LBNL- 1006983

Electricity end uses, energy efficiency, and distributed energy resources baseline: *Commercial Sector Chapter*

Authors:

Lisa Schwartz, Max Wei, William Morrow, Jeff Deason, Steven R. Schiller, Greg Leventis, Sarah Smith, and Woei Ling Leow, Lawrence Berkeley National Laboratory

Todd Levin, Steven Plotkin, and Yan Zhou, Argonne National Laboratory[1]

Joseph Teng, Oak Ridge Institute for Science and Education

[1] Transportation section

Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory

Energy Technologies Area

January 2017

This work was supported by the Department of Energy, Office of Energy Policy and Systems Analysis, under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Acknowledgments

The authors thank the U.S. Department of Energy Office of Energy Policy and Systems Analysis (EPSA) for sponsoring and guiding this work, including John Agan, Erin Boyd, Natalie Kempkey, and Jenah Zweig. The authors also thank the following organizations that provided comments on the draft report: DOE's Office of Energy Efficiency and Renewable Energy (EERE), the Energy Information Administration (EIA), the Environmental Protection Agency (EPA), the National Association of Regulatory Utility Commissioners (NARUC), the National Association of State Energy Officials (NASEO), the Regulatory Assistance Project (RAP), and the American Council for an Energy-Efficient Economy (ACEEE).

In addition, the authors appreciate the peer reviewers who provided valuable input: *for the residential sector*, Craig Christensen and Eric Wilson, National Renewable Energy Laboratory (NREL), and Richard Faesy, Energy Futures Group; *for the commercial sector*, Michael Deru and Shanti Pless, NREL; *for the industrial sector*, Kelly Perl, Energy Information Administration, Diane Graziano and Danilo Santini, Argonne National Laboratory (ANL), and Keith Jamison, Energetics; *for the transportation sector*, John German, International Council on Clean Transportation and Danilo Santini, ANL; *for distributed energy resources*, Genevieve Saur and Ben Sigrin, NREL, and Peter Cappers, Lawrence Berkeley National Laboratory; and for *evaluation, measurement, and verification*, Jane Peters, Research Into Action, and Ralph Prahl, Ralph Prahl and Associates and Steve Kromer, Kromer Engineering. Finally, we are grateful for copy editing support by Mark Wilson.

Any remaining errors, omissions, or mischaracterizations are the responsibility of the authors.

Scope and Organization

This report was developed by a team of analysts at Lawrence Berkeley National Laboratory, with Argonne National Laboratory contributing the transportation section, and is a DOE EPSA product and part of a series of "baseline" reports intended to inform the second installment of the Quadrennial Energy Review (QER 1.2). QER 1.2 provides a comprehensive review of the nation's electricity system and cover the current state and key trends related to the electricity system, including generation, transmission, distribution, grid operations and planning, and end use. The baseline reports provide an overview of elements of the electricity system. This report focuses on end uses, electricity consumption, electric energy efficiency, distributed energy resources (DERs) (such as demand response, distributed generation, and distributed storage), and evaluation, measurement, and verification (EM&V) methods for energy efficiency and DERs.

Chapter 1 provides context for the report and an overview of electricity consumption across all market sectors, summarizes trends for energy efficiency and DERs and their impact on electricity sales, and highlights the benefits of these resources as well as barriers to their adoption. Lastly it summarizes policies, regulations, and programs that address these barriers, highlighting crosscutting approaches, from resource standards to programs for utility customers to performance contracting.

Chapters 2 through 5 characterize end uses, electricity consumption, and energy efficiency for the residential, commercial, and industrial sectors as well as electrification of the transportation sector. Chapter 6 addresses DERs—demand response, distributed generation, and distributed storage.

Several chapters in this report include appendices with additional supporting tables, figures, and technical detail. In addition, the appendix also includes a separate section that discusses current and evolving EM&V practices for energy efficiency and DERs, approaches for conducting reliable and cost-effective evaluation, and trends likely to affect future EM&V practices.

This excerpt from the report focuses on the Commercial Sector. The table of contents included here shows the detailed scope of topics in the complete report. The full report is available at https://emp.lbl.gov/publications/electricity-end-uses-energy.

Description of Energy Models[a]

Unless otherwise noted, this report provides projections between the present-day and 2040 using the "EPSA Side Case," a scenario developed using a version of the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS). Since the EPSA Side Case was needed for this and other EPSA baseline reports in advance of the completion of EIA's Annual Energy Outlook (AEO) 2016, it uses data from EIA's AEO 2015 Reference Case, the most recent AEO available at the time. However, since AEO 2015 did not include some significant policy and technology developments that occurred during 2015, the EPSA Side Case was designed to reflect these changes.

The EPSA Side Case scenario was constructed using EPSA-NEMs,[b] a version of the same integrated energy system model used by EIA. The EPSA Side Case input assumptions were based mainly on the final release of the 2015 Annual Energy Outlook (AEO 2015), with a few updates that reflect current

[a] Staff from DOE's Office of Energy Policy and Systems Analysis authored this description.

