, no device or system is truly wireless unless it is battery powered, which is not typical of lighting systems. While wireless lighting control devices tend to be preferable for ease of installation and programming—especially in applications where minimal construction disruptions occur, such as existing building renovations or retrofits—a hybrid of wireless and wired controls may initially be most cost-effective, because wireless devices historically have been significantly more expensive than wired ones. However, as technology changes rapidly and more sophisticated economic metrics make it easier to value energy efficiency (e.g., costing on a life-cycle basis as opposed to simple payback of equipment costs), wireless lighting controls will become increasingly prevalent.

2.2.6 Lighting Systems Efficiency Efforts in the Industry

Electric utilities have begun to pursue efforts to improve the efficiency of lighting systems through their non-profit organizations. For example, the Northwest Energy Efficiency Alliance and the DesignLights Consortium™, a project of Northeast Energy Efficiency Partnerships (NEEP), have started developing policies that would help enable lighting systems to be eligible for utility-supported incentive programs.

In addition, NEMA worked with its members and other organizations to form the "C-137 Committee" and to adopt the ANSI standards-setting process. The C-137 Committee has established two ad hoc working groups that address energy efficiency. One of the groups, focusing on energy measurement and prediction, is developing a standard that will define the way in which energy measurements of lighting systems are reported. The second working group has begun work on several lighting applications that are expected to address energy efficiency.

2.2.7 Non-Lighting Benefits of a Systems Approach

While the focus of this SEI report is on improving a building's energy efficiency through a systems approach, the integrated design practices that will yield systems efficiency improvements also can lead to other "non-energy" benefits, among which is the potential for very significant gains in human comfort, productivity, safety, and health.

Research into these types of benefits is ongoing, but results to date show that many measures that improve lighting system efficiency also yield non-energy benefits. For example, the integration of daylighting with electric lighting results in increased occupant comfort, improved aesthetics, and health benefits (e.g., through minimizing disruption of circadian rhythms), and leads to better performance. Moreover, integrated design practices can take into account daylighting's effects on building thermal performance (i.e., the envelope and HVAC system) to ensure balance among all building systems. Opportunities to achieve these types of non-energy benefits through a systems approach will be explored to a greater extent in Phase Two of the SEI.

2.2.8 Conclusions and Next Steps - Research and Policy Recommendations

In addition to the opportunities for product performance enhancement and operational improvements discussed above, as well as codes and standards, the proliferation in this digital world of even finer points of control will enable almost endless possibilities for lighting system optimization and efficiency gains. This often is referred to as the "Internet of Things (IOT)"—the potential for every device or component to have its own internet protocol (IP) address. The implications for commercial building lighting systems could be substantial.

Intelligence and connectivity will be embedded into sensors and actuators (i.e., LED drivers). Most computing will take place within a building's boundaries. The Internet will be used for commissioning, analytics, and establishing a web identity for products and systems, the latter referring to digital avatars (Rubinstein et al., 2011).

This is not science fiction; it already is beginning to take place. The number of connected devices will increase exponentially over the next decade. This phenomenon, when ultimately realized in the building arena, will allow unprecedented levels of control and system optimization. Building system "silos" can be avoided first by using Internet-disseminated messages to modify behavior of installed legacy lighting controllers; later, proximal networks of devices will inter-communicate on an ad hoc basis to allow for interactions among different applications. Before this can happen, however, we must know more about building system interactions and be able to develop more sophisticated software and control systems to take advantage of these new capabilities.

The collective experience and knowledge of professional practitioners in this area has contributed to the following key points and recommendations:

1. Lighting design practitioners have long espoused the benefits of treating lighting as a system. Lighting systems encompass the areas of hardware (luminaires, fixtures, sensors, and controls), software (e.g., for scheduling, control algorithms, networking with each other and with other building systems), interior design (e.g., surfaces, furniture/partition layouts, colors, and textures), and the building envelope (e.g., skylights and windows); and require knowledge of the occupants and tasks, energy efficiency, and maintainability.
2. Employing integrated design concepts during the design phase is essential to realizing maximum energy efficiency while ensuring system and device compatibility, as well as maximizing the efficiency of a building's overall operations.
3. System design and system performance need to be measured and evaluated based on numerous criteria, including energy efficiency and energy consumption.
4. Optimized lighting systems that are energy aware (i.e., report their energy use in real time) have a number of advantages, such as providing energy consumption information for use by utilities and energy regulators, and for verifying building code compliance. Energy information can support the financing of retrofits through Energy Services Performance Contracting (ESPC), Utility Energy Service Contracts (UESC), and other financing models.
5. Use of the most efficient devices, or combinations thereof (e.g., the combination of the most efficient lamp, ballast/driver, and reflector/optics), does not necessarily produce the most efficient lighting system. A systems-oriented approach is crucial to ensure that optimization produces higher overall efficiencies than maximization of each individual component.
6. Thorough commissioning and periodic re-commissioning are essential to ensure that energy targets are met both initially and on an ongoing basis. This likely will require a higher level of training of commissioning officials, particularly when a systems approach is utilized. Organizations such as the Building Commissioning Association will need to be involved to help meet this challenge.
7. Use of a power-based metric, such as LPD, can increase the use of highly-efficient components or even systems, but saving energy must be concomitant with reducing power over a period of time. As the old adage says, "what gets measured gets managed." The use of Portfolio Manager's EUI, ASHRAE's bEQ (Building Energy Quotient), or both, can prove useful in monitoring, improving, and ensuring building system efficiency.

2.2.8.1 Research Roadmap

The following areas are recommended for further research and analysis:

1. Optical modeling of the effects and benefits of reflective surfaces, furnishings, and interior design/layout to avoid uncomfortable glare/shadows/contrast.

2. Study of the interaction of lighting/daylighting and miscellaneous loads with heating/cooling loads to maximize energy efficiency.

3. Analysis and quantification of the effects on building occupants of glare from daylighting systems.

4. Preparation of an annotated bibliography of studies and development of a lighting system design guide on the effect of lighting systems on circadian rhythms and other effects on occupant health, well-being, and productivity.

2.2.8.2 Policy and Technical Recommendations

1. Obtain normative lighting data for buildings across the country. To this end, develop a nation-wide data collection strategy (e.g., benchmarking of lighting systems) to support a systems approach, working with organizations active in this field (e.g., LBNL).

2. Employ a return on investment (ROI) approach as a preferred method over a payback period approach.

3. Conduct additional literature searches and modeling exercises to further quantify the benefits of daylighting and to explore the relationship of lighting systems to other building systems, specifically HVAC systems and building envelopes.

4. Explore opportunities to promote lighting system efficiency through legislative action (e.g., tax incentives that reward efficient building upgrades) or mandatory reporting of building energy usage.

5. Track the Lighting System Standard activities of the NEMA-initiated "C-137 Committee" to ensure compliance with the new standard, increased adoption of lighting systems, and compatibility of nomenclature, and to keep abreast of new system protocols.

6. Consider and incorporate non-energy benefits into activities to promote a systems approach. Proper environments for building occupants should parallel building system efficiency to produce high performance buildings.

7. Coordinate with the American Society of Interior Designers (ASID) to determine how best to integrate interior design and lighting design into building design guidelines and potentially into codes.

Recommendations Pertaining to Lighting System Boundaries and Integration with Other Building Systems

1. To address the issue of lighting system interfaces, adopt working boundary definitions, so that a collection of devices sufficient to operate lighting, including daylighting, is collectively considered the "lighting system." While this activity may require setting arbitrary boundaries and identifying multiple functions for some devices (e.g., sensors), it will allow projects to proceed with consistency and minimal confusion.

2. Deploy common communications protocols among all building systems, so that lighting, HVAC, "dynamic" windows, sensors, and other systems all are able to communicate with one another. Rather than search for the "ideal" protocol, select one that works technically and is in widespread use in non-building systems, then demonstrate it with a few projects and examine the results.

3. Develop and/or implement common technical system design and procurement specifications to accelerate the uptake of lighting controls in buildings (and to ensure that installation and programming remain simple and involve relatively minimal effort). Procurement specifications should ensure that control devices will perform accurately with lighting equipment.

4. Address performance measurement and the tension between central control and distributed functionality by designing systems that combine distributed functionality with centralized monitoring and reporting. The performance measurements of greatest interest are energy used and energy saved.

5. Integrate post-occupancy considerations into every aspect of the design and construction processes. This means:
   - Assess occupant satisfaction regularly and make it part of rating systems, such as LEED, and perhaps part of eligibility requirements for utility rebates, preferential tax treatment, or other incentives.
   - Make commissioning and systems operations an integral part of the construction process and set of responsibilities shared by the construction team.
   - Modify codes and standards such that occupant satisfaction becomes an integral part of design and construction requirements.

The recommendations listed above range from straightforward (#1, 2 and 3) to more difficult, complex, and innovative (#4 and 5). During Year Two, the SEI will specify in greater detail the types of policy, market, and technological changes that will be needed to advance this systems-oriented approach, in addition to any necessary changes to existing laws, codes, and standards to implement these recommendations.

2.3 Other Building Systems

The previous sections discussed two major building systems, lighting and HVAC&R, which account for about 60 percent of total primary energy use in commercial buildings (U.S. DOE, 2012a).

The remaining 40 percent of energy is used for a wide range of other building services, including cooking equipment, office electronics, and a variety of other types of equipment, whether plugged into receptacles or hard-wired and specific to the building and occupancy type (e.g., elevators and escalators, pool pumps, X-ray and magnetic resonance imaging (MRI) equipment, laboratory fume hoods). Still other types of building systems do not use energy directly, but can significantly affect the loads that need to be met by other equipment. The prime example of this is the building envelope, both its glazed and opaque elements. Finally, systems such as electrical distribution wiring and on-site generation (where present) represent essential parts of the energy-related infrastructure serving the building and linking it to the outside world.[15] During Year One of this SEI, two of these other building systems have been examined: miscellaneous electrical loads (MELs or "plug loads") and building-level DC power distribution. These are the topics of the next two sections. As the project continues in Year Two, the SEI will consider additional building systems, which may include:

15 Estimates for 2010.

- Energy storage systems (electrical and thermal storage);
- On-site power and cogeneration;
- Information technology;
- Vertical transport (elevators and escalators); or,
- Commercial building "process" equipment (e.g., commercial food preparation, laboratories, medical diagnostic and treatment devices, laundry equipment).

2.3.1 Miscellaneous Electric Loads

Miscellaneous electric loads (MELs) in buildings, also often referred to as "plug" or "process" loads, are generally defined as electric loads resulting from electric devices not responsible for space heating, cooling, ventilation, water heating, or lighting. MELs are produced by hard-wired and "plug-in" electrical devices, and include televisions and home entertainment centers, personal computers and other office equipment, security systems, data center servers, elevators, medical and research equipment, kitchen appliances, and many other devices. McKenney et al. (2010) provide a list of 28 typical commercial MELs.

MELs are responsible for a large, and growing, portion of delivered energy consumption in commercial (and residential) buildings and to some extent are offsetting the energy savings achieved by technical improvements in lighting, HVAC, and building envelopes (EIA, 2013). While MELs are found in most buildings, their mix, density, and share of total building energy use varies widely, from (non-refrigerated, non-automated) warehouses with relatively few MELs to data centers, hospitals, and restaurants that have a very high device and load density. McKenney et al. (2010) suggest that MELs can account for anywhere between 10 and 60 percent of commercial building energy consumption. Consistent with this estimate, Lobato et al. (2011a) report that MELs are responsible for approximately 25 percent of the total electrical load in a minimally code-compliant commercial building but, in a high-efficiency building, MELs can comprise more than 50 percent of the total electric load. MELs also affect the cooling, and heating loads of buildings, due to the generation and dissipation of heat into the conditioned spaces. Therefore, minimizing MELs is critical in the design and operation of energy-efficient buildings.

Three strategies warrant consideration for improving the energy efficiency of MELs; these are complementary rather than mutually exclusive. The most basic strategy consists of energy efficiency improvements to individual pieces of equipment, or components. As discussed in earlier sections of this report, technological advances have driven efficiency gains in heating and cooling equipment, increased the thermal resistance of windows, walls, and other building envelope components, and improved the efficacy of light sources and fixtures. Distinguishing between efficiency improvements due to energy-saving features when a device is active, as opposed to those due to "standby" or "sleep" mode controls, can prove useful. Computers, other commercial IT equipment, televisions, and additional consumer electronic products have seen efficiency improvements both in active and "standby" mode, as a result of technological advances as well as market pressures—enhanced by voluntary ENERGY STAR® labeling—and, in a few cases, due to mandatory standards and labels.

A second, complementary approach to MEL energy efficiency pertains to control, monitoring, and tracking of individual MEL equipment or groups of devices. [16] Such efforts help reduce wasteful energy use by devices left on when not in use (including those that lack a built-in "standby," or "sleep," mode, or where such a capability has not been enabled). Monitoring also can help ensure that individual devices are performing as designed and, thus, help building managers minimize energy waste, due to faulty or broken equipment.

A third strategy involves the integration of MEL controls with central building management systems/energy management systems (BMS/EMS), often referred to as "integrated performance systems." This type of effort could involve the integration of wireless or wired controls with the main control system(s) of a building.

Although addressing the efficiency of MELs at the equipment level will result in energy reductions, greater energy savings (and reduced costs) might be achieved by integrating MEL controls, including monitoring and diagnostic tools, with other building systems. MELs, therefore, comprise one important component that needs to be integrated into a more holistic building performance analytic system. Integrating MEL controls will help ensure that all building systems are operating efficiently and optimally. To achieve this goal, control and monitoring systems first must be installed, followed by the application of continuous monitoring-based commissioning, optimization procedures, and fault detection and diagnostics (FDD).

A review of several case studies and interviews with vendors suggests that benefits and costs of integrating MEL controls with other controls may depend on circumstances and on the type of MEL. For example, on/off controls for a range of equipment, such as computer monitors, desk lamps, space heaters, and other occupancy-related devices in offices and school classrooms could be usefully integrated with lighting controls. In other cases, such as vending machines and kitchen equipment, a timer system might make more sense but might benefit from being integrated with a BMS. For large buildings and new construction, integrating MELs and other controls may save money and potentially simplify installation and operations. For an existing building with a BMS in place, installing a separate system to control MELs may make the most sense; the same might be true for smaller buildings or those with diverse occupancy types.

Occupant education and engagement can have a significant impact on the energy reduction of MELs. Mercier and Moorefield (2011) discuss the need for occupant behavioral changes as part of an MEL reduction measure. Similarly, Metzger et al. (2012) studied the interaction of occupants with advanced power strips. This project revealed that the largest savings were on loads that run continuously (24 hours a day, 7 days per week); these included printers (27–69 percent reduction, depending on the type of control) and miscellaneous equipment (51–81 percent reduction, depending on the type of control).

2.3.1.1 Potential Benefits

The combination of developing more energy-efficient MEL equipment, implementing MEL control systems, and integrating these with central BMSs has the potential to significantly improve the energy efficiency of building systems and thereby help

16 In the last several years, many control enhancements were added to ASHRAE Standard 90.1 (and other standards). The majority of these enhancements have been for the HVAC/mechanical and lighting systems; however, one modification was the requirement for automatic receptacle control (ASHRAE Standard 90.1-2013, Section 8.4.2), which affects those MELs that are "plug" loads rather than hard-wired.

meet future energy efficiency—and sustainability—goals. Recently, the combined effects of market forces and building code requirements have begun to produce a new generation of MEL control devices that also monitor and report actual plug-load energy use over time. A few of these systems have produced case studies that include either measured or estimated energy savings:[17]

- The on/off controls proposed for 242 vending machines, water fountains, computer monitors, printers, and copiers across several buildings of Salem (NJ) Community College will save an estimated 22,000 kWh/year (35 percent).
- One private school in Morgan Hill, CA has integrated the control of 175 classroom computers during off-peak hours with lighting and HVAC circuits in six of its buildings. As a result, the school realized 85 percent energy savings for the controlled personal computers (PCs) and other plug loads.
- A 60-acre theme park uses wireless controllers to manage plug loads, HVAC equipment and thermostats, and lighting in approximately 90 buildings, rides, and other facilities. In addition to estimated electricity savings of over 1.2 million kWh/year, the facility reports significant peak load savings, due to remote monitoring and controls.

2.3.1.2 Current Status

The continuing rapid growth in MEL energy use and the consequent need for MEL energy savings are well supported by numerous studies, and provide a strong rationale for an enhanced focus on the efficiency and control of these loads. Until now, most of the emphasis related to MEL efficiency has been on reducing energy use at the device level, most notably the reduction of power used by office IT and other electronic equipment when in "standby," or "sleep," mode. More recently, receptacle-level or broader systems-level communications and controls (both wired and wireless) have been introduced into the market, allowing simultaneous monitoring and control of multiple devices—and the potential to integrate energy management of MELs with that of other building energy systems. In the future, systems-level monitoring and control of MELs likely will become increasingly common, as will integration of MEL systems with other systems and with the building as a whole.

MEL Equipment Efficiency:

- The efficiency of individual pieces of equipment is covered by programs such as the voluntary ENERGY STAR® labeling program and by mandatory appliance efficiency standards developed and enforced by DOE and, in some cases, by state agencies, notably the California Energy Commission (Intermatic, 2014).
- As technology and products continue to evolve (very rapidly, in the case of office and consumer electronics), a continuous effort will be made to certify new equipment for ENERGY STAR® and for other labeling programs—such as the Federal Trade Commission (FTC)'s "EnergyGuide" label—as well as for appliance standards, where applicable.
- One study (Lobato et al., 2011a) identified 41 MEL categories, of which 39 percent are subject to the ENERGY STAR® labeling program. However, newer studies (Kwatra et al., 2013; EIA, 2013) suggest that the number of MEL categories is increasing rapidly. This

17 The following bullets are from manufacturer-sponsored case studies and have not been independently verified. Sources are from phone interviews with several manufacturers conducted in October-November 2015. For this report, we have masked the sources because some of the data are proprietary or commercial-product specific.

significant increase of MEL categories and the potential reduction in the percentage of covered MELs suggest the need for additional research and development into enhancing the energy efficiency of MELs and coverage of MELs by programs and standards that already exist.

MEL Local Control Systems:
The capabilities of MEL local control systems are well covered in the literature, and these systems are readily available. A short investigation identified at least eight vendors that can provide a variety of automatic receptacle controls or automatic power strips, based on occupancy and scheduling. In addition, these receptacles can be controlled remotely using a wireless ("Wi-Fi") network and their electrical consumption can be measured. Guidance on which local control method to use for a particular device also is provided (for example, Lobato et al., 2011a, Table 2-2).

MEL-Integrated Controls, Tracking, and Data Analytics:
Most of the equipment and service providers identified for local plug load devices also offer the capability of integrating the locally-controlled device(s) with a BMS. Therefore, in terms of availability, integration does appear to be a viable option. However, it also seems to be used more as a feature added to a BMS for localized control, rather than for full integration (e.g., with HVAC systems) to optimize operation. Tracking and monitoring as well as data analytics also are in their early stages of development and implementation. More investigation is required.

Quantification of Energy and Cost Savings and Energy Modeling:
To economically rationalize the application of enhanced plug load equipment and controls beyond minimum code requirements, the potential energy and cost savings need to be quantified. Using energy modeling to quantify energy savings can be somewhat challenging, due to the uncertainty and randomness of turning plug loads on and off. Potential savings can be estimated based on case study data (Acker et al., 2012; Metzger et al., 2012), but additional case studies are needed to provide more robust data.

Codes and Energy Standards for MELs:
ASHRAE Standard 90.1 (which is referenced in many local codes) and Title 24 of the California Code of Regulations, Building Energy Efficiency Standards, address various aspects of plug load controls, such as automatic receptacles (State of California, 2015).

2.3.1.3 Technical, Market, and Policy Barriers

For existing commercial buildings, cost is a primary barrier to pursuing system efficiency improvements related to MELs and MEL integration. Such costs include MEL equipment upgrades, electrical system upgrades, control system upgrades, use of data analytics platforms, and technical support. Limited implementation is a possibility, but, not surprisingly, would reduce the potential for energy savings.

With respect to new buildings, for which local energy codes require control systems for MELs (and more advanced BMSs), costs will be associated primarily with adding equipment and controls beyond the minimum requirements as well as for software to analyze data, and staff time to service and maintain the system and to review and act on monitored data and diagnostics.

The following potential barriers also could arise:

- Technical expertise might be lacking or insufficient to integrate MEL controls with a building BMS. A brief literature review suggests, however, that at least some equipment and service providers possess such knowledge. Industry expertise on the development, implementation, and tracking of integrated control procedures and data analytics might be lacking.
- As with other building systems (e.g., HVAC, lighting), having efficient MEL equipment and MEL control systems does not guarantee a more efficient building. Installing monitoring systems and ensuring the availability of trained staff are essential to ensuring that systems operate and perform properly.
- Building operators might be reluctant to apply more sophisticated integrated control systems and procedures.
- Local MEL controls, such as advanced power strips, might require operations and maintenance personnel to update controls and troubleshoot incorrect operations and communication failures on a regular basis. Thus, the potential for increased maintenance could be a deterrent.
- Since the use of MELs is directly related to occupant behavior, a lack of occupant buy-in or acceptance could be a potential barrier (Metzger et al., 2012).
- The number of case studies might be insufficient to support the quantification of reductions in energy use and cost savings from MEL control systems. Metzger et al. (2012) provide data for eight GSA buildings, of which six buildings applied MEL control systems. However, not all of the available MEL control methods were evaluated in this study.
- Widespread adoption of more sophisticated MEL controls requires a well-defined and accepted procedure to model these systems and reliably predict energy savings and paybacks on investment; such a procedure might not yet exist. Note that Pacific Northwest National Laboratory (PNNL, 2011a, Section 5.2.3.2) describes a procedure used to quantify the savings from ASHRAE Standard 90.1-2013, Section 8.4.2, Automatic Receptacle Control.

2.3.1.4 Recommendations and Next Steps

Next steps should focus on filling the information gaps described herein and developing a plan (based on the findings) to reduce MEL energy consumption in buildings through systems-level controls and integration with other building systems. The following activities warrant further effort:

1. Investigation of opportunities for enhancing the efficiency of plug loads or hard-wired devices, which are not included in current energy efficiency programs (such as ENERGY STAR) or covered by state standards.

2. Development of more case studies in which all MEL control methods are analyzed. These will be particularly beneficial in providing data to economically justify the implementation of these control systems. Case studies involving integrated MEL controls also will be worthwhile—especially if these case studies allow comparisons of savings and cost-effectiveness of MEL controls at different levels of aggregation (single device, multiple MEL devices, and integration of MELs with other building system controls).

3. Analysis of data center efficiency as a candidate for MEL reduction (along with other systems strategies, such as heat recovery, server "virtualization," and so forth).
4. Investigation into miscellaneous thermal loads, including those using natural gas (e.g., commercial cooking equipment) as well as electrical equipment. These types of loads can be considered for investigation during Year Two of this SEI.
5. Further development of open-system protocols to make it easier to integrate MEL device controls and link these with BMS integration capabilities.
6. Use of more advanced procedures for MEL management, optimization, and system integration, including active monitoring of occupancy. Silva and Poll (2012) explore the implementation of a knowledge-based system to support plug load management.
7. Energy tracking, reporting, and use of data analytics platforms. These activities have gained momentum in the last several years, especially for HVAC systems, but seem to be in the early stages of development and implementation. This concept could be expanded to MELs, as well, although more investigation into this topic is needed. The utilization of data analytics for MELs might be less complex than for HVAC systems, since the latter requires a large number of reliable sensors and other measuring devices (e.g., temperature, humidity, pressure, flow, current/voltage/power). Monitoring MELs, however, will rely less on multiple sensors and other instrumentation.
8. Development of well-defined and accepted procedures for modeling MELs, to encourage the use of more sophisticated MEL controls. These procedures also could be used for building designs that exceed minimum standards, such as ASHRAE Standard 90.1.
9. Analysis of the economic feasibility of increasing the current code requirement that 50 percent of all receptacles be automatic and, based on the results, consideration of whether to pursue future code modifications.
10. Addition of minimum efficiency requirements for existing and newly-developed MEL devices to the ENERGY STAR labeling program or federal and state standards.
11. Exploration of the possibility of developing incentives and rebates for MEL enhancements (equipment and controls) that exceed the minimum requirements to comply with efficiency standards.

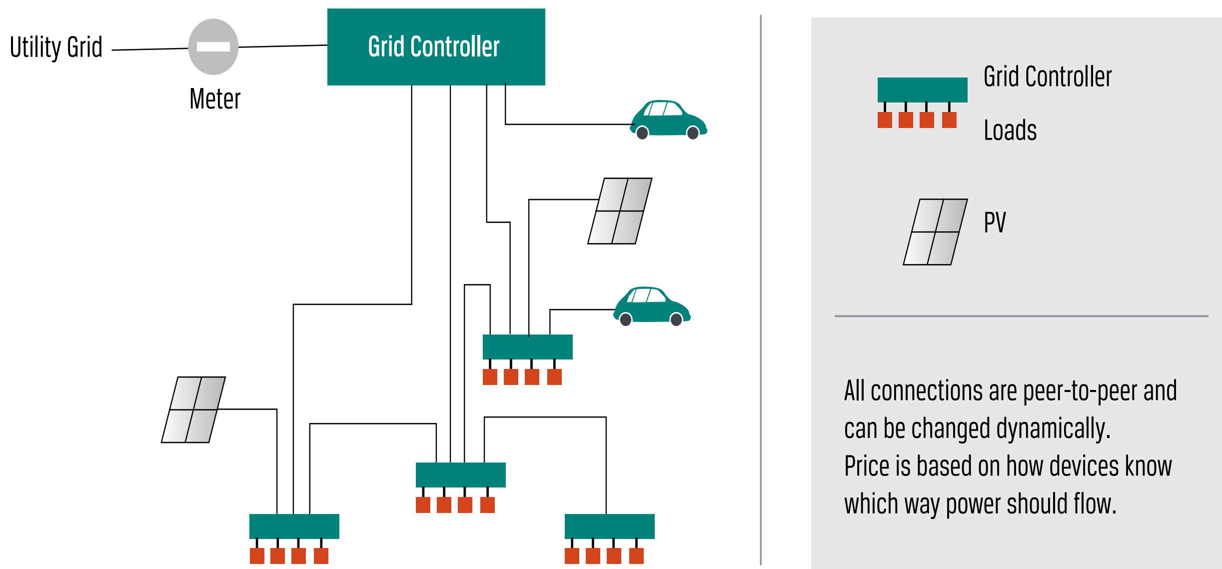
2.3.2 Building-Level Direct Current Power

Economic and environmental pressures, including the increased focus on reducing carbon emissions from the buildings sector, have been driving efforts by efficiency advocates, policymakers, utilities, and the industry to explore the potential of DC power systems in buildings. The use of DC power within a building can contribute to achieving many goals related to the reduction of energy demand—including increasingly prevalent zero net energy (ZNE) building targets—as well as other goals (e.g., grid balancing, expanded control options, and improved safety and reliability) (EPRI, 2006). Using an in-building DC infrastructure (microgrid) provides new opportunities for meeting these energy and environmental goals by enabling the utilization of renewable energy in its native state of direct current.

DC power is particularly applicable to a building systems efficiency approach because on-site PV generation can directly power building loads, such as lighting, without transmission and AC-DC conversion losses. Advancements in on-site renewable energy generation and energy storage are making these types of systems more cost effective.

Figure 2.8 illustrates a DC microgrid with multi-directional energy flow between generation, storage, and other DC loads.

Figure 2.8 – Saving Energy Through Intelligent DC Power Systems in Buildings



Source: Brown & Nordman, 2015

In general, DC distribution can deliver energy savings by:

- Reducing AC-DC conversion losses and AC-AC transformer losses, both in active and "standby" modes;
- Trimming distribution losses within a building (although most studies suggest that this effect is relatively minor); and,
- Making it more feasible to replace AC-driven devices with "native-DC" devices, not only for computers, telecommunications, and consumer electronics, but also for lighting, control systems, and motors (especially those in variable-speed applications).

The largest opportunities for efficiency gains from using direct current power to run DC loads include motors, LED lighting, office equipment, refrigeration appliances, data centers, and fast-charging of electric and hybrid-electric vehicles, each requiring a potentially unique DC infrastructure from 12 to 380 Volts (Ton et al., 2008).

Research by a number of entities demonstrates that medium voltage (380 Volts) DC is seven-to-eight percent more efficient than AC power (Hardcastle, 2013). DC electrical distribution, combined with "smart" technologies that facilitate the multi-directional flow of information and communications, could thus help achieve additional system efficiency gains. Such managed, multi-directional power flowing among generation sources, storage, and loads likely would allow for more efficient equipment utilization and, potentially, for less capital-intensive installations than today's AC distribution.

Commercial buildings implementing DC microgrids with on-site generation and storage are also demonstrating lower life-cycle costs. For example, a recent National Renewable Energy Laboratory (NREL) report examined the potential for DC versus AC power, based on a Bosch DC microgrid system installed in several types of commercial buildings across the country (Fregosi et al., 2015). This study, which considered only DC-powered lighting and ceiling fans (i.e., not DC-powered HVAC motors or other end-uses), found two-to-five percent savings in whole-building electricity use with the DC distribution system, along with a six-to-nine percent improvement in PV utilization. Moreover, the study found that:

> "By transitioning most of the major hard-wired loads in a building to the DC distribution system, customers can expect up to 30 percent lower total cost of ownership over the life of the system, higher reliability, and optimized use of renewable generation compared to a conventional AC microgrid. At scale, the capital cost is anticipated at 15 to 20 percent lower than a comparable AC system; the operating costs will also be significantly lower." (Fregosi et al., 2015)

The bulk of these cost-of-ownership savings came from reduced capital costs rather than energy cost savings. Additional benefits of DC Power might include lower installation costs in emerging retail display/signage (product pricing and messaging) markets; more reliable/resilient power behind the meter; and better system capacity utilization by moving to an inherently asynchronous distribution means (direct current), instead of synchronous distribution (alternating current).

2.3.2.1 Technical, Market, and Policy Barriers

Accelerating the economic and environmental benefits of the use of DC power will require identifying and addressing the barriers to its faster adoption. A number of technical, market, and policy barriers remain to deploying DC power more broadly. For example, installation cost remains a barrier, especially in retrofitting existing commercial buildings. Additional barriers—including insufficient standards and equipment pricing—often are encountered with early stage technologies.

Challenges specific to DC power deployment include limited end-use DC product availability, a lack of consumer awareness about the benefits and availability of DC power distribution, limited availability of DC safety and distribution control equipment, and insufficient workforce training on DC power installation and testing requirements. Finally, DOE test procedures used for standards, labeling, and utility incentive programs may need to be changed to accommodate DC-powered as well as conventional AC-powered office and consumer electronics, lighting, appliances, and HVAC equipment (see Appendix 4 on Appliance and Equipment Standards).

To help overcome these barriers, industry will have to develop products and systems that:

- Offer a better performance/cost ratio for standardized DC solutions across multiple building applications;
- Provide at least the same capabilities—including energy efficiency, control, and longevity—as equivalent AC solutions; and, perhaps most importantly,
- Are cost-effective when viewed from an overall system perspective.

2.3.2.2 Current Status

Recent market growth and cost reduction of PV systems in the U.S., investments in battery systems (which also are DC power sources), and an increasing fraction of building loads that operate internally on DC are creating new demands and expanding opportunities to generate, store, distribute, and consume DC power in commercial applications (Kann et al., 2015). The growing domestic and global markets for zero net energy (ZNE) buildings powered by a digital DC infrastructure also create a leadership opportunity for the U.S. electrical industry, similar to that which arose for the U.S. with respect to the telecommunications and internet sectors in the 1990s. These markets likely also will help create more domestic manufacturing jobs and contribute to economic growth.

The global market for DC power in commercial buildings is projected to grow from $609 million in 2013 to $9.7 billion in 2020, according to a 2013 analysis (Navigant Research, 2013a). Grid-connected commercial buildings are one of four "critical power" vertical markets leading much of the growth for DC power, according to a companion report; the other three are data centers, telecommunications, and military bases (Navigant Research, 2013b). The overall global market for DC networks, including these four sectors, is expected to grow from $2.8 billion in 2015 to over $15 billion in 2024 (base case scenario).[18]

According to the National Science and Technology Council, aggressive adoption of energy efficiency technologies will reduce building energy consumption by 60 to 70 percent (C2ES, 2009). The remaining 30 to 40 percent of energy must come from on-site generation to achieve zero net site energy (Fregosi et al., 2015). This on-site generation, if it comes from intrinsically DC sources, such as solar PV or fuel cells, can be utilized much more efficiently with DC distribution to DC-powered end-uses in a building, (e.g., lighting, electronics, and HVAC powered by DC motors and drives).

Many researchers, early adopters, and manufacturers believe that the use of DC power, particularly for electrical distribution infrastructure (or the distribution system), combined with "smart grid" technologies and capabilities within buildings, would help achieve systems efficiency benefits, as well as broader goals, such as ZNE buildings. This "vision" consists of on-site distributed energy resources, perhaps also combined with energy storage at some future point in time; however, it also includes maintaining connectivity to the electric grid and using "smart grid" technologies and capabilities to help manage energy usage, as well as to achieve other benefits, such as resilience and reliability (e.g., reduced power outages).

Other options include microgrids (e.g., for hospitals or university campuses, or, eventually, connecting disparate sources, such as a gasoline station, bank, and supermarket). These microgrid scenarios likely also still would require connectivity to the electric grid—and could incorporate "smart grid" systems as well.

The vision also includes native DC loads, such as LED lighting, HVAC systems, and IT infrastructure. The core of the architecture and value proposition is the managed, multi-directional flow of power and information among generators, loads, and end users, yielding greater efficiency gains than today's AC distribution, as well as more of the other types of benefits mentioned above.

Several recent research efforts have helped advance work in this area. Examples include the following:

18 Other scenarios in this report project revenues from DC power installations as of 2025 ranging from about $24 to $33 billon globally.

- A May 2014 report entitled, Direct Current Scoping Study, Opportunities for Direct Current Power in the Built Environment, was published by DOE's Building Technologies Office and identifies key stakeholders and research activities. This report also highlights several demonstration projects that were completed by the EMerge Alliance (PG&E, 2014).
- The "Direct Current as an Integrating and Enabling Platform" Research Project by LBNL, in partnership with the Electric Power Research Institute (EPRI) and California Institute for Energy and Environment (CIEE), and sponsored by the California Energy Commission (CEC), aims to enhance knowledge regarding the various applications of DC power, focusing on building retrofits, and including design of AC-DC hybrid systems. This study also examines new residential sites.
- A report by Navigant entitled Direct Current Distribution Networks, Remote and Grid-Tied Nanogrids and Microgrids for Telecommunications, Data Center, Commercial Building, and Military Applications was published in 2015 (Navigant, 2015).
- Navigant's Analysis, "Community, Residential, and Commercial Energy Storage – Distributed Energy Storage Systems for Energy Cost Management and Grid Management: Global Market Analysis and Forecasts 4Q 2014," notes that commercial (and residential) energy storage systems are anticipated to far exceed expected growth and highlights some of the remaining market challenges of combined on-site generation and storage (Navigant, 2014).
- A "DC Microgrids Scoping Study – Estimate of Technical and Economic Benefits" was published by Los Alamos National Laboratory in March 2015 (Los Alamos National Laboratory, 2015).
- PricewaterhouseCoopers' 2015 "Global Power & Utilities Survey" examines the declining costs of renewable energy, and breakthroughs in energy storage systems, along with new "smart" technologies that are accelerating distributed energy generation and stimulating new business models (PricewaterhouseCooper, 2015).

2.3.2.3 Next Steps

- The following additional efforts in this area would be beneficial for identifying and helping to advance the contributions of DC power to improve building systems efficiency:
- In-depth cost analyses of building AC-DC and DC-DC configurations, including microgrids, transformational products, safety equipment, equipment loads, and control systems.
- Development of techno-economic models of hybrid AC-DC distribution network types, including on-site generation, storage, and grid integration for building classes with critical decision paths and financial impacts.[19]
- Forward-projecting architectural studies that examine scenarios for different topologies, including applications that are best suited for hybrid and transitional solutions for existing buildings—and possibly also for whole-building DC distribution systems, although market transformation toward DC is unlikely to reach whole building installations at the outset, particularly for retrofits of existing buildings.
- Expansion of existing power and communication standards—such as Power over Ethernet (POE) or USB-Power Delivery (PD), a branch of the USB standard providing higher power—to support DC system designs and performance/cost scenarios that

19 Techno-economic modeling is a type of modeling carried out to help ensure that market-driven prices for new technologies can be achieved. It is typically "part of the 'stage-gate' process in the corporate management of product development and related research."

can be reliably compared with AC designs.

- Technology and market trends already are driving roadmaps and standards for DC distribution equipment and voltages toward standardization across the full building ecosystem, including LED lighting; motors for HVAC, refrigerators, and clothes dryers; actuators; [20] active daylight controls; office equipment; and distributed data centers. However, more activity in this area is warranted.
- Reference architectures and case studies also are needed.[21]
- Reviews of current energy test methods are needed for appliances, equipment, and lighting that are "covered" products for federal standards and labeling programs. Such analyses will help determine the types of changes that might be needed to enable DC-powered devices and/or models to be compared on an equal footing with the same types of devices using conventional AC power.

Finally, a need exists to fill the following information gaps:

- Identification of technology "enablers" that work within current utility rate structures, and remain relevant in an evolving utility environment, to provide an end-to-end system of DC generation, storage, distribution, and consumption;
- Integrated roadmaps of the different components and/or systems that need to converge to make an effective AC-DC or DC-DC architecture;
- Building system DC conversion architectures and strategies for existing buildings; and,
- Building-level DC distribution strategies.

2.4 Multi-Systems Integration in Existing Buildings

Having examined several types of building systems—mechanical systems, lighting systems, and miscellaneous electric loads (MELs)—this section addresses the integration of these systems, particularly in existing buildings. While the preliminary focus of the SEI is on new construction, the members of the SEI recognize that improving efficiency in existing buildings is critical for increasing overall building efficiency: The most recent CBECS survey data from the Energy Information Agency (EIA) show that approximately 5.6 million commercial buildings existed in the United States as of 2012, with a typical lifetime of several decades (EIA, 2015a). Effective strategies for reducing the energy use and environmental impacts of the commercial building stock thus need to include existing building retrofits, in addition to improved codes and market-oriented measures for new construction.

As noted earlier in this report, achieving maximum building efficiency is only possible by recognizing that buildings are made up of multiple systems and optimizing their integrated performance. Integrated control solutions (either for new construction or retrofits) tend to be more readily applied to large (i.e., over 50,000 square feet) commercial buildings. These larger projects often

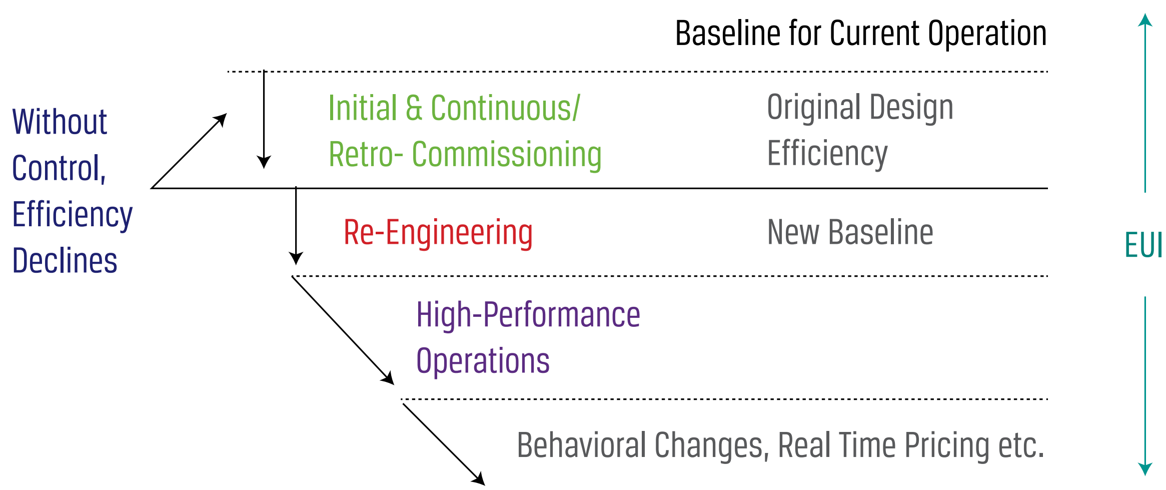
20 An actuator is a type of motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion (Merriam-Webster, 2011). A common example in commercial buildings is actuators used to adjust air dampers for outdoor-air economizers or variable-air-volume (VAV) systems.

21 "A reference architecture is a document or set of documents to which a project manager or other interested party can refer for best practices. In information technology, a reference architecture can be used to select the best delivery method for particular technologies within an IT service catalog" (Rouse, 2013).

have more complex systems and their greater energy usage provides a compelling return on investment for integrated solutions. Smaller, simpler buildings tend to use more packaged systems; however, they also can benefit from systems integration. Many of the solutions being developed for residential applications (e.g., "the Internet of Things") might be good candidates for use in smaller commercial buildings.

Integrated systems provide the controls and feedback needed for buildings to operate at peak efficiency. The processes and tools provided through systems integration provide a path to enhanced performance over time; without these, building efficiency (as measured by EUI) will tend to degrade over time (see Figure 2.9).

Figure 2.9 – Illustration of Building Efficiency Over Time and Benefits of Controls Retrofits



Source: Courtesy of Paul Ehrlich, Building Intelligence Group

Systems integration and improved control systems also can lead to building improvements that have many other associated energy and non-energy benefits, including improved comfort, lower cost, and better integration of microgrids and distributed energy resources (e.g., solar PV, wind energy). As more public and private building owners broaden the scope of their financial analyses to include such factors, a systems integration approach and improved control systems can capture this broader set of co-benefits to help justify added investments.

In existing buildings, integrated system retrofits can be implemented through a variety of approaches. These include:

- Retro-Commissioning: A process either to bring a building back to its original operating parameters or modify its operations to improve performance. Retro-commissioning also includes a process to verify and test performance. This option is best applied to newer buildings (0–5 years old) as a method to improve energy performance at minimal cost.
- Sequenced Planned Retrofits: This process consists of systematic upgrades and improvements to a building's systems, often driven by a plan or multi-year initiative. For example, an office tower might upgrade its central plant, then plan to upgrade its control systems, lighting systems, and HVAC systems, as old tenants move out and are replaced with new ones.

- Energy Retrofit: Large-scale upgrades across systems including HVAC, lighting, and controls. These programs may be owner-initiated or the result of a utility- or energy service company (ESCO)-led effort.
- Building Renovation: Improvements to building systems may be implemented as part of a larger planned renovation of a building, often for aesthetic and operational purposes, rather than solely for efficiency reasons.
- Deep Retrofits: These are extensive, coordinated changes to building systems, including to the building envelope (NBI, 2011). For instance, an existing building that is updated to use operable windows, natural ventilation and shading, with associated changes to its HVAC systems and controls to benefit from reduced cooling loads, would be considered to have undergone a "deep retrofit." Deep retrofits may only be economically effective when done as part of a larger building renovation.

Programs to influence behavior also can be very effective in both new and existing buildings. Behavioral strategies to improve building system efficiency may involve either building operators or managers, building occupants (i.e., the people living or working in a building), or both.

There is a great deal of existing research about ways in which to maximize savings, based on changing the behavior of building operators;[22] in fact, many of the multi-system integration tools that are relevant to new construction or to major retrofits (e.g., BMS) are intended to make such energy-saving behaviors easier to perform and easier to assess. Also, various forms of occupant feedback and incentives—both financial and psychological—have been introduced to encourage awareness and behavior with respect to energy efficiency and/or conservation.

2.4.1 Technical, Market, and Policy Barriers

Many successful projects involving the use of integrated controls have been deployed in existing buildings, yet many challenges remain to broadly implementing such solutions. These include:

Obsolete Control Systems: Many existing buildings have control systems that may be functional but are practically obsolete. Examples include older mechanical or electronic systems, or pneumatic systems, which are operated by air or gas under pressure. Even direct digital controls/building automation system (DDC/BAS) controls may be proprietary or obsolete in some buildings.