[b] The version of the National Energy Modeling System (NEMS) used for the EPSA Side Case has been run by OnLocation, Inc., with input assumptions by EPSA. It uses a version of NEMS that differs from the one used by the U.S. Energy Information Administration (EIA).

technology cost and performance estimates, policies, and measures, including the Clean Power Plan and tax credits. The EPSA Side Case achieves the broad emissions reductions required by the Clean Power Plan. While states will ultimately decide how to comply with the Clean Power Plan, the Side Case assumes that states choose the mass-based state goal approach with new source complement and assumes national emission trading among the states, but does not model the Clean Energy Incentive Program because it is not yet finalized. The EPSA Side Case also includes the tax credit extensions for solar and wind passed in December 2015. In addition, cost and performance estimates for utility-scale solar and wind have been updated to reflect recent market trends and projections, and are consistent with what was ultimately used in AEO 2016. Carbon capture and storage (CCS) cost and performance estimates have also been updated to be consistent with the latest published information from the National Energy Technology Laboratory.

As with the AEO, the EPSA Side Case provides one possible scenario of energy sector demand, generation, and emissions from present day to 2040, and it does not include future policies that might be passed or unforeseen technological progress or breakthroughs. EPSA-NEMS also constructed an "EPSA Base Case" scenario, not referenced in this report, which is based primarily on the input assumptions of the AEO 2015 High Oil and Natural Gas Resource Case. Projected electricity demand values forecast by the EPSA Base Case and Side Case are very close to each other (within 3% by 2040). However, the values forecast by the EPSA Base Case are closer to those that were ultimately included in the AEO 2016 Reference Case.

EPSA Side Case data also are used when most-recent (2014) metrics are reported as a single year or are plotted with future projections. Doing so ensures consistency between current and forecasted metrics. Overlapping years between historical data and data modeled for forecasts are not necessarily equal. Historical data are revised periodically as EIA gathers better information over time, while forecasted cases, which report a few historical years, do not change once they are released to the public.

List of Acronyms and Abbreviations

Acronym / Abbreviation	Stands For
ACEEE	American Council for an Energy-Efficient Economy
AEO	Annual Energy Outlook
AMI	advanced metering infrastructure
AMO	DOE Advanced Manufacturing Office
ARRA	2009 American Recovery and Reinvestment Act
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEV	Battery Electric Vehicle
CAFE	Corporate Average Fuel Economy
CAISO	California ISO
CBECS	Commercial Buildings Energy Consumption Survey
CFLs	compact fluorescent lamps
CHP	Combined Heat and Power
CO^2	carbon dioxide
CPP	Clean Power Plan
CPP	Critical Peak Pricing
CPUC	California Public Utilities Commission
CSE	cost of saved energy
CUVs	crossover utility vehicles
DCLM	Direct Control Load Management
DER	Distributed Energy Resources
DOE	U.S. Department of Energy
DSM	demand side management
DSO	Distribution System Operator
EAC	DOE's Electricity Advisory Committee
EERS	energy efficiency resource standard
EIA	U.S. Energy Information Administration
EM&V	Evaluation, Measurement, and Verification
EMCS	Energy Management Control Systems
EPA	U.S. Environmental Protection Agency
EPSA	DOE Office of Energy Policy and Systems Analysis
ERCOT	Electric Reliability Council of Texas
ESCOs	energy service companies
FCTO	DOE's Fuel Cell Technology Office
FCV	Fuel Cell Vehicle
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
FFV	Ethanol Flex-Fuel Vehicle
FITs	feed-in tariffs
FRCC	Florida Reliability Coordinating Council
GDP	gross domestic product

Acronym / Abbreviation	Stands For
GHG	greenhouse gases
GWP	global warming potential
HEVs	hybrid electric vehicles
HOV	high-occupancy vehicle
HVAC	heating, ventilation, and air-conditioning
Hz	hertz
ICEs	internal combustion engines
ICLEI	International Council for Local Environmental Initiatives
ICT	information and communication technologies
IDM	Industrial Demand Module
IECC	International Energy Conservation Code
IEMS	Industrial Energy Management Systems
IL	Interruptible Load
INL	Idaho National Laboratory
IRP	integrated resource planning
ISO	Independent System Operator
ISO-NE	ISO-New England, Inc.
ITC	investment tax credit
kWh	kilowatt-hours
LBNL	Lawrence Berkeley National Laboratory
LCOE	levelized cost of electricity
LCR	Load as a Capacity Resource
LDV	light-duty vehicle
LED	light emitting diode
LEED	Leadership in Energy and Environmental Design
Li-ion	Lithium-ion
LMP	locational marginal pricing
LR	learning rate
LSE	load serving entity
MATS	Mercury and Air Toxics Standards
MECS	Manufacturing Energy Consumption Survey
MELs	Miscellaneous Electric Loads
MISO	Midcontinent Independent System Operator
MMWh	million megawatt-hours
MRO	Midwest Reliability Organization
MRO-MAPP	Midwest Reliability Organization-Mid-Continent Area Power Pool
MUSH	municipalities, universities, schools, and hospitals
NEMS	National Energy Modeling System
NERC	North American Electricity Reliability Council
NPCC	Northeast Power Coordinating Council
NPCC-NE	NPCC-New England