Poor Initial Design: Many control systems were poorly designed from the start, resulting in inadequate performance (both in terms of comfort and efficiency).

Lack of Integration: The vast majority of control systems are primarily intended to be temperature control systems; thus, they were not designed to, and do not, integrate well with systems other than HVAC. Such control systems also lack the capability for "intelligence" to communicate with and/or facilitate optimization across a range of systems.

Lack of expertise: Industry expertise is limited, in terms of evaluating existing systems and designing and installing upgraded, integrated systems.

22 See, for example, Proceedings of the annual conference on Behavior, Energy, and Climate Change at http://beccconference.org/. Also see (Moezzi et al. 2014; Bin 2012; and Elliott 2012).

Cost: The cost to carry out large-scale upgrades to existing buildings is another outstanding issue; in many cases, such upgrades are considered to be too expensive for the benefits provided.

While some expertise, as well as products, exist today that can readily be used to help improve systems and facilitate "deep retrofits" in existing buildings, the up-front costs and complexity have limited their widespread deployment. However, new and emerging technologies have the potential to reduce the costs and complexity of system upgrades for new and/or existing buildings. Some examples of this include:

- Wireless communications, which can reduce the costs of connecting system components, such as sensors, light fixtures, and other devices.
- Network Integration: Connecting systems and/or devices to an existing internet protocol (IP) network can facilitate high-speed connectivity using existing infrastructure.
- The costs of electronic devices and/or systems tend to decrease over time as products become more readily available in the marketplace (i.e., "Moore's Law"). This phenomenon should continue to help reduce the costs of controls and systems integration.

2.4.2 Next Steps

Overcoming the barriers to scaling up multi-systems integration in existing buildings will require tools, processes, and products that can readily be applied to help lower the costs, complexity, and risks of conducting integrated retrofits.

- ***Process:*** A practical, affordable methodology is needed to evaluate the types of systems that exist in a building, and whether these include controls and/or integration. Technical and economic plans for conducting upgrades also will need to be developed. Conducting this type of analysis for smaller buildings in an affordable manner can be especially challenging.
- ***Products:*** Products specifically designed for retrofits are needed that can reduce project costs and improve performance.
- ***Contracting:*** Proper installation of integrated systems and controls is highly dependent on the capabilities of engineers and contractors, which can vary substantially. Simplified products and workforce training in these areas are needed to ensure better contractor performance and commissioning.
- ***Modeling Tools:*** Improved tools are needed for identifying and analyzing the economic benefits of an integrated, multi-system retrofit.
- ***Financing:*** Options need to be developed to help an owner finance and pay for a retrofit over time using resulting energy savings, with minimal complexity and transaction costs.
- ***Scale:*** Solutions that work in larger and more complex buildings may not be easily tailored to smaller and simpler buildings. Packaged solutions might be part of the answer for many smaller buildings. One example is the Advanced Rooftop Unit (Advanced RTU) program that helps commercial building owners and operators replace their old RTUs with more efficient units or retrofit their RTUs with advanced controls.[23]

23 For more information, see http://www.advancedrtu.org.

2.5 Building-to-Grid Integration

The convergence of smart sensing, metering, and control technology with remote and wireless connectivity, and data analytics of "big data"[24] for buildings and the grid, are enabling interactions in which buildings can act as distributed energy assets. With regard to building-to-grid (B2G) integration, DOE notes that: "As electricity demand continues to increase, integrating buildings and the electricity grid is a key step to increasing energy efficiency. Intermittent and variable generation sources, such as photovoltaic systems, as well as new load sources, such as electric vehicles, are being installed on the grid in increasing numbers and at more distributed locations. At the same time, smart sensing, metering, and control technology is increasing grid operators' situational awareness, helping building owners pinpoint efficiency opportunities, and allowing home owners to see and adjust their energy use on their smart phones" (U.S. DOE, n.d. a).

This B2G integration (sometimes referred to as a new "transactive energy ecosystem") is envisioned as a seamless, dynamic, and cost-effective end-to-end electricity system, capable of balancing demand and capacity requirements, while also enabling the integration and scaling-up of renewable generation and energy storage, maximizing electric vehicle (EV) value (e.g., having EVs provide power back to the electric grid), and offering consumers the opportunity to actively participate in demand management/ demand response and energy efficiency programs.[25, 26] Enabling B2G interactions will thus accelerate the integration of intermittent renewable energy resources and energy storage. Doing so also will empower building owners, operators, and tenants to monitor and control their energy use and costs and to dynamically participate in energy markets.

In the context of this report, B2G integration can be seen in two ways: first, as an important system in and of itself—one that extends beyond the building's boundary—and, second, as a significant means of integrating and adding value to other building systems, including HVAC, lighting, and miscellaneous electrical equipment. Ideally, much of the same communications and control infrastructure needed for integrated system- or building-level monitoring and control can provide a foundation for B2G interactions, such as demand response and "ancillary grid services," that both improve grid reliability and create an added source of revenue (under proper market or regulatory conditions) to the building owner.

2.5.1 Potential Benefits

Potential benefits of building-to-grid integration include the following:

- Accelerating the integration of renewable energy resources and storage, both on the grid and behind the meter.
- Enabling the proactive and continuous optimization of loads and grid resources, to benefit both the building owner and the grid operator.

24 "Big data" refers to extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behavior and interactions.

25 As defined by the Federal Energy Regulatory Commission (FERC), demand response refers to "changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" (FERC, 2015).

26 Transactive energy is "the ability for consumers and end devices to buy and sell energy and related services in a dynamic and interactive manner" (Gridwise, 2015).

- Enabling buildings to more readily use on-site generation and storage to "flatten" a commercial building's energy load profile, thereby reducing demand charges and the need for grid owners to invest in peak generation, transmission, and distribution capacity.
- Similarly, where time-of-use rates exist, enabling buildings to purchase power from (and supply power to) their utilities during the most economically attractive periods.[27]
- Enhancing the value of EVs—by empowering customers to better manage the timing (and cost) of vehicle charging—and potentially allowing EV batteries to operate as supplemental storage for the grid or for on-site generation.

B2G integration also can facilitate a utility's ability to make short-term reductions in building electrical loads (or provide added power from on-site generation), and thereby save energy during periods of peak demand and/or high prices. Some aspects of these types of benefits are discussed in greater detail below.

2.5.1.1 Quantifying Benefits

Quantifying the monetary and non-monetary benefits of B2G is difficult since circumstances differ from one utility to another, and change over time. Determining who is likely to realize these gains also can be a challenge: the generating utility or grid operator, the building owner or other customer, or a middle market aggregator or power broker. The answer depends in large part on the wholesale or retail regulatory structures and, in some instances, on market changes (e.g., in certain situations in which competitive markets have begun to replace regulated tariffs). These changes are occurring amidst rapidly-transforming technology, policy, and market environments, as utilities and the costs and characteristics of generating resources continue to evolve.

For a given commercial building, realizing tangible benefits from B2G will depend not only on the characteristics (and controllability) of loads in that building, but also on a utility system's load curve and generation mix, as well as the prevailing tariffs and utility incentives available to customers—or the ability of those customers to access wholesale markets, either directly or through load aggregators. The same capabilities needed to monitor, diagnose, and control systems with respect to B2G integration also can provide direct economic benefits in the context of day-to-day energy management. These benefits include lower energy use and peak demand, preventive maintenance, and often improvements in occupant comfort and satisfaction. While potential energy and peak power savings have been quantified in some cases, the examples remain too limited and diverse to enable an overall estimate of B2G benefits nationwide.[28]

27 "Instead of a single flat rate for energy use, time-of-use rate plans are higher when electric demand is higher. In return, time-of-use rate plans at all other times will be lower than the peak rate." The PG&E Definition of Time-of-Use Rates is available at: http://www.pge.com/en/mybusiness/rates/tvp/toupricing.page.

28 In addition to the sources cited here, the U.S. DOE website on B2G offers background information and related links (http://energy.gov/eere/buildings/buildings-grid-integration). Many other reports discuss the potential for continuous monitoring and rapid-response control of end-use loads to provide ancillary services that enhance grid reliability and power quality, as well as ways to establish the market value of demand-side services and recommendations for market and regulatory actions that would improve the ability of end-users to provide these services and be compensated: Booth et al., 2010; CPUC, 2010; U.S. DOE, 2011; U.S. DOE, 2014a; EPRI, 2011; EPRI, 2015; Hesser, 2010; Hirst and Kirby, 2003a; Hirst and Kirby, 2003b; Hurley et al., 2013; Kirby, 2008; Kirby and Kueck, 2000; Kroposky and Pratt, 2014; Satchwell and Hledik, 2013; and Woolf et al., 2013.

2.5.1.2 Demand Response

One important source of benefits from B2G integration is demand-response (DR), or the ability to make short-term reductions in building electrical loads (or provide added power from on-site generation) at times of system peak demand or high generation costs. The potential for continuous monitoring and rapid-response control of end-use loads also can provide ancillary services that enhance grid reliability and power quality; these are described in Subsection 2.5.1.3 below. Finally, a report by the consulting firm Navigant concluded that extensive use of DR also can help significantly reduce carbon dioxide (CO2) emissions by reducing end-use demand as well as changing the system fuel mix and increasing the use of renewable generation (Goetzler, 2014).

2.5.1.3 Improving Grid Reliability

While well-controlled building loads provide direct benefits to a building owner through reductions in energy and peak demand charges, they also have a potential to improve grid reliability by providing "ancillary services," which are functions (beyond generation and transmission) provided by the electric grid that facilitate the continuous flow of electricity to maintain grid stability and security.[29] A 2006 Oak Ridge National Laboratory (ORNL) issue paper is a useful introduction to ways in which demand-side resources can provide grid reliability and other ancillary services (Kirby, 2006). The report concludes that:

> "Demand response is not a perfect reliability resource, but neither is generation. Some loads can respond much faster to reliability events than most generators, making them more valuable than generation. Power system stability can be enhanced by the appropriate use of responsive load. Providing reliability services is a better match to the physical capabilities of some responsive loads than peak reduction or energy efficiency. Encouraging responsive loads to provide reliability services, including spinning reserve, can free up generating capacity to provide energy."

Another early report on the role of end-use loads in providing ancillary services to the grid analyzed several markets—the Electric Reliability Council of Texas (ERCOT) and PJM (Mid-Atlantic) Regions in the U.S., as well as markets in Australia, the United Kingdom, and the Nordic countries (Heffner et al., 2007). For two of these markets (ERCOT and Nordic countries), the report concluded that end-use loads, such as industrial batch processes, commercial refrigeration, electric water heaters, dual-fuel boilers, and high-mass buildings could provide about one half of the total capacity needed for ancillary services, at a fairly modest investment cost (i.e., about two to three percent of the total dollar value of the potential transactions) (ERCOT, 2015).

2.5.2 Technical, Market, and Policy Barriers

Building owners/operators are unlikely to invest in B2G-capable end-use devices in the absence of necessary utility "smart-grid" infrastructure, standardized communications protocols, and rate-setting policies and market mechanisms that provide a suitable sharing of benefits between a utility (or grid operator) and its customers. Conversely, utilities are unlikely to provide that infrastructure without some expectation that they will be able to recover their investments. In addition:

29 FERC defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser, given the obligations of control areas and transmitting utilities within those control areas, to maintain reliable operations of the interconnected transmission system. Ancillary services supplied with generation include load following, reactive power-voltage regulation, system protective services, loss compensation service, system control, load dispatch services, and energy imbalance services" (FERC, 2016).

- Building design processes and operations often are pursued in isolation, without consideration of the added value in terms of the financial, resiliency, and other benefits that B2G integration can yield.
- Similarly, many utilities and grid operators are not accustomed to thinking either of loads or of distributed generation sources on the customer side of the meter as an integral part of "their" system. End-use loads typically are seen as a need to be met by the grid, not as a resource to be managed jointly by utilities and their customers. In addition, distributed generation sources often are viewed by utilities as a source of competition, rather than as added resources that can enhance grid operations.
- Current B2G interactions are fairly limited in scope (i.e., typically involving a small number of building owners/operators responding to a request to a specific grid-related need or event). Building-level decisions and actions thus tend to be reactive, rather than pro-active, and manual, rather than automated, in nature.[30]
- B2G interactions are challenging for small- to medium-sized buildings, given the level of investment required and potential for a relatively low financial return.

2.5.3 Vision and Recommendations

Even broader than B2G integration, the recent surge of interest in the "Internet of Things" (IoT) envisions fully-interoperable connections among devices and systems: within a single building (or industrial facility), between a building and the electric grid (or a microgrid), and directly between devices/systems within a building and any number of outside service providers—all via the internet. This interoperability "vision" is not limited to energy management, grid reliability, and/or resilience; it also can include a wide range of business and operational activities, from equipment maintenance and inventory control to security.[31]

To realize this transactive energy ecosystem, buildings and the grid both will need to be "smart" and will need an open, interoperable system to facilitate transactions of electricity and energy-related services. "Smart" buildings will require advanced building automation and control solutions to efficiently respond to and manage the changing energy needs of buildings, occupants, utilities, and the environment. Areas of innovation needed with regard to "smart" buildings include:

- Open architecture platforms that provide for interoperability of systems, applications, and consistent user interactions;
- Highly-automated, easy-to-deploy, cost-efficient sensors and controls for new and older, "legacy" building systems;
- Data standardization and quality assurance;
- Data analytics, models, and predictive algorithms; and,
- Reliable cybersecurity and privacy protections for building owners and occupants.

30 An important exception is the growing body of work on "automated demand-response"; see the publications of the Demand Response Research Center (DRRC) at Lawrence Berkeley National Laboratory (DRRC, 2016), and the industry sponsored Open ADR Alliance (http://www.openadr.org/).

31 DOE's Interoperability Vision website, with a technical summary and presentations from two workshops that were held in April 2014 and March 2015, is at: http://energy.gov/eere/buildings/downloads/technical-meeting-buildings-interoperability-vision. This site also contains a February 2015 report on the "Buildings Interoperability Landscape."

In addition, a workforce will be required that possesses knowledge of building science, systems integration, and diagnostics.

Suggested areas for continued B2G work under the Systems Efficiency Initiative include:

- Interview utilities/grid operators and commercial building owners to better understand their awareness of B2G opportunities and constraints—particularly in terms of adding value to HVAC, lighting, and other building systems.
- Discuss with the electricity-related regulatory community their views of B2G implementation and ways in which it could fit with emerging systems approaches and business and regulatory models.
- Identify case studies of potential and demonstrated energy and cost savings, improved grid reliability, and building system benefits resulting from B2G integration and demand response.
- Engage in dialogue with DOE on the further development of a "transactional" framework for B2G integration and its relationship to a systems approach.
- Monitor the development of B2G policies and programs in states such as New York and California, as well as the evolution of industry activities (e.g., Continental Automated Buildings Association, ASHRAE) related to "intelligent" buildings.
- Consider possible changes to federal laws, regulations, policies, and research and development programs that would help advance B2G integration.
- Review current provisions or proposed changes to building codes, standards, green building rating systems, and advanced energy design guidelines to support B2G implementation.

Energy use within the buildings sector as a whole and at the individual building level is undergoing increasing scrutiny by the public, policy makers, and building owners.

ACHIEVING THE POTENTIAL

Technological innovation and better analytic and regulatory tools create new opportunities for achieving improved efficiencies in individual building systems and systems-efficient buildings. For these efficiencies to be fully realized, however, some changes are needed to the existing market structure and the building industry ecosystem, as well as to current building codes and appliance standards.

The buildings sector is not currently structured to generate systems-focused performance. The industry is generally characterized as highly fragmented—with design decisions, construction practices, and building operations divided and subdivided into distinct disciplines with little consultation among the various actors regarding the way in which such decisions and practices affect other elements of a given project. This current situation favors the optimization of efficiency for individual components, but not necessarily the optimization of systems. This "siloed" approach to design and construction proves to be effective as long as performance criteria and metrics remain focused on individual components and are only regulated or measured within distinct time periods in a project life cycle, or for a limited number of performance characteristics. However, as performance requirements expand under the concept of high-performance buildings, and as policymakers and building owners look to measure and improve actual building performance, the need is growing for new approaches to realize additional energy savings and other benefits.

Energy use within the buildings sector as a whole and at the individual building level is undergoing increasing scrutiny by the public, policy makers, and building owners. Migrating to a systems efficiency approach will be crucial to optimize building design and operation, and to achieve energy efficiency and environmental objectives, as well as other increasingly critical goals, such as reliability, resilience, and security.

To date, most building-related regulations and owner-performance requirements have focused on the design and construction processes, to the exclusion of the operations phase. While such design and construction-related requirements are important for setting the foundation for how buildings will use energy, they perpetuate the current component efficiency approach rather than encouraging attention to the ways in which components and building systems interact. If the building market is to move toward systems-oriented efficiency, market participants and policy makers will need to examine the factors inherent in the current market and regulatory structures that hinder the achievement of system-level efficiencies.

This section highlights some of the critical market barriers to adopting a systems efficiency approach, as well as some possible approaches to overcoming—or at least mitigating—these obstacles. The section also highlights industry and market practices, industry-developed standards and metrics, and training, certification, and other policies and programs that are being or could be implemented by governments (federal, state, and local), utilities and energy suppliers, and the private sector to support a systems approach.

While some of the recommendations in this section could be implemented in the short term, others will require more time. For example, standards, metrics, and policies could take several years to be developed, approved, and adopted into use by the building industry.

3.1 Market Barriers and Opportunities

This section discusses the various market barriers—and associated opportunities—that result from the overall building market structure, industry practices, and the roles of a wide variety of actors and initiatives. These include government policies and programs (at all levels), industry-developed standards and metrics, utility programs, and training and certification programs.

3.1.1 Market Structure and Industry Practices

The market for design and construction of commercial office buildings or multi-family residential buildings poses several challenges for energy efficiency.

3.1.1.1 Fragmentation and Process Disconnects in Procurement

One of the principal challenges is related to fragmentation and process disconnects in procurement. Historically, "design-bid-build" has been the prevailing project delivery mechanism in this market. Such an approach intentionally separates the design and construction functions, presumably with the hope of receiving the lowest possible bid for construction services. This results in the treatment of building design and construction as commodities, and fails to capture the potential performance benefits and life-cycle cost reductions that could be realized by consulting across the design and construction teams. Design teams typically receive minimal feedback regarding the actual viability of a design (i.e., whether a building actually can be constructed in a functional manner, based on a particular design, or whether they are using the best design to achieve their intended results). Further, construction teams generally have few opportunities to interact with and understand the intent of the design team. Meanwhile, the operations team often is excluded from the entire design-bid-build phase, and must fend for itself once it is handed the keys to a building.

While some developers have attempted to address the disconnect between design and consruction teams through a single "design-build" contract, a more comprehensive solution is the "Integrated Project Delivery" model.[32] Integrating people, systems, business structures, and practices as a team working under a single contract, the Integrated Project Delivery concept begins at the earliest stages of design and continues throughout project "hand-over" to a client. This approach facilitates optimized design and construction processes through increased opportunities for collaboration and consultation, and can include the expanded engagement of operations personnel. Several new practices are emerging within the industry, such as pre-installation testing

32 For more information, see http://info.aia.org/siteobjects/files/ipd_guide_2007.pdf.

and commissioning, which enable building professionals to determine how various systems and devices actually perform in relation to one another throughout the life of a building.

3.1.1.2 Fees, Timelines, and Risks

Accompanying this increased focus on life-cycle performance and changing procurement methods should come an increased focus on the fundamentals of the design and construction processes—mainly the allocation of fees, times of engagement, and risks involved. With today's commonly used procurement methods, a significant share of the fees associated with a building's design may be allocated early in the project timeline. While this certainly is important for the design team, a lack of funds beyond this stage may exacerbate the disconnect between design, construction, and start-up commissioning, and inhibit coordination across a project's timeline. In addition, this funding issue can limit the amount of feedback shared with the design team on the actual outcomes associated with the decisions made during the design phase. Moreover, if the entire fee is spent during the design phase, then the design team is incentivized to pursue the next project, rather than provide uncompensated services to the project owner.

Further, if the design team is contracted to deliver designs that comply with current codes and specifications that are strictly focused on individual components and theoretical design requirements (as opposed to systems-based or actual, measured building performance), then additional practices or services (such as energy modeling, project monitoring, or post-construction engagement) are deemed to be "additional services" and, therefore, are unlikely to be prioritized by the owner/developer. To overcome this barrier, the value of such services to the owner and the impact on long-term performance of the project must be clearly demonstrated. Over the years, few attempts have been made to incorporate the actual energy performance of a new building into the fee structure both for building designers and contractors (Eley et al., 1998; Stein et al., 2000; Jones, 2014); this practice is still the exception, rather than the rule. However, the "Savings by Design" program, run jointly by several California utilities, is attempting to change traditional cost-based fees and increase the front-end investments in integrated design by targeting incentives both to the designer(s) and the construction firms, based on either whole-building or system-specific performance.[33]

In addition to addressing issues related to project fees and timelines for engagement, the building industry must re-examine its current approach to allocating risks, including the risk of poor energy performance and consequent high operating costs. Currently, the bulk of a project's risk falls on the building owner—often the party that is least able to mitigate such risk. Building owners often lack a deep understanding of the design and construction processes and rely on architects, engineers, and contractors to fill such roles. Despite the importance these practitioners place on setting the foundation for long-term building performance, almost all of the performance risk is placed on the owner and its operations and maintenance team.

3.1.1.3 Focus on Operations

Operational considerations remain largely absent from decision-making processes in the design and construction phases—

33 For more information, see Section 3-2 of the program handbook at http://www.savingsbydesign.com/book/savings-design-online-program-handbook#booknode-445.

despite the fact that the operations phase comprises nearly all of a building's energy use over the course of its life cycle. Fortunately, many positive developments occurring within the industry could help shift the focus to a systems approach or a life-cycle performance approach. The emergence of Integrated Project Delivery and other integrative processes—whereby parties establish goals in a team environment for a project's design, construction, and operational phases—will help ensure a more systems-oriented approach (Cheng, 2015; McMillen et al., 2015; SeventhWave, 2015). Commissioning, a results-oriented process to ensure that all building systems are installed, operated, and maintained to perform as designed, helps increase the focus on the interactions among individual components and ultimately will support a systems-oriented approach. New contracting methods, including performance-based contracting, design-build-operate-maintain (DBOM), and public-private partnerships, also are placing increased focus on incorporating operations and performance into a project contract. Well-designed, outcome-based codes and related policies further facilitate opportunities to address the design-construction-operations gap by emphasizing actual, measured building performance as a desired end goal (Colker et al., 2011; Colker et al., 2015).

Other efforts are emerging to help bridge the gaps among design, construction, and operations. Benchmarking and disclosure programs (whether voluntary or mandatory) are designed to help illuminate the importance of energy-efficient building operations and the value of investing in energy-saving retrofit projects, but also may be able to influence decisions made during the design and construction phases. Using actual, metered data to support the expansion of "feedback loops" across the design, construction, and operations processes can facilitate advancements in building performance. Benchmarking and disclosure are discussed in greater detail below.

3.1.1.4 Public Sector Challenges and Opportunities

Public sector projects pose particular challenges and opportunities for achieving measured energy performance improvements through systems-based approaches. As discussed above, many government agencies still rely on a design-bid-build procurement process—either due to statutory requirements or reluctance by legislators or agency personnel to use unfamiliar methods. As long-term owner-occupiers, federal, state, and local governments can benefit from a focus on life-cycle costs. However, many requirements currently prohibit (or severely limit the interest in) optimization across a project's life cycle. In many cases, the capital and operating budgets are separate, either by design or because responsibilities or jurisdictions for each are divided among different offices or agencies. This separation perpetuates an initial-cost focused process, despite the opportunity for long-term savings to be realized in reduced energy and/or operations and maintenance costs over a building's life. Such a situation also often discourages operations personnel from participating in the project design and construction processes.

3.1.1.5 Focus on Short-Term Investments

As with the frequent disconnect between capital and operating budgets, the practice of project development for short-term gains also can result in lost opportunities to optimize operations, due to a similar emphasis on initial costs. If a building developer does not intend to own or operate a building following completion of construction, then s/he has an inherent economic incentive to focus on lowering the initial costs of procuring the systems and components that go into a building, rather than incorporating future energy costs into the decision-making process. Building owners bear the consequences of such choices.

Well-designed benchmarking and disclosure programs can provide investors with information on whole building or tenant site energy performance to support informed decision making. Incorporating systems-level performance requirements into codes and policies can help maximize the benefits that are captured. Policies focused on building operational efficiency should be expanded to help eliminate the gaps among design, construction, and operations and to "protect" future purchasers and tenants. Examples include:

- Requiring the utilization of "Construction-Operations Building information exchange" (COBie)[34] to ensure that important data from design and construction are captured in a useful form for building operations.
- Engaging the operations and maintenance (O&M) team, to the extent practical, during the design and construction phases.
- Formulating project budgets to allow continued design and construction team engagement post occupancy.
- Implementing whole building and major system commissioning, with a strong focus on preparation of operations manuals and operator training.

Some developers and owners already place a premium on buildings that meet particular levels of energy performance (EPA, 2006). However, it is unclear whether this type of premium is well understood by initial project developers, because, for them, the actual performance of a project remains unproven. Yet, investments in design and construction are important for building energy efficiency. Early engagement with the investment and valuation sectors can help identify a path forward in addressing these challenges.

3.1.1.6 Recommendations Related to Market Structure and Industry Practices

- Support the expanded use of systems commissioning by building developers, designers, and engineers to help establish and then deliver on owner performance requirements across a project's life cycle. This will require educating building owners about the value of such services.
- Increase the emphasis on actual, measured building and/or system performance through new and emerging contracting tools, voluntary energy rating systems, codes, policies, and practices. Sharing of best practices, sample contracts, and case studies will be required, along with efforts to address industry concerns around liability for non-performance. Tax incentives and utility programs should incorporate requirements based on actual, measured reductions in energy use for a building as a whole, and/or for building systems.
- Examine public procurement models for opportunities to expand these to support life-cycle budgeting and building system efficiency to optimize cost-effective performance. Expand the use of performance-based contracting requirements and public-private partnerships, as well as design-build-operate-maintain (DBOM) contracts; examples include the GSA Federal Center South, the State of Washington 1063 Block Replacement, and the Long Beach Courthouse (Maruska et al., 2013; Digiambattista-Peters, 2012).
- Incentivize owners to demand, and contractors to offer, Integrated Project Delivery to promote a coordinated approach to a

34 For more information, see https://www.nibs.org/?page=bsa_cobie and https://www.wbdg.org/resources/cobie.php.

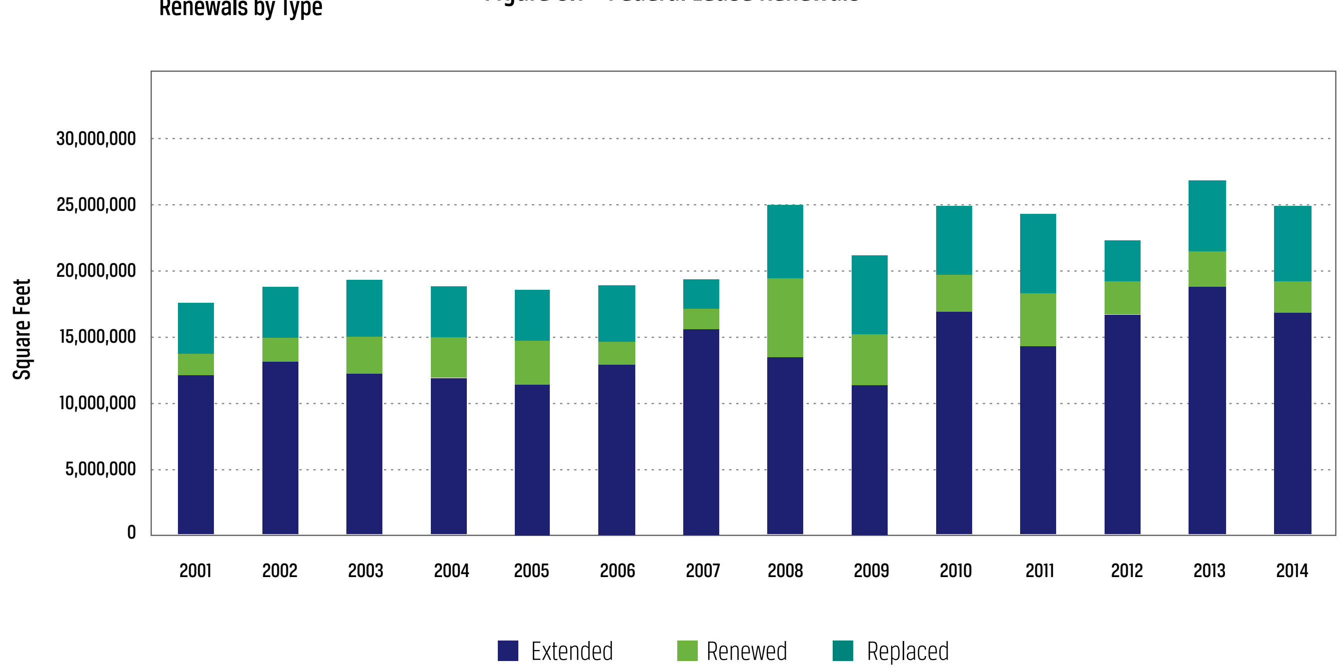
project's design, construction, and operational phases.

- Develop case studies of projects using Design-Bid-Build versus Design-Build and Design-Build-Operate-Maintain to compare performance benefits, including initial versus total costs of ownership.
- Incorporate systems-level requirements and operations-focused criteria into baseline codes, "stretch" or "reach" codes,[35] rating systems, and other policies to ensure efficient long-term performance and a balanced focus on design, construction, and operations.
- Encourage dialogue among the building industry and representatives from the legal, financial, and insurance sectors regarding fees, timelines, and risks of a systems-based approach.

3.1.2 Government as a Leader and Market Builder

The federal government is one of the largest building owners in the United States. According to the New York Times, "[t]he government owns or manages more than 900,000 buildings or other structures across the country—office buildings, courthouses, warehouses and other property types—making it the nation's largest landlord" (Pristin, 2011). States, counties, and cities also own a significant number of buildings. In addition, government agencies may be the primary or only tenant in leased buildings. As Figure 3.1 illustrates, the GSA renews, replaces, or extends leases for an average of 20 million square feet of buildings every year (Stout, 2015).

Figure 3.1 – Federal Lease Renewals



Source: Colliers International, 2015

As a result, government agencies are in a unique position to address the issue of systems efficiency for both new and existing buildings.

35 Also known as "above-minimum" codes, which allow building owners/designers to voluntarily exceed the minimum energy codes, or allow cities or counties to adopt more stringent codes than the broader jurisdiction.

3.1.3 Federal, State, and Local Government Policies and Programs

Numerous policies and programs implemented at the federal, state, and local levels affect the design, construction, and operation of buildings. Such policies and programs (e.g., tax incentives, energy efficiency benchmarking and disclosure, building codes) provide numerous opportunities for incorporating a systems approach into tools, guidance, and mandates that affect building efficiency.

One key example pertains to treatment in the federal tax code of depreciation periods for equipment. For federal tax purposes, equipment that is attached to a building is depreciated over the life of a building (now set at 39 years), even though much of this equipment has a much shorter service life (i.e., 20 years or less). When equipment fails before it is fully depreciated, an incentive exists to repair rather than replace it, instead of having to write off the undepreciated value, even though the original equipment may be less efficient or not properly optimized as part of its larger system. By shortening the depreciable life of equipment to be more consistent with its useful life span, this particular disincentive to invest in more efficient equipment and systems would be reduced. Shorter depreciation periods could convince building owners to install more efficient equipment more quickly, which could lead to a greater number of owners/operators incorporating system approaches into such retrofits.

3.1.3.1 Technical, Market, and Policy Barriers

Because depreciation periods are set in the tax code, they require an act of Congress to change them. Changes to the tax code are scored by the Congressional Budget Office (CBO), based on estimated revenue impacts to the federal government over a ten-year period following the effective date of the change. This means that any shortening of depreciation periods would decrease government tax revenues over this same ten-year period, even though such changes would be revenue neutral over a 39-year period (the current depreciation period).

3.1.3.2 Potential Benefits

Incentives for replacing equipment more quickly would enable buildings to reap the benefits of the many types of equipment that have achieved significant efficiency improvements over the past several decades. For example, a typical light fixture used to illuminate 80 square feet of office space might use less than 60 watts of power, compared to as much as 150 watts used by a lighting fixture installed 20 years ago. Increased opportunities exist to improve other aspects of a lighting system, as well, such as adding or upgrading lighting controls when the fixtures are replaced. A similar situation applies to chiller and air conditioner systems in commercial buildings, where component efficiency has significantly increased over the past 20 years (see Figure 2.1), and controls and other system-oriented opportunities can add to the energy savings.

3.1.3.3 Current Status

Legislation has been introduced to establish depreciation periods based on average service lives for equipment, and to allow depreciation periods to be modified by the Internal Revenue Service (IRS) rather than requiring an act of Congress. However, such legislation is unlikely to be enacted in the near term.

3.1.3.4 Recommendation

Bills addressing the depreciable life of energy-related building equipment and systems should be introduced or re-introduced and considered as part of tax reform legislation in Congress—preferably with an incentive to upgrade efficiency when equipment is replaced (Sachs et al., 2012).

3.1.4 Benchmarking, Disclosure, and Labeling

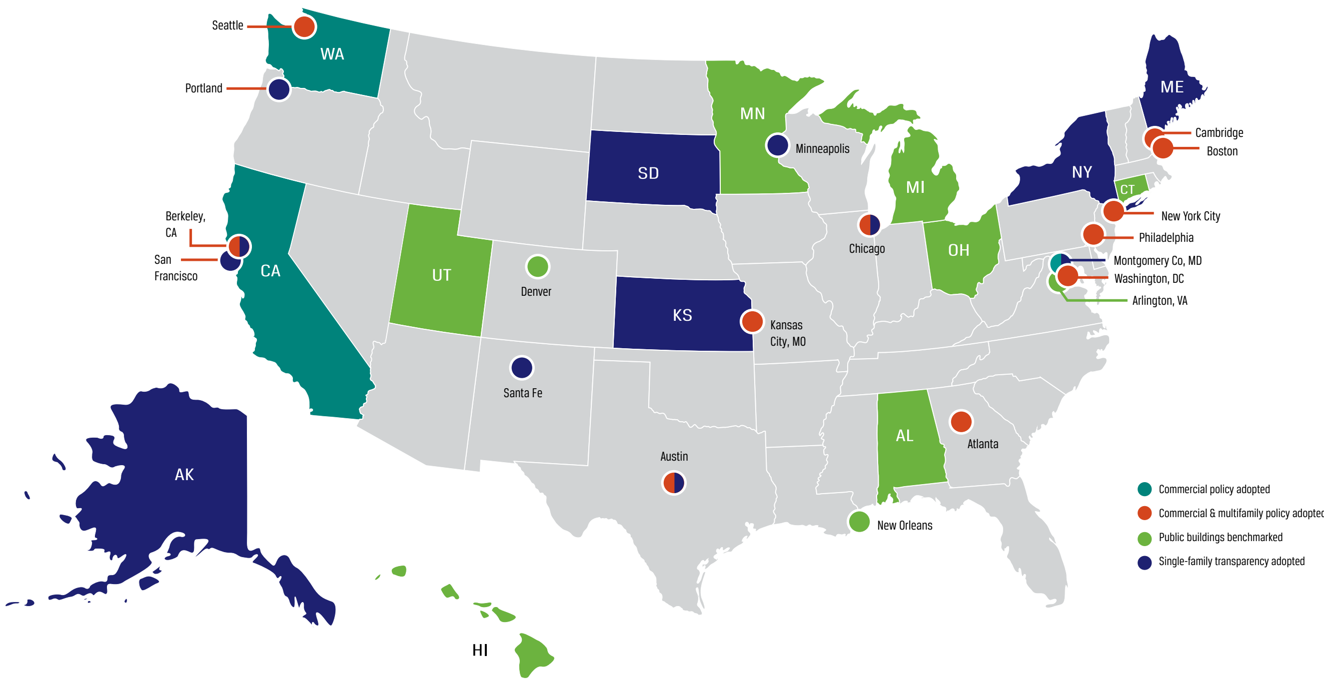
Benchmarking is an important process to monitor facility energy use and understand overall building performance. Many building owners and facility managers benchmark their facilities as a best practice for their own management purposes. The EPA's ENERGY STAR Portfolio Manager software tool is commonly used for voluntary benchmarking and often is the reporting mechanism used for mandatory benchmarking and disclosure programs. The ENERGY STAR® 1–100 score used in Portfolio Manager for certain building types provides owners of multi-building portfolios the ability to compare the performance of their own buildings with that of similar buildings nationwide. Owners use Portfolio Manager and the ENERGY STAR® scores to track progress in energy management and prioritize investments in energy saving improvements. Baselines currently used for the ENERGY STAR scores, derived from the 2003 Commercial Buildings Energy Consumption Survey, are in the process of being updated with results from the latest (2012) national survey. Advocates of more detailed building data analytics note that even buildings with a high ENERGY STAR score using Portfolio Manager may still have significant energy savings opportunities, while other buildings may receive poor benchmarking scores due to the presence of data centers or other intensive energy uses not fully captured by the ENERGY STAR normalization methods (Fisher, 2013; Scofield, 2014).

While the ENERYGY STAR® Score is useful in comparing the actual energy used by commercial buildings, energy use is influenced not only by the building's physical characteristics but also by the type of occupancy, usage patterns, facility management practices, and many other factors that may change over time. Thus, a second, complementary approach to building energy benchmarking is provided by an "asset rating" that can assess the physical characteristics and efficiency of the building envelope, energy-using equipment, and systems. The "Building Energy Asset Score" developed by DOE provides a 1-10 rating based on the efficiency of these more permanent "energy assets."[36] The combination of an operational energy rating such as the Energy Star Score plus an asset rating like the DOE Asset Score can provide a more complete basis for benchmarking and comparing the energy performance of commercial buildings than either rating tool taken alone.

In general, benchmarking is conducted at the whole-building level. Whole building benchmarking, by nature, assesses the overall energy performance of buildings by capturing the efficiency from the building equipment and systems, building controls, maintenance and occupant behavior to provide a general assessment of how the building performs. To the extent practical, sub-metering and benchmarking at the systems level would be extremely valuable to measure and compare the efficiencies of various building systems, and to help owners pinpoint the areas that are in need of improvement.

36 http://energy.gov/eere/buildings/building-energy-asset-score

Figure 3.2 – U.S. Building Benchmarking and Transparency Policies



Source: Institute for Market Transformation, ©2015

A number of communities have adopted either voluntary or mandatory benchmarking programs (Figure 3.2), some of which require that buildings be benchmarked and energy performance disclosed on an annual basis. These benchmarking and disclosure ordinances typically require that recent building performance information be made available to potential buyers or tenants of a building. In some jurisdictions, such as New York City, such information also must be made available to the general public, either through reporting the data publicly on the internet or by posting the data at the building site. Other jurisdictions, such as the city of Seattle, require that such information be submitted to the city as a basis for evaluating the performance of the building stock as a whole.

Some evidence exists that benchmarking and disclosure policies are beginning to affect building owner investment decisions, utility targeting of customers to participate in energy efficiency programs, and transactions in the building market (IMT, 2015). By requiring building owners to collect and report energy performance information, attention is drawn to building performance, especially if the building is part of a larger portfolio. Also, by allowing prospective buyers or tenants to see this information, an energy use comparison can become part of the market evaluation when considering alternate properties.

Comparing benchmarked buildings that were built under recent building energy codes against buildings built under previous, less stringent codes (or in some cases, without any codes at all) can have a significant impact in a competitive real estate market. Relative energy performance becomes a financial consideration in these transactions. As developers and building owners recognize that relative energy performance has a market value, they begin to expect their design teams to address building performance as part of the design contract. Linking benchmarking data with data on building characteristics, accompanied by analytics, can be extremely valuable in understanding how various decisions in design, construction, and operations affect overall energy performance, especially for newer buildings that have not yet undergone any major renovations or retrofits.

A benchmarking and disclosure program can improve policy decisions by highlighting which strategies are most effective in reducing energy use. This type of program also can help determine where and how energy goals should be set and provide verification as to whether the established goals are being met. However, such market pressures also can have a "down side," in the case of buildings with limited prospects for energy upgrades, such as historic buildings or those with limited access to capital.

In the case of retrofits, pre-retrofit benchmarking data (of at least two calendar years) can help establish expectations regarding post-retrofit results. Post-retrofit benchmarking data over one to two years can help demonstrate actual achievement of intended results and also, in the aggregate, can help demonstrate the value of retrofits to skeptical owners, financiers, insurance underwriters, and appraisers. With the availability of data on actual, measured energy use, members of the design and construction communities can more readily see how past projects are performing and incorporate lessons learned into their future projects. Thus far, these "feedback loops" generally have been lacking.

3.1.4.1 Recommendations

To enable and support benchmarking at the systems level as well as at the whole-building level, standards development organizations should create test procedures and simulation programs, validated with field measurements, so that building designers and owners can perform "apples to apples" comparisons. In addition, state and local governments should adopt sub-metering requirements into building codes to support future systems level benchmarking.

3.1.5 Building Energy Codes

Many aspects of the design and construction of commercial buildings in the U.S. are governed by energy codes and standards that set minimum requirements for new and renovated buildings. These codes are often based on model codes and standards developed by two non-governmental standards-setting organizations, ASHRAE and the ICC. Building codes (which cover a range of structural, mechanical, electrical, and health and safety topics in addition to energy) then are adopted—sometimes with changes—by the state or local authority having jurisdiction. The model codes and standards are created and updated every three years through a stakeholder process, although some also are updated under a "continuous maintenance" process, through which modifications can be made between the dates of formal publication of a new standard. The relevant model codes are the ICC's International Energy Conservation Code both for residential and commercial buildings and ASHRAE Standard 90.1 for commercial buildings. Further discussion of building energy codes is provided in Appendix 3.

Examples of "above code" or "green" building codes and standards, often used as voluntary guidance for marketing purposes, as well as criteria for utility incentives, include the U.S. Green Building Council's LEED rating program, ASHRAE Standard 189.1, the International Green Construction Code (IGCC), ENERGY STAR® Buildings, ENERGY STAR Homes, and the NAHB/ICC National Green Building Standard for homes.

3.1.5.1 Potential Benefits

From a systems perspective, the key benefits of a building code are that requirements can be included in the code to govern the efficiency of building systems—not just components. One limitation, however, is that code compliance and enforcement apply principally to new construction and some major renovations (including HVAC equipment replacement). On paper, energy code requirements apply broadly to almost all changes in an existing building that are performed under permit but, in practice, compliance and enforcement of energy efficiency provisions tend to be much weaker for tenant remodeling, equipment replacement, and other changes to an existing building.

Some building code requirements already take advantage of system efficiencies. For example, HVAC fans above a certain size (i.e., 5.0 horsepower) are required to be installed with some form of speed control to increase energy savings during part-load operation. With respect to lighting, certain fixtures are required to be connected to occupancy sensors, and some areas are required to use daylight dimming controls. Combined with maximum lighting power density requirements, these lighting control requirements improve the efficiency of lighting systems.

Ideally, the code development process will shift from prescriptive requirements that inform performance requirements to one in which building system performance is the starting point and prescriptive options are developed based on measurable performance criteria (Conover et al., 2013). This approach may reduce the complexity of a systems approach and would be especially useful for smaller buildings, for which detailed systems analyses often are not cost-effective.

Finally, "outcome-based" requirements largely bypass the shortcomings of either a prescriptive or performance-based approach, instead focusing on the overall energy use of an occupied building in actual operation and automatically taking into account systems interactions.[37] "Outcome-based" approaches must be designed carefully to ensure that building energy efficiency improvements are actually realized and sustained, and to avoid unintended negative consequences (such as higher energy consumption, higher energy bills, and pollutant and greenhouse gas emissions). Also, an "outcome-based" approach to code compliance may be difficult to apply to a partial building renovation or other changes in an existing building.

3.1.5.2 Technical, Market, and Policy Barriers

A number of impediments exist to maximizing the positive effects that building energy codes can have on systems efficiency. One major barrier is the common preference to use the prescriptive option for code compliance rather than a performance-based compliance path. As previous sections have noted, transitioning from component-based to system-based requirements will be critical to optimizing future energy use in buildings; however, implementing prescriptive systems-based requirements may pose a challenge to current industry-developed standards and metrics. For example, such standards would likely be very complex, since they would combine requirements for multiple components and their interactions. Focusing on performance, however, would provide a greater opportunity to address systems impacts: The performance requirements are set, then the design must demonstrate an ability to meet these requirements.

Another barrier is that current mandates surrounding the use of energy codes are weak. The consensus process used to develop model codes does not include any pre-determined levels of efficiencies that are expected to be reached in any given code cycle; thus it is difficult to anticipate increased stringency in future model codes. Although the federal Energy Conservation

37 For a discussion of the code formats and the pros and cons of each, see Colker et al., 2011.

and Production Act (ECPA) requires states to adopt the most recent model energy codes, and the American Recovery and Reinvestment Act (ARRA) requires states to demonstrate 90 percent compliance with ASHRAE Standard 90.1-2010 by 2017, there are no negative consequences for not complying with these requirements, so there tends to be little uniformity of building energy standards across the country.

Finally, the energy codes (as with all building codes) are administered primarily at the local level, and local governments are constrained in the resources they have available to provide basic services, much less the enhanced services that increased energy code enforcement will require. Not only are municipal budgets very tight, but there is often political resistance to increase permit fees that might allow more professionalized building department services. Additionally, studies have shown that more than 80 percent of the current code enforcement workforce in the U.S. is expected to retire within the next 15 years (ICC, 2014). The pipeline of new professionals entering this workforce is thus insufficient.

3.1.5.3 Current Status

After many years of minimal increases in energy code stringency, model codes achieved significant advances between 2006 and 2015. The most current versions of model codes for commercial construction represent a 38–42 percent improvement over the codes that were in place in 2006 (see Appendix 3). Expectations for the next code development cycle (ASHRAE Standard 90.1-2016 and IECC 2018) are for more modest increases in energy efficiency requirements.

Adoption of the current codes, as noted above, remains varied. As of 2016, only seven states are enforcing the IECC 2015 or ASHRAE Standard 90.1-2013, while nine states have never adopted a state-wide energy code, as required by federal statute. Other states are using older versions of the codes (see Figure A3.2 in Appendix 3).

DOE and several states recently have conducted studies to better understand the rates of compliance with energy codes in new construction. Most of these studies have focused on the residential market, but the few studies that have looked at commercial construction indicate rates of compliance often well below 75 percent. A number of reasons explain why compliance with energy codes is low, including the perception that such codes are very complex with respect to commercial buildings, and the lack of agreement regarding where the ultimate responsibility for compliance lies.

3.1.5.4 Recommendations

A number of challenges face the development and adoption of systems-focused standards and metrics and "outcome-based" requirements. These include the need to incorporate new technologies, resource availability at the agency responsible for code enforcement, and the complexity of accounting for operational energy use, rather than setting requirements for design and construction criteria alone. A need remains to develop tools and guidance for the architecture, engineering, and construction (AEC) community on how to design and construct to such "outcome-based" requirements. Some specific recommendations follow.

- The next version of ASHRAE Standard 90.1 will be published in 2016 and the next version of the IECC will be published in 2018. Several proposals for these model codes would increase or incorporate system efficiencies. In the longer term, both ASHRAE and the IECC should explore covering additional building loads (such as plug loads), enhance sub-metering requirements, consider greater use of performance criteria for systems and whole-building energy use (modeled or actual), and give increased attention to systems efficiency when the code applies to existing buildings.

- Federal incentives, in the form of grants or other funding, could spur more rapid adoption by the states (or localities) of new and updated model building codes. States and localities face tight budgets for codes personnel and training. However, it is strongly recommended that any future federal funding for building codes be tied to a state's compliance with existing federal requirements regarding energy code adoption and compliance.
- Increased training of architects, engineers, and construction contractors is needed to prioritize building energy performance (and systems efficiency). Increased training of code officials by organizations such as the ICC (with support from federal and state agencies) also would produce significant benefits, by assisting them with enforcement provisions related to systems efficiency.
- The design, construction, and enforcement infrastructure must be updated to allow for data collection and regulation of energy use past the occupancy stage of buildings. The current system is ill-suited to the development and employment of "outcome-based" energy efficiency regulation.
- Alternate approaches to code enforcement will need to be developed to mitigate the impact of the anticipated decline of the code enforcement workforce.
- Performance metrics, test and rating methods, and mechanisms for third-party certification of systems energy performance should be designed by standards development organizations to support code compliance. Code officials then could inspect based on "as-built" compliance with the design.

3.1.6 Appliance and Equipment Efficiency Standards

Minimum efficiency standards for appliances and other energy-using equipment have been applied at the federal level since the U.S. Congress passed the National Appliance Energy Conservation Act of 1987 (NAECA).[38] This law subsequently was amended in 1992, 2005, and 2007 to expand the universe of covered appliances and require new DOE rulemakings to set minimum energy efficiency standards for these appliances.

DOE's appliance and equipment energy efficiency program currently covers more than 60 products, which account for about 90 percent of home energy use, 60 percent of commercial building energy use, and about 30 percent of industrial building energy use. As a result of standards currently in place, DOE reports that American consumers saved about $58 billion on their utility bills in 2014 (U.S. DOE, 2015b). A full discussion of appliance standards is provided in Appendix 4.

38 While Congress had enacted the National Energy Conservation Policy Act in 1978 to require DOE to issue federal appliance standards for 13 appliances, from 1982 to 1983 DOE proceeded to issue a series of "no standard" standards, while simultaneously approving waiver requests from several states that allowed such states to issue their own appliance standards. After DOE's "no standard" standards were invalidated by the D.C. Court of Appeals, Congress enacted the 1987 National Appliance Energy Conservation Act to establish specific federal efficiency standards for 11 appliances (See *Report on the Activity of the Committee on Energy and Commerce for the 99th Congress* (H. Report 99-1038), pp. 248-250, and, *Report on the Activity of the Committee on Energy and Commerce for the 110th Congress* (H. Report 100-1114), pp. 103-104) This law also generally preempted state standards for appliances covered by federal standards.

In recent years, DOE has increased the number of "covered" products that it is regulating. Currently, DOE is engaged in, or is proposing, rulemakings to update the current energy efficiency standards for a wide range of consumer and commercial appliances. In addition to these rulemakings, some appliances or equipment not currently covered by DOE's federal standards could become subject to new standards in the future, either through the enactment of new legislation or through DOE rulemakings. DOE also may be able to make use of its appliance standard-setting authority to promote building system efficiency, if "covered" products and equipment are interpreted to include a building system or subsystem comprised of various energy-consuming articles or components. However, amendments to existing law may be required to ensure DOE's legal authority in this regard.[39]

3.1.6.1 Potential Benefits

While opportunities exist to improve the efficiency of many individual pieces of equipment,[40] given the major strides made in equipment efficiency over the past 30 years, even greater energy savings opportunities may be available through a focus on improving the ways in which various pieces of equipment in a system function together. For example, while it is technologically feasible to improve slightly the full-load efficiency of integral horsepower electric motors, much larger savings (i.e., 20 percent or more) could be achieved by looking at the entire motor system, including variable speed control, the efficiency of the motor-driven equipment (e.g., fans, pumps, and compressors), and the various other devices that make up a motor system (Nadel et al., 2002). Similarly, more energy can be saved by looking more holistically at entire lighting and HVAC&R systems.

3.1.6.2 Current Status

Increasingly, DOE and other parties are examining opportunities to address systems issues through the standard-setting process. For example, an update to the commercial rooftop air conditioner standard will use the IEER metric, which is an average of mechanical cooling efficiency under four different load conditions (although it does not include ventilation, heating, and system features, such as economizers, or energy recovery). In a recent rulemaking for pumps, industry and efficiency supporters negotiated an "extended product" performance standard and test procedure that address not just the pump, but also the motor, drive, and other components that typically are installed together with the pump; however, this standard still excludes system features, such as piping layout and sizing, that affect heat losses and pumping energy requirements.

A systems approach will pose new challenges for the appliance standards-setting process that will need to be resolved, including which appliances, components, and types of equipment should be covered under the systems approach, and which should continue to be subject to component standards. While items purchased by a consumer post-construction (such as room air conditioners, refrigerators, stoves and ranges, microwaves) presumably would remain subject to traditional component

39 Even within its current authority to set appliance standards, DOE has already taken some steps in this direction. For example, the negotiated standard proposed for rooftop unitary air conditioners and heat pumps includes gas furnaces installed with these units. Another example is the DOE standard for walk-in coolers and freezers, which includes two major mechanical components as well as walls and doors of the walk-in enclosure (and also often includes lighting). The standard provides options for considering components supplied by different manufacturers and assembled on-site to help ensure that these components work efficiently together.

40 See, for example, DeLaski, A., et al., 2015. Also, the draft of a forthcoming report on next-generation standards by the American Council for an Energy-Efficient Economy (ACEEE) and the Appliance Standards Awareness Project (ASAP) anticipates a potential to save more than 100 quads, cumulatively from sales through 2050, simply from updating future standards for currently "covered" products to today's best-available efficiency levels. The draft report also refers to substantial added savings from improved test methods.

standards, other items, such as central air conditioning and heating systems, installed lighting systems, elevators, escalators, and other systems might be well-suited to coverage under a systems approach. Enforcement of a systems-level efficiency standard also may require new approaches, particularly in situations in which different manufacturers and installers are responsible for different parts of the system.

Finally, with the emerging interest in DC power distribution within buildings (see Section 2.3.2), many more types of appliances and equipment—including LED and fluorescent lighting, computers, office electronics, and consumer electronics—could be reconfigured to directly use distributed DC power. This, in turn, would mean that a number of current energy test procedures, used not only for DOE's efficiency standards but also for the FTC EnergyGuide appliance labels, ENERGY STAR® certification, and utility incentive programs, would need to be revised to allow for either AC- or DC-powered configurations.

3.1.6.3 Recommendations

- New systems-oriented efficiency metrics and test procedures should be developed by manufacturing trade associations and DOE that can be performed in test laboratories at minimal incremental costs.
- Changes in test methods, tools, standards, labeling, and incentive programs also should provide for DC-powered appliances, equipment, and lighting, wherever applicable.
- Utility, federal, and state incentive programs for these same products could facilitate these efforts.
- DOE should consider ways in which it might use its existing legal authorities to promulgate rules covering certain building systems.
- Congress should consider legislation that would amend the Energy Policy and Conservation Act (EPCA) either to direct DOE to develop energy efficiency rules for certain specified building systems and subsystems or add new legislative language that clarifies that EPCA's existing authorities should be read to cover such building systems and subsystems.

3.1.7 Utility Policies and Programs – Utility of the Future

As discussed in the section on Buildings-to-Grid integration, the utility industry is changing—driven both by technological and market forces—and will increasingly interact with many non-utility service providers, such as providers of distributed generation, energy storage systems, and home and building energy management, security, communications, and entertainment systems (which extend well beyond energy management). Utilities will need to manage much more complex grids involving these systems and their providers and, in some cases, may even compete directly with them. In addition, as the grid, homes, and buildings become "smarter," opportunities to manage energy use and provide value to customers will increase. To successfully operate in such a future, utilities will need to offer value-added services to customers. Energy efficiency is an important area in which value-added services can be provided; surveys show that efficiency services are highly valued among customers.

3.1.7.1 Technical, Market, and Policy Barriers

A broad range of potential benefits is envisioned from a utility focus on building systems. Many of these involve changes to the grid, homes, and buildings, as well as to the operation of building systems (U.S. DOE, 2008). This will require both utilities and regulators to recognize changing circumstances and to experiment with new business and regulatory models, so that customers receive services they want at reasonable costs, while utilities provide returns to their shareholders and investors. Among the policies that will need to evolve are those to facilitate the utilities' role as a systems integrator, those pertaining to rate structures (e.g., toward greater "time-of-use" rates and rates to reduce peak demand), and a likely shift toward performance-based regulation.

Barriers include challenges encountered with systems approaches in past demand-side management (DSM) programs, the amount of time and resources needed for successful programs, and the possible longer time frames associated with systems retrofits rather than component retrofits or installation. Building system technology changes, as well as more recent experience with such programs and a better ability to conduct system simulations, may help overcome such barriers.

3.1.7.2 Current Status

A few states and utilities are starting to experiment with changes to business and regulatory models, including rate structures. New York is in the midst of its Reforming the Energy Vision (NY REV) process (NYS Department of Public Services, 2016), and Minnesota has a process underway known as the "e21 Initiative" (Great Plains Institute for Sustainable Development, 2013). In addition, Massachusetts and California are working on grid modernization-related efforts and both have requested grid modernization plans from their utilities; a number of utilities already have complied (Commonwealth of Massachusetts, 2016). Public Service Electric & Gas (PSEG) in New Jersey also is developing a grid modernization plan. It is notable that the grid modernization filings of both PSEG and National Grid (in Massachusetts) include a large role for energy efficiency in their evolving business plans (King, 2014; Izzo, 2014). With the significant changes to regulatory models, the emphasis on building systems that are both more efficient and more responsive to energy grids may increase.

3.1.7.3 Recommendation

More experimentation is needed, both by regulators and utilities, to determine how best to adapt current business models and regulations to advance the public policy goals of ensuring a reliable, safe, and affordable supply of electricity, as well as better realizing efficiency opportunities on both the supply and demand sides. By encouraging investments in more efficient and more grid-responsive building systems, may be possible to create more "win-win" situations in terms of energy supply and customer demand-side applications and technologies.

3.1.8 Utility/Energy Supplier Incentive Programs

Utilities spend nearly eight billion dollars per year on energy efficiency programs, which help them and their customers save energy and ultimately may help avoid the need to construct new power plants or invest in costly distribution system upgrades. A substantial majority of these funds is directed toward prescriptive and other non-systems measures. For example, a national database of energy efficiency programs shows that 1,260 "rebate programs" currently are being offered in the United States, the vast majority of which are geared toward specific types of equipment (DSIRE, n.d.).

Many utilities operate in states with Energy Efficiency Resource Standards (EERS), which consist of annual requirements for the states to attain certain levels of energy efficiency, usually defined in terms of percentages of electricity sales. Prescriptive measures geared toward specific appliances or components (such as furnaces, air conditioners, LED light bulbs, occupancy sensors) tend to be favored since they usually are easy to implement, operate, and evaluate. Customers also are likely to be able to complete the projects themselves rather than hire third parties.

Focusing on efficiency upgrades at the systems level can provide even larger potential energy savings, as documented throughout this report. Incentive programs for these types of measures, however, face several challenges: They likely are perceived to take more time, have higher up-front costs, require third-party installation, be more complicated in terms of commissioning, and vary to greater extents in terms of actual energy savings. Efforts to address these issues and perceptions are needed to pave the way for effective utility and supplier systems-efficiency incentive programs.

3.1.8.1 Potential Benefits

A September 2015 ACEEE study that examines potential savings from 18 different energy efficiency measures finds that, of the total building energy savings (over 20 percent of energy use) achievable by 2030, more than one half would involve systems measures (York et al. 2015). Examples include whole building programs for new construction and residential and commercial retrofits, "smart" building programs, advanced lighting design programs, strategic energy management initiatives, programs to promote highly-efficient HVAC systems with quality installation, and programs that provide feedback to consumers on their energy use and ways in which to better manage it.

According to a recent report published by the Edison Foundation's Institute for Electric Innovation, more than 50 million "smart" meters were installed in the United States by the end of 2014 (Institute for Electric Innovation, 2014). A significant number of "smart" gas and water meters also have been installed. Utilities and/or customers can use the information from "smart" meters on a real- or near-real-time basis to monitor and control energy usage, particularly during periods of peak demand. In the not-too-distant future, customers' ability to use "smart" technologies to monitor and manage the energy usage of smart appliances and smart systems will expand beyond a niche market into the mainstream. In addition, utilities will be able to leverage their "smart" meter infrastructure to develop and offer programs designed to work seamlessly with "smart" information and communication technology and systems to help customers better manage their energy usage.

3.1.8.2 Technical, Market, and Policy Barriers

While systems efficiency initiatives are more difficult to set up and market than prescriptive programs, the declining opportunities for further efficiency gains from some prescriptive measures—discussed in the beginning of this report—suggest that, in the future, opportunities for savings will increasingly come from systems efficiency improvements. In many cases, regulators and customers will need to be educated about systems opportunities, and regulators and utility managers will need to be open to experimentation. In some instances, new incentive and evaluation techniques will be needed.

Utility incentives for system-level efficiency improvements will require development of reliable methods for predicting energy savings and cost-effectiveness as well as measuring and validating such estimates after the fact—methods that are credible and convincing to utility regulators as well as customers. One step in this direction is the "Getting Beyond Widgets" project recently launched by Lawrence Berkeley National Laboratory in cooperation with several utilities (LBNL, 2016).

Since system efficiency measures may take longer to install (especially in existing buildings), and may have higher up-front costs, engaging customers in systems-oriented programs likely will require more effort than programs focusing on prescriptive measures for individual equipment. This is especially true if the utility incentive program has a near-term expiration date, or there is a possibility that the incentive funding will no longer be available by the time the system project has been installed. Therefore, utilities that offer program choices will likely see higher participation rates in programs with prescriptive incentives for individual equipment compared to programs that offer "custom" incentives for systems-level upgrades. However, to achieve sustained energy savings, it will be increasingly important for all participants—including regulators, utilities, building owners, and consumers—to move toward a systems efficiency approach.

3.1.8.3 Current Status

A significant number of systems-oriented programs exist, including many for newly-constructed homes and commercial buildings, as well as customized system incentives for existing buildings. While many systems-oriented programs are still in their infancy, lessons can be learned from early adopters.

3.1.8.4 Recommendations

- Utilities should pilot new systems-oriented programs and publish the results, so others can benefit from the knowledge acquired. Examples of possible initiatives to improve building systems efficiency include "smart" building programs focused on particular building systems and strategic energy management efforts.
- States should revisit their EERS mandates to ensure that they reward systems efficiency approaches. As an increasing number of systems programs are implemented, systems-oriented incentives should be focused on optimizing total energy savings to meet long-term state EERS goals (e.g., "the program will save X amount of electricity from X building systems by the year 2030").
- To increase the number of customers that install more energy-efficient systems within a building, utility and state programs may need to be redesigned to ensure that system projects have the same or improved returns on investment compared to projects that only incentivize prescriptive measures.
- For customers with limited capital, leasing or third-party programs may need to be established by utilities, financial institutions, or government agencies to increase the number of systems-efficiency upgrades in existing buildings.

3.1.9 Training and Certification

One critical aspect of a successful system efficiency approach is the training and certification of those who design and specify building systems, enforce building codes, and operate the systems within buildings.

There is a need for state and local code officials as well as design and engineering professionals to have:

- Greater awareness of systems efficiency measures;
- Increased expertise in integrated design and passive design; and,
- Expertise in system-level (as well as whole building) commissioning.

3.1.9.1 Technical, Market, or Policy Barriers

Much of the building energy efficiency training underwritten by the U.S. Department of Energy and by state governments has traditionally focused on training for code enforcement personnel. There remains a strong need for training for policy makers (those who adopt codes and policies and can make energy enforcement a priority), design professionals (who design and specify building systems), and builders.

In addition to the availability of training for the relevant stakeholders, another barrier is the lack of clear incentives to pursue such training and certifications. In the absence of mandates (i.e., certification required to perform certain functions), it is challenging to persuade these market players to prioritize energy efficiency at the same level of health, safety, and structural requirements in the code.

3.1.9.2 Current Status

In all fifty states, architects and engineers are licensed for the purposes of protecting the health, safety and welfare of the public. In many states, these professionals are required to obtain continuing education credits to retain licensure. Generally, this licensure is applicable for the broad knowledge needed to practice architecture and engineering, and is not focused on specific knowledge sets such as energy efficiency. Due to licensure, liability insurance for design professionals is a substantial financial obligation.

Builders and contractors are registered or licensed in some states, but the applicability of these state statutes is uneven. Similarly, the licensure or certification of code officials differs from state to state, although the ICC offers a wide range of specialty certifications related to code enforcement. Liability exposure for code officials is typically limited under state laws for municipal immunity.

ASHRAE offers certifications that are relevant to systems energy efficiency. In addition to certifications for High-Performance Building Design Professionals and Building Energy Modeling Professionals, there are certifications for Commissioning Process Management, and for Operations and Performance Management.

3.1.9.3 Recommendations

The objective of improving systems efficiency in buildings can only be realized when those who design and construct the built environment—along with their clients—place a premium on energy performance. It will also be important to address the persistent shortage of code enforcement personnel. Specific recommendations include the following:

- The membership associations for the primary stakeholder groups should be encouraged to provide and incentivize training and specialty certifications related to energy efficiency in general, and specifically to systems efficiency.
- State licensure boards should consider offering specialty certifications on energy performance for licensed professionals.
- Federal, state and local government agencies can greatly influence market transformation toward systems efficiency by requiring appropriate training and certifications for design professionals and building trades working on public buildings.

3.2 Valuation and Prioritization of Systems Efficiency

Continued efforts to quantify the value (including energy and non-energy benefits) of energy efficiency and to prioritize efficiency as a key pathway toward meeting high-level goals (e.g., zero net energy buildings) will help promote systems efficiency as an important approach for achieving increasingly ambitious efficiency goals.

3.2.1 Documenting Multiple Benefits of Energy Efficiency

End-use customers will be more likely to invest in systems approaches the more they appreciate the multiple benefits of energy efficiency in general, and systems efficiency, in particular. While energy savings are one of the primary benefits, the many non-energy benefits should be actively documented and promoted. For example, optimized HVAC systems can improve occupant comfort, and optimized motor systems can improve the quality of manufactured products and reduce material waste (Nadel et al., 2002). Numerous studies have been carried out regarding these multiple benefits, including in multi-family and commercial buildings. Some studies have estimated that the quantifiable non-energy benefits are on the order of 25–50 percent of the total benefits of energy efficiency (Russell et al., 2015; Livingston et al., 2014). More work is needed to characterize and quantify these benefits to support the incorporation of non-energy benefits into programmatic and regulatory approaches.

3.2.1.1 Recommendations

Some non-energy benefits (e.g., the value of water savings) are fairly easy to quantify, but many others (e.g., the impact of improved indoor air quality on health and workplace productivity) are not. More research is needed by DOE, national laboratories, and energy efficiency organizations on these benefits as well as on improved analytic methods. Particular attention should be directed toward commercial and multi-family buildings. Quantifying these benefits, to the extent possible, would enable them to be included in utility cost-effectiveness tests to a greater extent. Once the benefits are better documented, they should be provided to customers and all decision-makers in an objective and comprehensible manner. Compelling case studies also could facilitate efforts to reach individual customers as well as policy makers.

3.2.2 Zero Net Energy or Carbon Goals

Zero net energy (ZNE) buildings (or building complexes) are generally considered to be buildings (or building complexes) that use a total amount of energy on an annual basis that is roughly equal to the amount of renewable energy created on site. However, there are a number of different definitions of this term, as well as the term "zero carbon" buildings (Pless and Torcellini, 2010). It is technically possible, under some definitions, for a "net zero" building to consume more energy and produce more emissions than a building that is not "net zero." A systems approach could help ensure that building energy use and emissions are minimized prior to accounting for any on-site energy production.

A number of targets have been established in the U.S. and around the world—at both the individual project and community level—for the development of ZNE (and/or carbon) commercial structures. Achieving ZNE or carbon goals requires thorough design processes that examine all opportunities to reduce energy consumption and production at a building site. Achieving such goals also requires an understanding of the system-level impacts. Unlike the current codes methodology, achievement of ZNE status requires demonstration of results during (and throughout) the operations phase.

In other words, achievement of a ZNE designation requires extensive modeling during the design process to understand the impacts of various potential energy production and consumption decisions and/or outcomes, as well as a robust monitoring and diagnostics process during the operations phase to ensure that systems actually are operating within their design parameters. Such modeling and monitoring must be done at the systems level to confirm that all information on energy use is understood and analyzed. A better understanding of the potential of systems efficiency improvements—and strategies for achieving them—will thus greatly enhance efforts to reach ZNE and carbon goals.

3.3 Next Steps for SEI

This SEI report, Greater than the Sum of its Parts, contains preliminary conclusions about opportunities for greater efficiency through a systems approach. During its second phase, the Alliance to Save Energy-led SEI will gather feedback from a broad range of stakeholders in the buildings industry as well as from local, state, and national policymakers to expand awareness of the Initiative and inform further analysis on the potential energy savings and other benefits of a systems approach.[41] Topics identified for possible additional analysis include the integration of HVAC&R and lighting systems with the building envelope and with electrochromatic windows, indoor environmental quality and its impact on human productivity, integrated procurement, and opportunities for open-systems software and interoperable hardware.

Ultimately, the SEI will develop a set of policy recommendations that form a roadmap to accelerate energy efficiency and productivity in buildings through a systems focus. The roadmap will propose specific recommended actions, including:

- Roles of specific stakeholders;
- Suggested timetables; and,
- Required resources.

Recommendations will focus on areas of highest potential gains for systems-level energy savings, possibly including development of new systems metrics; proposed changes to building codes, equipment standards, and green building rating systems; and federal and state tax incentives to support systems efficiency. The roadmap also will address opportunities to incorporate systems-oriented content into professional and technical training and certification curricula.

Industry experts and efficiency advocates agree that improving the efficiency of building systems is a key strategy for amplifying energy and cost savings, and for achieving the next level of efficiency in buildings. The Systems Efficiency Initiative provides a critical forum for understanding the energy savings potential of a systems approach and for developing strategies to achieve these savings.

41 For information about participating in the Systems Efficiency Initiative, please contact LVanWie@ase.org.

GLOSSARY

APPENDIX 1

APPENDIX 2

APPENDIX 3

APPENDIX 4

REFERENCES

GLOSSARY

ASHRAE Standard 90.1 (American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings) – Provides the minimum requirements for energy-efficient design of most buildings, except low-rise residential buildings. The standard offers, in detail, the minimum energy-efficient requirements for design and construction of new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements (ASHRAE, 2013).

ASHRAE Standard 189.1 – This standard provides minimum requirements for the siting, design, construction, and plan for operation of high-performance green buildings. It addresses site sustainability, water use efficiency, energy use efficiency, indoor environmental quality, and the building's impact on the atmosphere, materials, and resources. The standard also includes a section related to plans for construction and high- performance operation (ASHRAE, 2014).

Building-To-Grid (B2G) Integration – A seamless, dynamic, and cost-effective end-to-end electricity system, capable of balancing demand and capacity requirements, while also enabling the integration and scaling-up of renewable generation and energy storage, maximizing electric vehicle value, and offering consumers the opportunity to actively participate in demand management/demand response and energy efficiency.

Building Component – An element used in a building that is manufactured as an independent unit and can be joined with other elements (e.g., including electrical, fire protection, mechanical, plumbing, structural) (Burden, 2012). Common building components to which this report refers include HVAC equipment (air conditioners, furnaces) and lighting equipment (luminaires, ballasts) that are subject to appliance and equipment energy efficiency standards.

Building Energy Quotient (bEQ) – A building energy rating program that provides information on a building's energy use. Two separate workbooks, one evaluating As Designed potential and the other assessing In Operation performance, form the foundation of bEQ (ASHRAE, n.d.).

Building System – A combination of equipment, operation, controls, accessories, and means of interconnection that uses energy to perform a specific function. Building systems may be mechanical, such as climate control (HVAC) and water heating systems, or non-mechanical (e.g., lighting systems). For the purposes of the SEI, a building system refers to one of many systems within a building, rather than to a building as a whole (or in its entirety).

Other terms related to Building Systems:

- ***Energy-Efficient Building System*** – A building system that provides a high level of service or functionality for a given level of energy use.
- ***Building System Energy Efficiency*** – The ratio of (a) services or functions provided by a building system to (b) the amount of energy that system consumes directly, or the thermal load it imposes on other building systems.

- ***Systems-Efficient Building*** – A building in which multiple systems (e.g., lighting system, HVAC system) are designed, installed, and operated to optimize performance collectively with one another and with energy systems outside of the building to provide a high level of service or functionality for a given level of energy use. Note: Total building energy use can be reduced through system optimization, but maximum building efficiency is not necessarily obtained by maximizing the efficiency of each of the systems within a building independently, since building system interactions can negate some energy savings.
- ***Building Systems Integration*** – (1) The ability of multiple building systems to share communications, control, heat recovery, or other functions, and of devices to serve more than one system (such as occupancy sensors, wired or wireless communication protocols, or data loggers). (2) The design, fabrication, sizing, installation, and operation of multiple building systems to work effectively with one another and with energy and other types of systems outside the building, including through the use of user interfaces and dashboards for monitoring the system.

Commissioning – A quality-focused process to verify and document that a building and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the building's requirements. Retro-Commissioning is a process for bringing a building back to its original operating parameters, or modifying its operations for improved performance.

Demand Response – Changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized (FERC, 2015).

Energy Use Intensity (EUI) – An expression of building energy use as a function of its size or other characteristics. The EUI is calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross floor area of the building (ENERGY STAR®, n.d.).

Heating, Ventilating, and Air Conditioning (HVAC) System – The equipment, distribution elements, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning to a building or portion of a building (ASHRAE, 2013a).

Other terms related to HVAC systems:

- ***Energy Efficiency Ratio (EER)*** – The ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions (ASHRAE, 2013a).
- ***Seasonal Energy Efficiency Ratio (SEER)*** – The total cooling output of an air conditioner during its normal annual usage period for cooling (in Btu) divided by the total electric energy input during the same period (in watt hours) (ASHRAE, 2013a).
- ***Integrated Energy Efficiency Ratio (IEER)*** – A comparative metric representing the integrated full-load and part-load annualized performance of the mechanical cooling of the air-conditioning unit over a range of operating conditions. It is based on a volume weighted average of three building types and 17 climate zones and includes four rating points at 100 percent, 75 percent, 50 percent and 25 percent load at condenser conditions seen during these load points (ASHRAE, 2015a).

- ***Coefficient of Performance (COP)***-Cooling – The ratio of the rate of heat removal to the rate of energy input, in consistent units, for a complete refrigerating system or some specific portion of that system under designated operating conditions (ASHRAE, 2013a).
- ***Coefficient of Performance (COP)***-Heating (heat pump) – The ratio of the rate of heat delivered to the rate of energy input, in consistent units, for a complete heat pump system, including the compressor and, if applicable, auxiliary heat, under designated operating conditions (ASHRAE, 2013a).
- ***Integrated Part Load Value (IPLV)*** – A single number figure of merit expressing part-load efficiency for equipment on the basis of weighted operation at various partial load capacities for the equipment calculated per the method described in AHRI Standard 550/590-2015 (ASHRAE, 2015b).
- ***Power usage effectiveness (PUE)*** – The ratio of computer room (or data center) total energy or power divided by IT equipment energy or power, calculated in accordance with industry-accepted standards (ASHRAE 2013a).

High-Performance Building – An energy-efficient building that may also: (a) produce non-energy benefits such as improved safety, security, occupant health/comfort/amenity, workplace productivity; or (b) improve the performance of energy systems outside the building, such as improved distribution or microgrid reliability, increased generation of wind or solar power, or a reduced use of inefficient generating plants during peak load periods.

International Energy Conservation Code (IECC, 1998-2015) – This Code establishes minimum regulations for energy-efficient buildings using prescriptive-and performance-related provisions. It addresses the design of energy-efficient building envelopes and installation of energy-efficient mechanical, lighting, and power systems through requirements emphasizing performance. The code contains separate provisions for commercial buildings and for low-rise residential buildings (three stories or less in height above grade). Each set of provisions, IECC—Commercial Provisions and IECC—Residential Provisions, is separately applied to buildings within their respective scopes (ICC, 2015).

Internet of Things (IoT) – Fully interoperable connections among devices and systems within a single building (or industrial facility), between the building and the electric grid (or a microgrid), and directly between the devices/systems within a building and any number of outside service providers—all via the Internet.

Lighting System – A collection of luminaires and related lighting equipment installed in an application to provide the right amount of light where and when needed.

Other terms related to lighting systems:

- ***Clerestories*** – Windows positioned above eye height or above an adjacent roof (DiLaura et al., 2011).
- ***Coefficient of Utilization (CU)*** – A metric that allows for the comparison of luminaire efficiencies in a particular environment; a measure of the percentage of light output reaching the work-plane after taking into account light losses due to luminaire efficiency, the proportions of the room, and how room surfaces either reflect or absorb light (DiLaura et al., 2011).

- ***Light Shelves*** – Horizontal shading and light reflecting elements along a window that intercept and redirect sunlight and sky light upward into a space (DiLaura et al., 2011).
- ***Luminaire*** – A complete lighting unit consisting of a lamp or lamps together with the housing designed to distribute the light, position and protect the lamps, and connect the lamps to the power supply (ASHRAE, 2013a).
- ***Luminaire Efficiency*** – The ratio of light output (lumens) emitted by the luminaire to the light output emitted by its lamps, or the percentage of light output that makes it out of the luminaire and into the environment (DiLaura et al., 2011).
- ***Luminaire Efficacy*** – The amount of light (in lumens) produced by a certain amount of electricity (in watts) for the entire luminaire, taking into account the light source, ballast, and luminaire losses. The Luminaire Efficacy Rating (LER) provides a metric for comparing the relative energy efficiency of fluorescent luminaires (NEMA, 2004).
- ***Luminaire Target Efficacy*** – Effectiveness of a luminaire in delivering light to a specific target area (e.g., for outside street and area lighting) as measured by NEMA Standard LE 6-2014 (NEMA, 2015).
- ***Optimal Lighting System*** – A collection of luminaires and related lighting equipment installed in an application to provide the right amount of light where and when needed, with consideration of human comfort, visibility, safety and security, the physical environment, and daylight integration.[42] Optimal lighting systems comprise multiple components, including luminaires and other hardware (fixtures, sensors, and controls), software (scheduling, control algorithms, networking with each other and with other building sub-systems), interior design (surfaces, furniture/partition layouts, colors and textures), and windows or skylights to minimize energy use while maintaining lighting quality.

Miscellaneous Electric Loads (MELs) – Electric loads resulting from electric devices not responsible for space heating, cooling, ventilation, water heating, or lighting. Also referred to as "plug" or "process" loads, MELs are produced by hard-wired and "plug-in" electrical devices, and include televisions and home entertainment centers, personal computers and office equipment, security systems, data center servers, elevators, medical and research equipment, kitchen appliances, and many other devices.

Techno-Economic Modeling – A type of modeling carried out to help ensure that market-driven prices for new technologies can be achieved. It is typically part of the "stage-gate" process in the corporate management of product development and related research.

Transactive Energy – The ability for consumers and end devices to buy and sell energy and related services in a dynamic and interactive manner (Gridwise, 2015).

Zero Net Energy (ZNE) Building – Also known as a net-zero energy building. A building in which the total amount of energy used on an annual basis is roughly equal to the amount of renewable energy created on the site.

42 NEMA "C-137 Committee."

APPENDIX 1

Commercial Building Load Profiles and Ambient Operating Conditions

Commercial Building Load Profiles

Table A1.1 breaks down actual and forecasted commercial building energy loads by function. HVAC&R loads (i.e., space cooling, space heating, and ventilation) are by far the largest users of energy in commercial buildings. Notable reductions in the percentage of overall building energy use are projected for lighting, due to improvements in efficiency; even larger improvements are likely due to the rapid introduction of light-emitting diodes (LEDs). Relative energy use for space heating is also projected to decrease, due to better building envelopes, and increased internal plug loads and miscellaneous loads, which emit excess heat into internal spaces; these effects will outweigh the reduction in lighting heat resulting from the switch to LEDs. This complex relationship between lighting, heating, and plug/miscellaneous loads underscores the need for systems analyses.

Table A1.1 – Projected Energy Use Distribution for all Commercial Buildings[43]

Energy Use	2010	2015	2025	2035
Lighting	13.6%	11.4%	11.3%	11.1%
Space Heating	26.6%	25.2%	23.1%	20.8%
Space Cooling	10.1%	6.1%	6.2%	6.2%
Ventilation	6.1%	6.1%	5.7%	5.5%
Refrigeration	4.5%	4.0%	4.2%	4.5%
Water Heating	6.7%	3.6%	3.6%	3.4%
Electronics	3.0%	7.1%	7.0%	6.8%
Computers	2.4%	2.1%	2.1%	2.1%
Cooking	2.3%	2.4%	2.4%	2.4%
Other	13.7%	15.2%	19.1%	24.2%
Adjust to SEDS	10.9%	16.9%	15.3%	13.1%

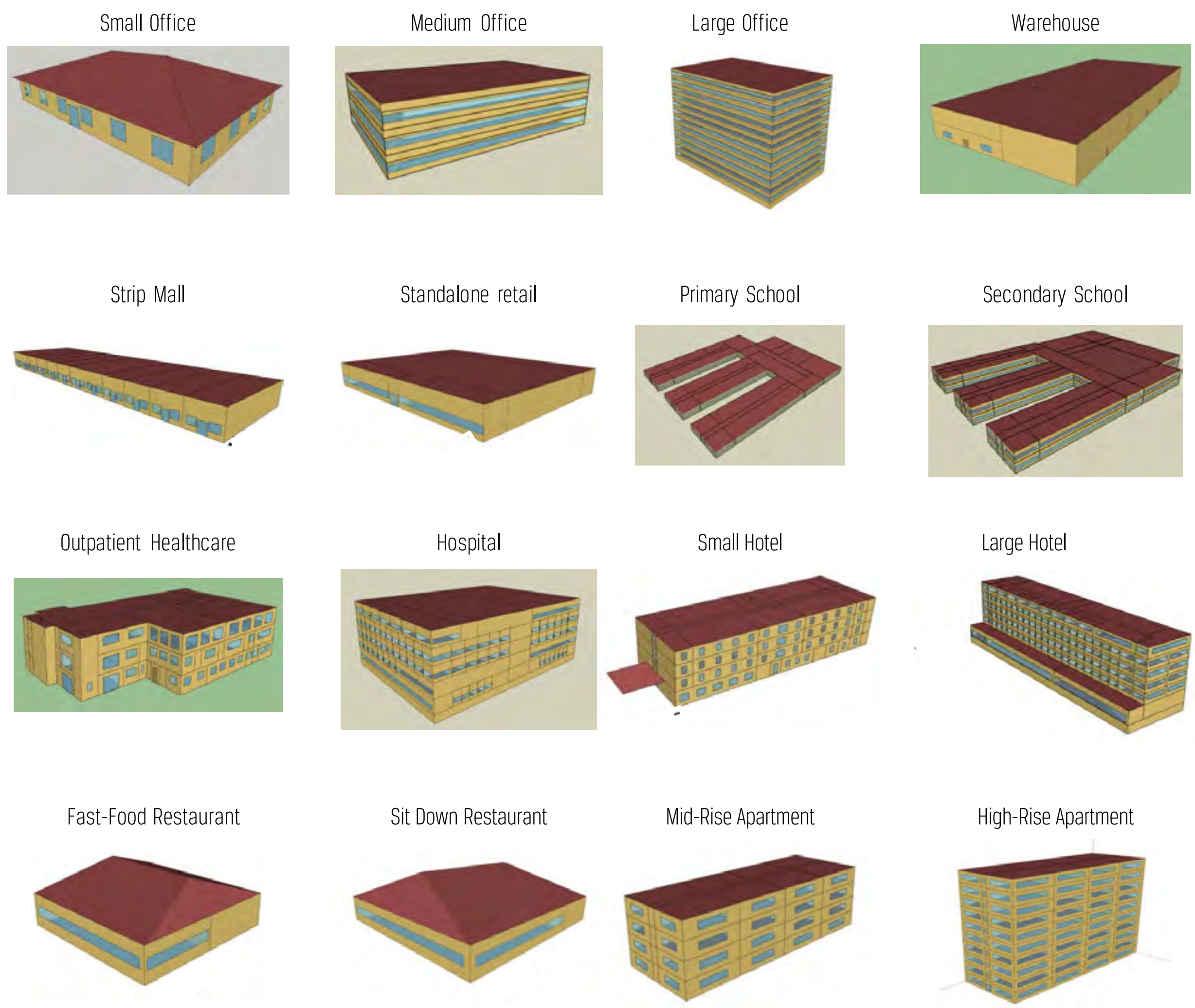
Source: U.S. Department of Energy, 2012c

43 Based on DOE 2011 Building Energy Data Book Report 2011_BEDB.pdf.

Understanding the way in which commercial buildings operate under real-world conditions is an important aspect of a systems efficiency approach. Commercial buildings seldom, if ever, run at full load. Instead, loads vary significantly by time of day, season, and climate region. Most commercial buildings are occupied during the day and unoccupied during the evening and weekends, which is the opposite of residential buildings.

The ASHRAE 90.1 Committee, with the assistance of the Pacific Northwest National Laboratory (PNNL), has developed 16 benchmark buildings that can be used to evaluate the load profiles of commercial buildings (shown in Figure A1.1, with further details in Table A1.2).

Figure A1.1 – ASHRAE 90.1 and PNNL Benchmark Building Models



Source: Pacific Northwest National Laboratory, 2014

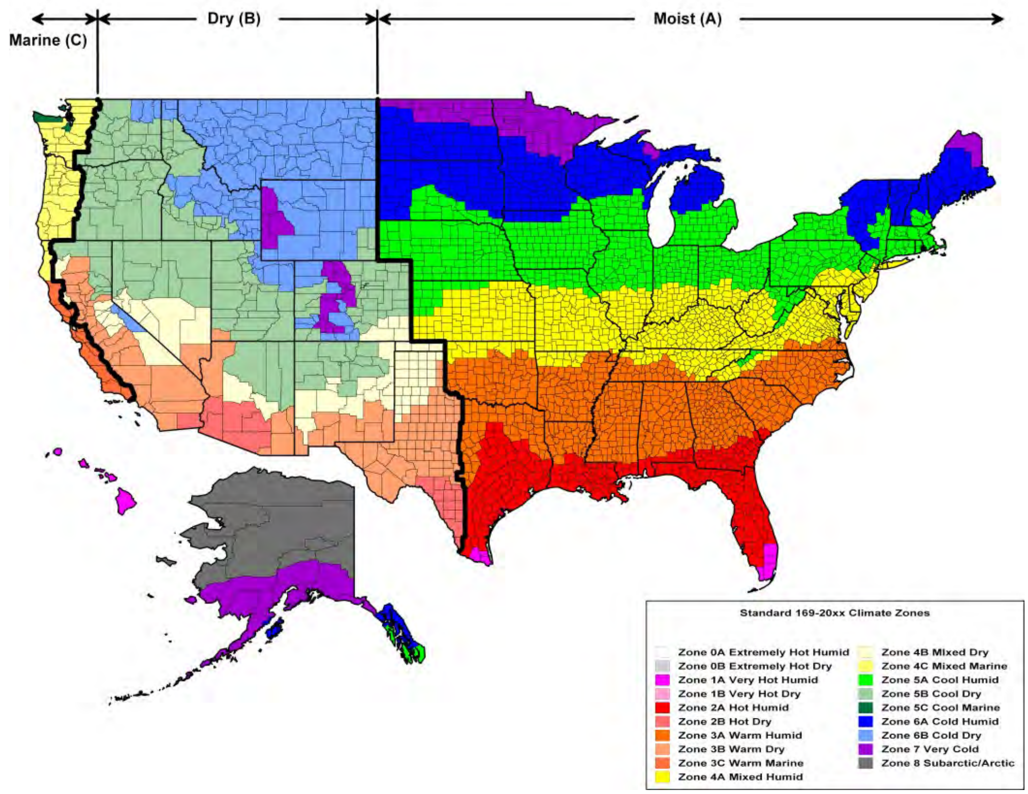
Table A1.2 – ASHRAE Standard 90.1 Benchmark Buildings

Building Type	Building Prototype	Floor Area (ft^2)	Number of Floors
Office	Small Office	5,500	1
	Medium Office	53,600	3
	Large Office	498,600	12 *(plus basement)*
Retail	Stand-alone Retail	24,695	1
	Strip Mall	22,500	1
Education	Primary School	74,000	1
	Secondary School	210,900	2
Health Care	Outpatient Health Care	40,950	3
	Hospital	241,410	5 *(plus basement)*
Lodging	Small Hotel/Motel	43,200	4
	Large Hotel	122,132	6 *(plus basement)*
Warehouse	Non-refrigerated warehouse	49,500	1
Food Service	Fast Food Restaurant	2,500	1
	Sit-down Restaurant	5,500	1
Apartment	Mid-rise Apartment	33,700	4
	High-rise Apartment	84,360	10

Source: Pacific Northwest National Laboratory, 2014

In addition, ambient operating conditions have significant impacts on the performance of many mechanical systems. To help evaluate these impacts, ASHRAE, in its Standard 169, developed 19 standardized U.S. domestic and global climate zones and requirements for these various zones. These zones were re-evaluated in 2013 using updated weather data (ASHRAE, 2013b). The nine main climate zones are further divided into 19 sub-climate zones: "a" for humid, "b" for dry, and "c" for marine. The climate zones for the United States are shown below in Figure A1.2.

Figure A1.2 – U.S. Climate Zones



Source: ASHRAE, 2013b

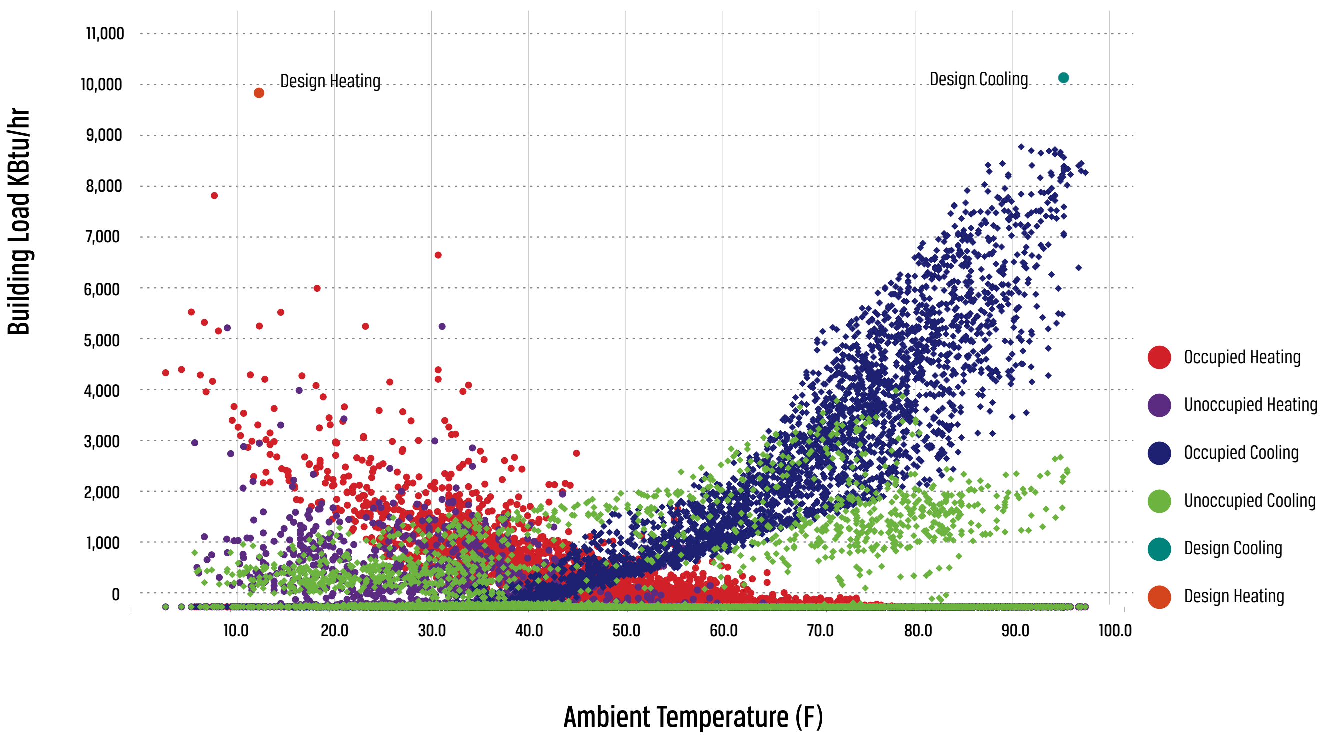
Examining the load profiles of a few prototype buildings is helpful to understand some of the issues related to maximizing energy efficiency and the need for a systems approach—particularly with regard to efficiency metrics.

a) Large Office Building

For example, Figure A1.3 shows a building load profile for a large office building in Baltimore, MD, which is in climate zone 4a (mixed humid). This typical large office building, when occupied, operates in a cooling mode even when it is cold outside—down to 36 degrees Fahrenheit (F)—because of the significant heat emitted from the internal plug loads, miscellaneous loads, lighting, and other internal mechanical equipment. To save on cooling costs, the compressor could be shut off and outside air brought in for "free cooling" using equipment called "economizers," when the outside temperature is low enough. However, current building efficiency metrics do not include the benefits of economizers and free cooling, despite the fact that many buildings are required to have economizers.

Note that there is considerable overlap of heating and cooling. This is due to the fact that interior parts of the building operate in a cooling mode during most of the year, while the perimeter of the building can require heating due to building envelope heat transfer losses. Heat is also required to warm ventilation air brought in from the outside, as required by ASHRAE 62.1. Many systems approaches can be used to address the re-heating of ventilation air, for example through re-setting supply air or the temperature in relevant zones, when a building is occupied, and control/management methods, such as "demand controlled ventilation" (automatic adjustment of ventilation equipment according to occupant choice). Additional options include transferring heat from cooling to heating zones and recovering energy from exhaust systems. These factors are not reflected in the efficiency metrics that are used today for HVAC&R equipment, but are aspects that could be included in a systems approach to efficiency.

Figure A1.3 – Large Office Building Load Profile – Zone 4a[44]

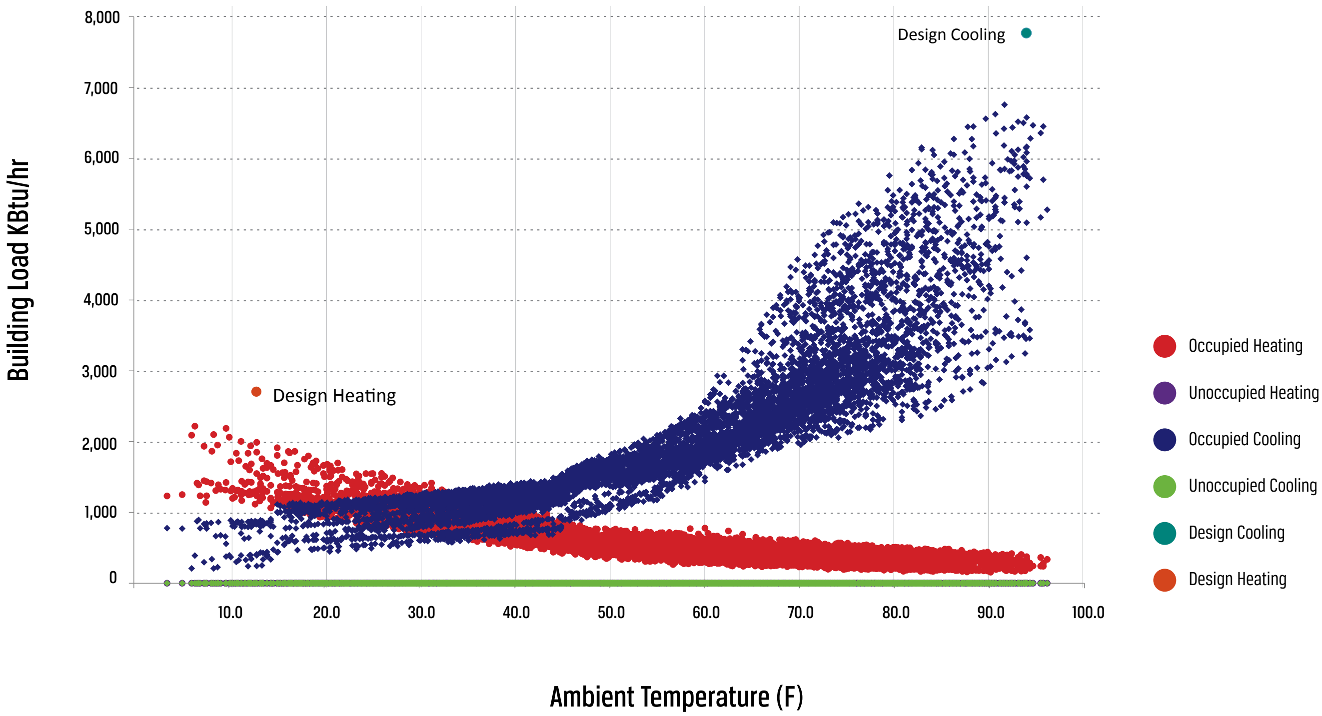


b) Large Hospital

Another prototype building that provides a useful example is a large hospital. The load profile for a hospital is considerably different from that of a commercial office building. Hospitals have larger air movement and ventilation requirements, and very high internal plug and miscellaneous loads. Figure A1.4 shows the load profile for a hospital in Baltimore. This building, unlike the office building, is occupied 24 hours/7 days a week, and it requires that significant cooling occur even down to the lowest outside air temperature, as well as heating up to very high outside air temperatures. Thus, such a building offers significant opportunities for energy savings through the use of air or water economizers, energy recovery from ventilation air, and transferring recovered energy from cooling zones to heating zones.

44 Load profile is based on ASHRAE 90.1/PNNL benchmark model for 2010 ASHRAE 90.1 Standard, compliant products.

Figure A1.4 - Commercial Hospital Load Profile - Baltimore Zone 4a[45]



These two examples illustrate opportunities to design systems approaches to save energy in various types of commercial buildings, based on their specific energy load profiles. The opportunities include using system enhancements such as economizers, energy recovery, evaporative cooling and other hybrid system approaches that are not considered in any minimum efficiency metrics today. Significant opportunities also exist to factor in "intelligent" control devices and/or other technologies or capabilities, such as demand ventilation, variable speed fans, supply air reset, static pressure reset, and variable water flow, which also are not reflected in current efficiency metrics.

45 Load profile is based on ASHRAE 90.1/PNNL benchmark model for 2010 ASHRAE 90.1 Standard, compliant products.

APPENDIX 2

Additional Real-World Examples of a Mechanical Systems Efficiency Approach

Example 1: Chilled Water System

For a large building using a chilled water system, one could examine the chiller, cooling tower, air handler, and pumps as a system. An example of this approach is shown in Figure A2.1.

Today, efficiency is "defined," or analyzed, only at the component level for the chiller and the cooling tower fan power, as shown by Option 1. For the chiller, efficiency is measured using full load and partial load metrics, based on a single chiller using standard average rating conditions. The metric for the cooling tower is based only on a full load, and only includes the power of the fan for a given condenser water flow rate. This approach does not take into account the sizing of the cooling tower, the impact of pump power and control, nor the air handler and the terminals in occupied spaces. It also does not factor in economizers, chilled water temperature reset, and other control methods or systems often used in buildings.

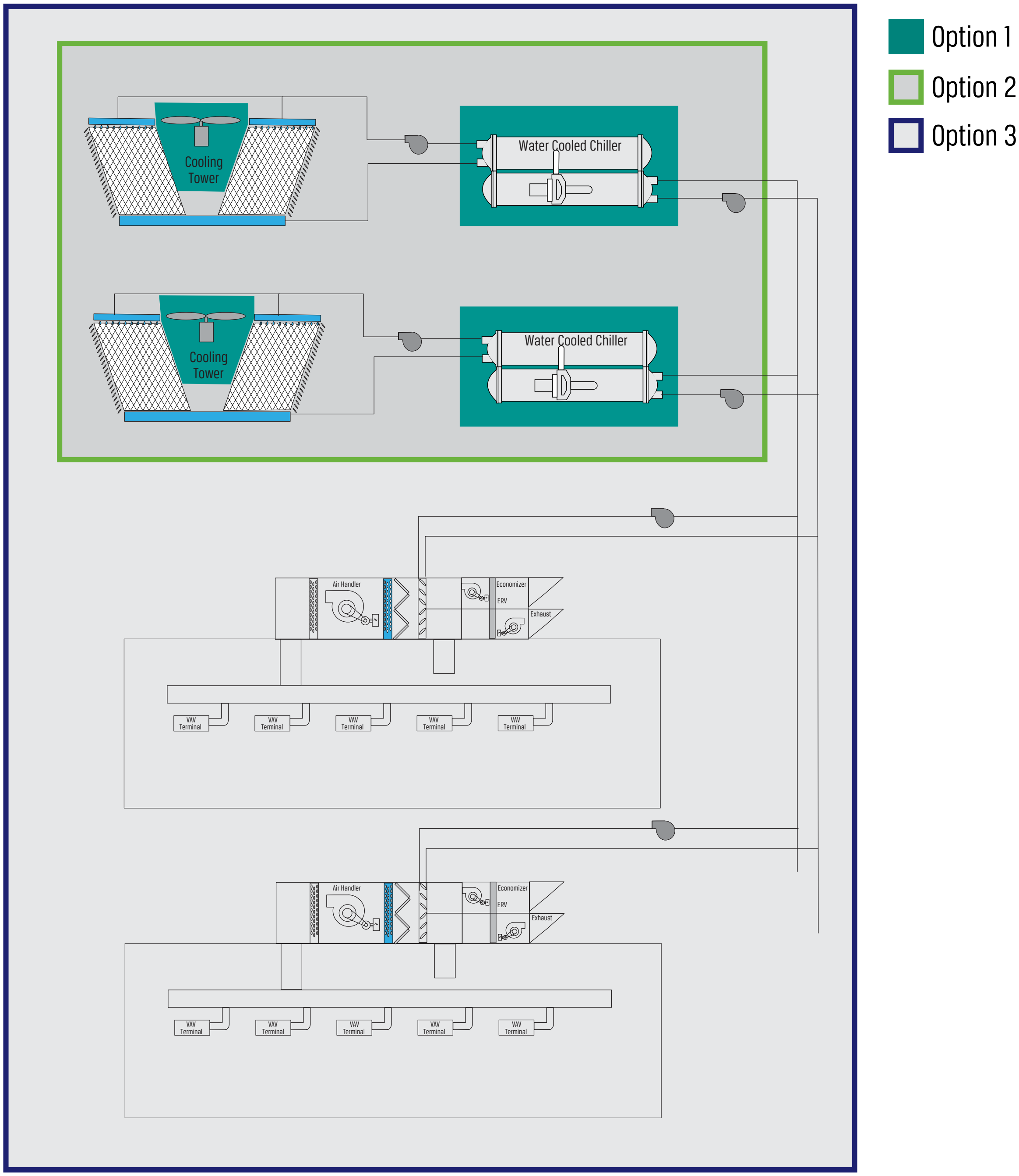
Moving toward a subsystem approach would involve incorporating additional portions of the system for energy management and performance analysis purposes. For example, Option 2 would consist of a subsystem approach for which the efficiency of the chiller, cooling tower, and pumping power would be considered; it would not factor in system features, such as airside economizers, space temperature reset, air handler efficiency, fan power, and controls. This type of approach could be implemented using a common overall climate zone condition and an average benchmark building. However, a better strategy would be to implement such an approach at a regional level, where factors pertaining to performance and equipment sizing can be addressed and analyzed.

Option 3 would consist of a full system approach, in which the chiller, cooling tower, pumps, air handler, air distribution terminals, and all components of a complete HVAC system would be included in the analysis.

To implement this type of systems approach will require the development of tools that are capable of conducting an annual analysis of the system as well as HVAC components. These do not yet exist, but work is underway at ASHRAE to develop technical models using the new ASHRAE 205 Standard; the AHRI Systems Working Group is developing systems-oriented tools.

To establish minimum efficiency targets, one concept being considered is to develop a baseline subsystem or system definition, which would factor in all of the current minimum efficiency standards where they exist and would rely on industry best practices, where such standards do not yet exist. This would then become the baseline system, and a proposed system would be required to use less energy when run through the simulation tool to show compliance.

Figure A2.1 – Typical Chilled Water System Diagram[46]



46 Figure developed by Richard Lord to demonstrate the Subsystem and Systems approach for the AHRI Systems Working group chilled water benchmark system.

Example 2: Commercial Rooftop Air Conditioning System

Another common system that is used in many commercial buildings is a packaged rooftop air conditioning system. Until 2010, the only metric used for these products was a full-load EER. In 2010, ASHRAE Standard 90.1 added the IEER metric. DOE will begin using the IEER as its regulated metric, beginning in 2018.

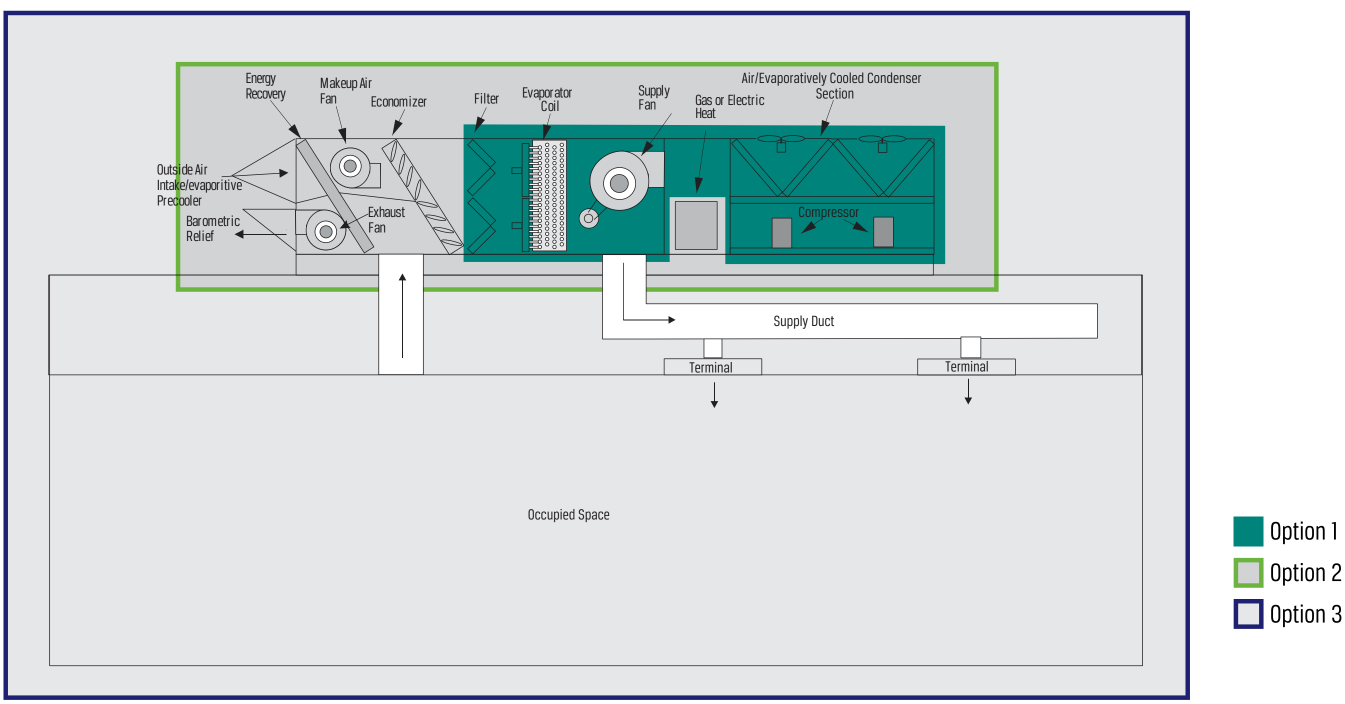
Figure A2.2 illustrates a typical rooftop AC system configuration, represented by the outlined box in pink, labeled Option 1. The current metrics used for this level of analysis are EER and IEER, which address the efficiency of a refrigeration system and indoor fan at common rating conditions.

Option 2, represented by the green box, also takes into account the impact of the economizer, energy recovery, ventilation fans, and some controls. A metric developed to include these effects could either be based on U.S. average conditions or—even better—on each of the climate zones.

Option 3 includes the full commercial rooftop air conditioning system, including terminals and controls options, such as demand ventilation, static pressure reset, and supply air reset.

Efficiency metrics for Options 2 and 3 will need to be developed and modeled. Computerized tools will likely be required to use these options at regional levels.

Figure A2.2 – Commercial Rooftop Air Conditioning System Diagram[47]



47 Figure developed by Richard Lord to demonstrate the Subsystem and Systems approach for the AHRI Systems Working group chilled water benchmark system.

APPENDIX 3
Building Energy Codes

The EIA estimates that 18 percent of the U.S. buildings that will be in place in 2030 have yet to be built. Since it is easier and more cost-effective to incorporate energy efficiency improvements during the initial design and construction of a building, and a typical new building may last for many decades, energy codes—in combination with other market-oriented strategies to encourage energy-efficient new construction—have great potential to yield cost-effective energy savings.

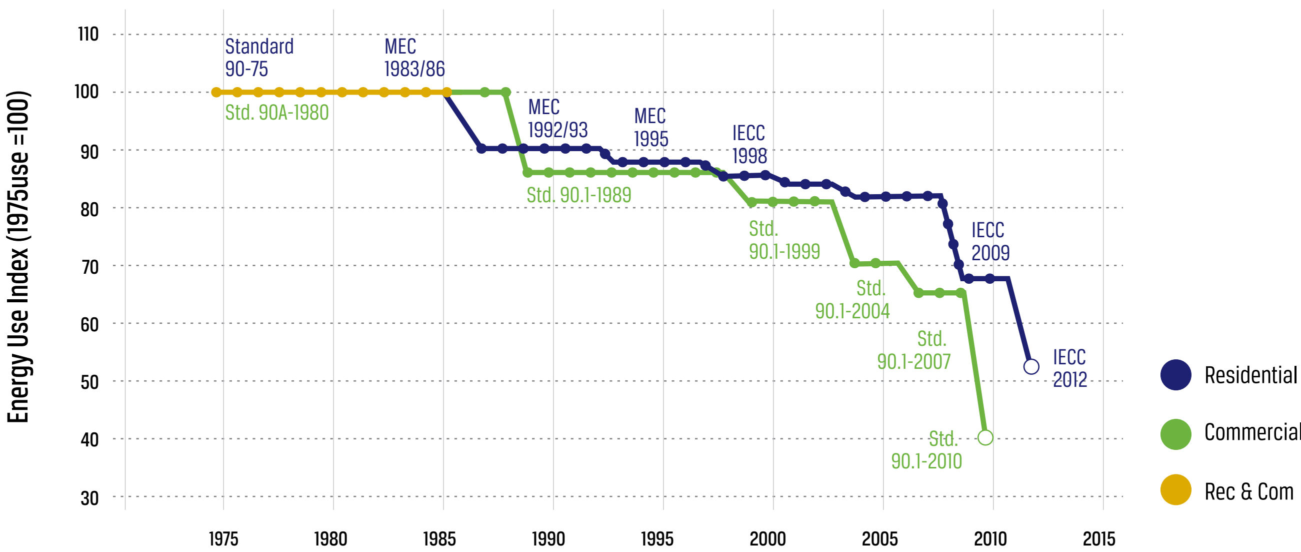
Building energy codes have long been a cornerstone of U.S. energy policy. Energy codes were first introduced nationally during the energy and economic crises of the 1970s, first in California under the 1974 Warren-Alquist Act, which directed the new California Energy Commission to set the "Title-24" mandatory efficiency standards for new homes and commercial buildings (Cal. Pub. Res. Code §25000-25009). Other states soon followed suit. At the federal level, a 1978 provision amended the Energy Policy and Conservation Act (EPCA) of 1975, which required states that received federal aid to create mandatory programs, including energy conservation standards for new commercial construction (U.S. DOE, 2010).

While building codes govern a range of building characteristics other than energy efficiency (e.g., structural, mechanical, and electrical features, among others), the primary energy efficiency provisions are contained in two model energy codes developed by non-governmental organizations, with extensive input from stakeholders. These are the International Energy Conservation Code (IECC), developed by the International Codes Council (ICC) for both residential and commercial[48] buildings, and ASHRAE Standard 90.1 for commercial buildings. Both of the model energy codes are updated on a regular three-year cycle, and ASHRAE Standard 90.1 is also open to a "continuous maintenance" process which allows modifications to be made any time during the update cycle.

Figure A3.1 shows the efficiency improvements in ASHRAE Standard 90.1 and IECC since the enactment of EPCA. Of course, these gains in the efficiency of the model code only translate into energy savings in actual buildings once the model code (or equivalent) is adopted and enforced by state and local agencies.

48 "Commercial" buildings in this context include medium- and high-rise residential buildings of four or more stories.

Figure A3.1 – Efficiency Improvements in ASHRAE Standard 90.1 and IECC (1975-2012)



Source: Sterner, 2014.

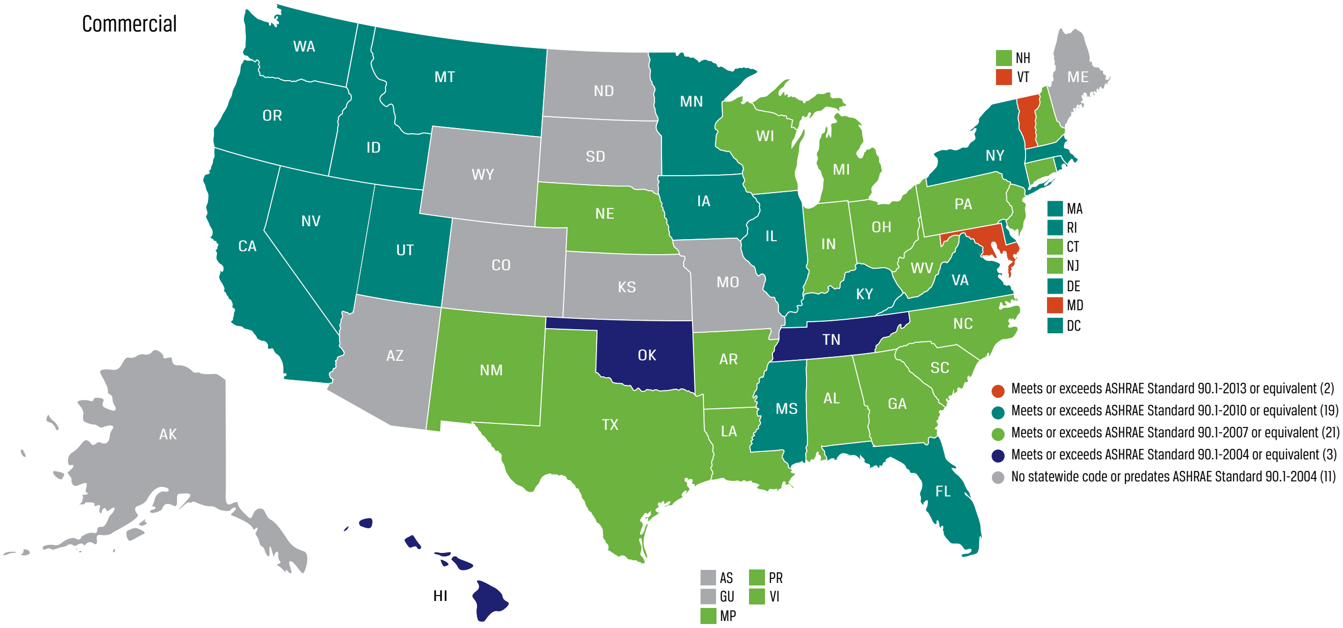
Under the Energy Policy Act of 1992, DOE reviews new residential and commercial building energy efficiency standards created by the IECC and ASHRAE (Pub. L. 102-486). Once DOE publishes a final "positive determination" that the new standard is more energy efficient than the previous one, states have two years to update their building energy codes and—for commercial building codes only—to certify to DOE that the state code meets or exceeds the new model code. Different states and localities adopt and enforce different versions of the model building energy codes—and some states have developed their own energy codes independent of the model codes. As a result, energy efficiency code requirements may vary by state and locality.

While there is no penalty under federal law if a state fails to meet this requirement, under the American Recovery and Reinvestment Act of 2009 (ARRA 2009, Public Law 111-5), states were provided incentives to update their building energy efficiency standards to meet or exceed ASHRAE 90.1-2007 and IECC 2006, which many states have done.

In September 2014, DOE issued a positive determination regarding ASHRAE 90.1-2013 and found it to yield national energy cost savings in commercial buildings of approximately 8.7 percent over the 2010 Standard, as well as 8.5 percent source energy savings, and 7.6 percent site energy savings (DOE, 2015c). These findings (i.e., this positive DOE determination) mean that states will be required to review and update the energy efficiency-related provisions of their commercial building codes to meet or exceed Standard 90.1-2013, and to certify that they have done so, by September 2016.

As of September 2015, 16 states' energy codes meet or exceed ASHRAE 90.1-2010, while six states have adopted energy codes that will meet or exceed ASHRAE 90.1-2013.[49] Most states are enforcing commercial building energy efficiency codes that were published before 2010 (ASHRAE 90.1-2007 or IECC 2009).

Figure A3.2 – State Energy Codes



Source: Building Codes Assistance Project, 2016

The adoption rate of the latest 2013 version has been slower than the adoption rate of the previous 2010 version, which in turn was adopted more slowly than the 2007 version. States are typically slow to adopt the latest building codes because of a lack of resources, such as a full time energy office. California has demonstrated that having such an office (i.e., the California Energy Commission) leads to the more rapid adoption and implementation of policies and codes that can help reduce per capita energy consumption.

The potential energy savings from building energy codes can be significant. For example, a March 2014 PNNL study[50] estimated the following increase in national energy savings from energy codes published to date, projecting these impacts into the future based on a number of assumptions (Livingston et al., 2014). Note that these numbers do not reflect the total impact of building energy codes, rather, the increased savings due to DOE efforts to support code improvements in stringency and to work with states and local jurisdictions to increase the rate of code compliance. Even though these estimates may thus represent a lower-bound estimate of total past and projected savings from codes, they suggest the magnitude of potential efficiency improvements if the model energy code stays on a path of continuous improvement, if states are encouraged to promptly adopt the latest model codes, and if state and local jurisdictions devote adequate resources to code implementation, training, and enforcement.

49 Building Codes Assistance Project, http://www.energycodesocean.org/code-status-commercial. To update this map, which shows codes currently in effect (not just adopted): as of February 2016, three more states had adopted ASHRAE 90.1-2013, according to DOE at https://www.energycodes.gov/status-state-energy-code-adoption.

50 Note: These numbers only include savings where DOE is providing assistance to states. A few large states, such as California and Florida, are not included.

Table A3.1 – Summary of Energy and Cost Savings from BECP Energy Code Activities

	Site Energy Savings,[a] quads	Primary Energy Savings [b] quads	FFC Energy Savings,[c] quads	Energy Cost Savings, NPV, billion 2012$
Historical				
Annual in 2012	0.2	0.48	0.5	5.0
Cumulative 1992-2012	2.0	4.0	4.2	44.6
Projected, 2013-2040 Construction				
Annual in 2040	1.2	2.2	2.3	5.2
Cumulative 2013-2040	22.0	20.1	41.6	185.7
BECP Total				
Annual in 2040	1.2	2.2	2.3	5.2
Cumulative 1992-2040	24.0	44.1	45.7	230.3

(a) *Site energy savings represent direct energy savings to the consumer. Site energy savings multiplied by the energy price represent energy cost savings to the consumer.*

(b) *Following the analysis methodolgy used by DOE's Appliance and Equipement Standards Program, site energy savings were first converted to the source energy terms, which includes energy used in generation, transmission, and distribution (primary energy).*

(c) *Energy used further "upstream" in the mining, processing, and transportation of fuels cycle was calculated using the NIA PLUS model and added to the primary energy savings to yield full-fuel-cycle (FFC) energy savings.*

Source: Livingston et al. 2014

Note that commercial buildings may contain a significant amount of equipment that uses energy, but is not currently regulated by building codes or by appliance/equipment energy efficiency standards. Examples include computers and other office equipment, data centers, and commercial cooking equipment. Thermal loads and ventilation requirements for these "process loads" or "plug loads" can significantly affect other building systems, notably HVAC equipment. To optimize the various building systems, additional equipment and systems should be considered explicitly in codes and standards (see the Section 2.3.1 of this report on "Miscellaneous Energy Loads").

For the energy code development process to address building systems in an integrated fashion, one limitation has been the traditional "silo" approach to developing code requirements, with experts in specific areas (e.g., insulation, windows, HVAC, lighting) focused on these individual building components. Existing high-performance building standards, such as ASHRAE Standard 189.1,[51] take a more holistic view. In the future, these approaches should become part of the process of updating baseline energy codes such as Standard 90.1.

51 Standard 189.1 addresses site sustainability, water use efficiency, energy use efficiency, indoor environmental quality, and the building's impact on the atmosphere, materials, and resources. This standard touches on each of these areas, as well as a separate section related to plans for construction and high-performance operation.

APPENDIX 4

Appliance and Equipment Efficiency Standards

Minimum efficiency standards for appliances and other energy-using equipment have been applied at the federal level since Congress passed the National Appliance Energy Conservation Act of 1987.52. This law was subsequently amended in 1992, 2005, and 2007 to expand the universe of covered appliances and require new DOE rulemakings to set minimum energy efficiency standards for these appliances. In addition to these federal appliance standards, efficiency standards at the state level date back to California's Warren-Alquist Act (SB 1575) passed in 1974 (California Energy Commission, 2016).

As part of this law, if DOE sets a federal energy efficiency standard for an appliance, individual states are "pre-empted" from setting their own efficiency standard for that particular "covered" appliance. This policy prevents multiple states from creating multiple standards for the same appliance, which could result in much higher costs for manufacturers and consumers. These standards are primarily applied at the level of individual pieces of equipment, but opportunities remain to capture additional systems-level savings as discussed below.

For many products that are used in commercial buildings, there is a multi-step process. First, new or updated equipment efficiency requirements are analyzed for feasibility and cost-effectiveness, reviewed, and then voted on by the ASHRAE 90.1 committee (after going through the appropriate subcommittee review) on a consensus basis. Second, the new or updated requirements are published for a public review. After public comments are received and incorporated, the committee may make revisions (and release the revisions for public review) or publish the original proposed changes. After resolving any comments, the new or updated requirements are published in the next version of ASHRAE Standard 90.1 (or a supplement). After the next version of ASHRAE Standard 90.1 (or supplement) is published, DOE reviews the new or updated equipment efficiency requirements and, under federal law, has the option of accepting the ASHRAE values or increasing the stringency based on a DOE analysis of energy savings and

52 While Congress had enacted the National Energy Conservation Policy Act in 1978 to require DOE to issue federal appliance standards for 13 appliances, from 1982 to 1983 the Department proceeded to issue a series of "no standard-standards" while simultaneously approving waiver requests from several states that allowed such states to issue their own appliance standards. After DOE's "no standard" standards were invalidated by the D.C. Court of Appeals, Congress enacted the 1987 National Appliance Energy Conservation Act to establish specific federal efficiency standards for 11 appliances (See *Report on the Activity of the Committee on Energy and Commerce for the 99th Congress*, (H. Report 99-1038), pages 248-250, and *Report on the Activity of the Committee on Energy and Commerce for the 110th Congress* (H. Report 100-1114), pages 103-4.) This law also generally preempted state standards for appliances covered by federal standards.

cost-effectiveness.

For many years, DOE missed many statutory deadlines set by Congress for the issuance of new or revised appliance efficiency standards. This led to litigation that ultimately forced DOE to move more quickly on standards, as well as to legislative action that required the Department to report to Congress regularly on the backlog of appliance standard-setting activities, and to take action to eliminate that backlog. When Congress passed the Energy Policy Act of 2005 (EPACT-05), it also required DOE to report periodically on actions taken to comply with the standards-setting deadline set forth in that Act. Over the last decade, DOE has responded by accelerating the pace of setting these appliance standards. In its August 2014 report to Congress, DOE indicated that "in total, action has been finalized for 22 of the original 22 backlogged products subject to a consent decree" (U.S. DOE, 2014b).

As a result of increasing efficiency standards, some appliances are close to reaching their maximum efficiency levels on a component basis. For example, with fluorescent lamps, in the 2014 rulemaking, DOE determined that the maximum increase in efficiency between the most recent (2012) baseline and the maximum technology (or "max tech") efficient product ranged from 2.9 to 4.1 percent (10 C.F.R. § 430 2014). With other products, the median paybacks of new efficiency standards have increased significantly, as have the estimated percentages of consumers with higher life-cycle costs rather than net cost savings from a more efficient appliance.

Current Status

DOE's appliance and equipment energy efficiency program currently covers more than 60 products, which account for about 90 percent of home energy use, 60 percent of commercial building energy use, and about 30 percent of industrial building energy use. As a result of standards currently in place, DOE reports that American consumers saved about $63 billion on their utility bills in 2015 (U.S. DOE, n.d. c). Since the beginning of 2009, 40 new or updated standards have been issued, which DOE reports will help increase annual savings by nearly 75 percent over the next decade. By 2030, it is estimated that cumulative operating cost savings from all standards in effect since 1987 will reach nearly $2 trillion, with a cumulative reduction of about 7.3 billion tons of carbon dioxide emissions, equivalent to the annual greenhouse gas emissions of 1.5 billion automobiles. Some examples of appliances and equipment covered by DOE's appliance standards include: refrigerators and freezers, room air conditioners, central air conditioners and heat pumps, commercial air conditioners and refrigeration, water heaters, furnaces, dishwashers, clothes washers and dryers, kitchen ranges and ovens, pool heaters, light bulbs, luminaires, fluorescent lamps and ballasts, ceiling fans, and dehumidifiers.

In recent years, DOE has increased the number of "covered" products that it is regulating. Presently, DOE is engaged in or proposing rulemakings to update the current energy efficiency standards for a wide range of consumer and commercial appliances, including:

- Battery chargers and external power supplies;
- Residential furnaces;
- Ceiling fans;

- Residential air conditioners and heat pumps;
- Portable air conditioners;
- Commercial/industrial pumps;
- Commercial/industrial fans and blowers;
- Computer and backup battery systems; and,
- Kitchen ranges and ovens.

Some of these rulemakings are in an early "Notice of Proposed Rulemaking" stage, while others are in later stages of the regulatory process. In other cases, DOE is examining new or revised test procedures to measure the efficiency of a particular appliance or piece of equipment.

In addition to these rulemakings, some appliances or equipment not currently covered by DOE's federal standards could become subject to new standards in the future, either through the enactment of new legislation or through DOE rulemakings. For example, some uncovered "plug loads" discussed in this SEI report could become the subject of future rulemakings.

DOE also might be able to make use of its appliance standard-setting authority to promote greater building system efficiency. It could be argued that a "covered product" on the consumer section of EPCA and industrial "covered equipment" could be read to include a building system or subsystem comprised of various energy consuming articles or components. EPCA's consumer and industrial equipment sections give the Secretary authority to define articles as covered beyond those that have been specifically enumerated by the Congress in the Statute.

State Laws and Regulations

Some appliances are not currently regulated by federal efficiency standards, but are regulated in some states. Congress or DOE might decide that some such appliances should be subject to federal standards in order to ensure uniformity rather than as many as 50 different ones.[53] In addition, federal standards can lead to economies of scale, which lowers the costs of improving efficiency for manufacturers and consumers.

Technical, Market, and Policy Barriers

Appliance and equipment efficiency standards are implemented and enforced at the point of manufacture, so such standards can capture only some system efficiency benefits. For example, such standards only address the regulated equipment and generally do not address other unregulated system components that are sold separately, usually by separate manufacturers. Likewise, standards do not address site-specific installation issues. In both cases, creative approaches (addressed throughout the SEI report) can sometimes be used to help solve system-oriented issues.

Appliance and equipment standards are based on standardized test procedures specific to each type of equipment; if the test

53 This point is illustrative, as it is highly unlikely all states will set standards. Currently 12 states have standards on at least one product (Gilleo et al. 2015) [ACEEE State Scorecard].

procedure does not reflect certain aspects of a system, then the standard will not address those aspects. Thus, amending test procedures to be broad enough to address key systems issues will be a critical first step to incorporating a systems approach into the current standards regime. In addition, testing labs must be able to test the entire "system" on a repeatable basis within a low range of measurement error (e.g., +/- 3 percent).

Because system efficiency can be complex, efficiency metrics will also need to be developed that can account for varying conditions that exist in commercial and residential buildings. For example, the age, condition, and length of ductwork plays a large role in the system efficiency of fan systems, heating systems, and cooling systems. Similarly, the age, condition, and length of pipe has a large impact on the system efficiency of service water and hydronic heating systems.

Addressing Systems Efficiency Using Efficiency Standards

Increasingly, policymakers, the buildings industry, and efficiency advocates are looking for opportunities to address system issues, recognizing the limitations discussed above. A few examples illustrate what has and can be accomplished in this regard.

Walk-in coolers and freezers: Initial standards for these products were set by Congress in the Energy Independence and Security Act (EISA) of 2007, based on standards that had been previously established in California. These standards consisted of prescriptive requirements for product components such as insulation levels of walls, ceilings, and doors, evaporator and condenser fan motor requirements, and interior lighting equipment. DOE revised these standards in 2014 to include multiple aspects of the system, including the refrigeration system. Under the final rule, DOE created a maximum annual "walk-in" energy factor for the refrigeration systems (in Btu/W-h), a minimum R-value for the panels, and a maximum energy consumption for the doors (in kWh/day). A manufacturer will sometimes sell many parts of the system, and other times will sell only some components. In these cases, the new DOE test procedure assumes that components not supplied by a manufacturer will be less efficient than typical components, providing an incentive for manufacturers to package their equipment with efficient components so that that they can get credit for efficient components and not be penalized for inefficient ones. As a result of a settlement from a lawsuit brought by AHRI over the final rule, a negotiated rulemaking process was established that addresses certain aspects of this final rule.

Rooftop commercial air conditioners: Currently, these products are regulated based on EER, which is a measure of unit efficiency on a hot day (95 degrees F). In a recently finalized update to this standard, all parties have agreed to use IEER, which is an average of efficiency under four different load conditions. Use of IEER addresses many more aspects of system efficiency and captures additional energy savings, since most air conditioners operate predominantly at conditions below 95 degrees F. In the analysis that led to the development of this standard, impacts of the standard on fan energy use were considered to capture the impacts of improved controls, even though not all fan energy use is captured in the test procedure for this equipment (i.e., fan energy is only counted when the refrigeration system is operational). Finally, the parties agreed to work together to incorporate into a future test procedure fan energy use when the refrigeration system is not operational, as well as economizer use. For efficiency standards published in ASHRAE 90.1-2013 that apply to other cooling equipment, both EER and IEER requirements exist that will help ensure that energy savings are achieved throughout the calendar year as well as during peak cooling conditions.

Pumps: In another recent rulemaking, industry and efficiency supporters negotiated a performance standard and test procedure that address not just the pump, but also the motor, drive, and other components that are typically installed together with the pump. In this way, customers are encouraged to consider the broader system in selecting pump packages that better match their needs and thus achieve greater system efficiency. Since some pumps (especially for replacements) are sold solely as the "bare pump," the standard also continues to ensure a minimum efficiency performance level for pumps and motors as individual components.

Next Steps

The three examples above indicate what can be done when DOE, manufacturers, efficiency supporters, and other stakeholders collaborate to seek ways in which to include systems efficiency issues in standards and/or standards development processes. Incentive programs can facilitate these efforts. For example, the same test procedure used for pump standards can be used for pump incentive programs. Incentive programs for rooftop air conditioners can switch to the IEER metric and can include fan energy savings when estimating energy savings and conducting cost-effectiveness tests.

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