Acronym / Abbreviation	Stands For
NPCC-NY	NPCC-New York
NREL	National Renewable Energy Laboratory
NYISO	New York ISO
ORNL	Oak Ridge National Laboratory
PACE	Property Assessed Clean Energy
PC	personal computer
PCTs	programmable communicating thermostats
PEV	plug-in electric vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PJM	PJM Interconnection, LLC
PTC	production tax credit
PV	photovoltaic
QER	Quadrennial Energy Review
QTR	Quadrennial Technology Review
R&D	research and development
RD&D	Research, development, and deployment
RECS	Residential Energy Consumption Survey
RETI	Real estate business trust
REV	"Reforming the Energy Vision"
RFC	Reliability First Corporation
RTO	Regional Transmission Organization
RTP	real-time pricing
SDG&E	San Diego Gas and Electric
SEIA	Solar Energy Industries Association
SERC	Southeast Electric Reliability Council
SERC-E	Southeast Electric Reliability Council -East
SERC-N	Southeast Electric Reliability Council -North
SERC-SE	Southeast Electric Reliability Council -Southeast
SGIG	Smart Grid Investment Grant
SPP	Southwest Power Pool, Inc.
SSL	solid-state lighting
TBtu	trillion British thermal units
TOU	time-of-use pricing
TRE	Texas Reliability Entity
TRE-ERCOT	TRE-Electric Reliability Council of Texas
TWh	terawatt-hours
USDA	U.S. Department of Agriculture
V2B	vehicle-to-building
V2H	vehicle-to-home
VAR	volt-ampere reactive
VOS	value of shipments
VTO	DOE's Vehicle Technologies Office

Acronym / Abbreviation	Stands For
WECC	Western Electricity Coordinating Council
WECC-CA-MX	WECC-California-Mexico Power
WECC-NWPP	WECC-Northwest Power Pool
WECC-RMRG	WECC-Rocky Mountain Reserve Group
WECC-SRSG	WECC-Southwest Reserve Sharing Group
ZEV	Zero Emission Vehicle
ZNEB	Zero-Net Energy Building

Table of Contents

List of Figures

List of Tables

3 Commercial Sector

In this report, the *commercial sector* refers to nonresidential buildings and excludes energy transportation demands for the sector, such as commercial vehicle fleets or delivery trucks. The U.S. commercial buildings market comprises 87 billion square feet (ft^2) of floor space.[1] Buildings are of all sizes, ages, and construction; have locations in all climate zones; and serve a variety of purposes. Commercial buildings account for approximately 18% of total U.S. energy consumption, 35% of U.S. electricity consumption, and 18% of the nation's carbon dioxide (CO^2) emissions.[2] In 2013, the United States spent nearly $180 billion to provide energy services to these existing commercial buildings.[3] From 2008 to 2012, more than 300,000 new commercial buildings were constructed, comprising more than 5.7 billion ft^2.[4]

New building construction in each state must meet the building energy codes for that state (Section 3.6.1). These are statutory requirements that specify minimum building construction standards for components such as insulation and windows. End-use services in the commercial sector include heating, cooling, water heating, ventilation, cooking, lighting, refrigeration, personal computer (PC) and non-PC office equipment, and a category denoted "miscellaneous end-use loads" or "Other" end uses to account for all other, minor, end uses such as elevators, escalators, and medical/lab/security equipment.[a] Many end-use equipment types are subject to federal energy efficiency standards for appliances and equipment, which cover about 60% of commercial building energy use.[5]

Building categories in the commercial sector are assembly, education, food sales, food services, inpatient health care, outpatient health care, lodging, office buildings, mall-based mercantile, non-mall mercantile, services, warehouse and storage, public assembly, public order and safety, religious worship, Other, and vacant buildings.[b] "Other" buildings include airplane hangars, laboratories, telephone-switching facilities, agricultural facilities with some retail space, manufacturing or industrial facilities with some retail space, some data centers or server farms, and some water utility facilities and wastewater treatment plants.[c] The commercial sector thus includes the municipal government, state government, universities and colleges, kindergarten through grade 12 schools, and health care including hospitals category (Table 3.1).

---

[a] These "Other" end uses are included in CBECS. The *2015 Annual Energy Outlook* includes the following additional end uses in the "Other" sector: distribution transformers, municipal water services, lift trucks, and forklifts.

[b] See the CBECS Building Type Definitions for a description of building categories (accessed November 5, 2015): https://www.eia.gov/consumption/commercial/building-type-definitions.cfm.

[c] The allocation of some buildings between the commercial and residential sectors and the commercial and industrial sectors can be challenging to define. Electricity consumption data reported by EIA for the commercial sector are based on survey data from electricity suppliers (e.g., utilities), which are typically based on number of customer utility accounts. Thus, a mixed-use building with a single master meter that is on a commercial electricity rate is classified as a commercial building even if it has some residential units, while a mixed-use building, which has individually metered retail and residential units, will count toward both residential and commercial electricity consumption. A large data center or wastewater treatment plant that is connected to the grid at a high voltage is reported as an industrial site and not a commercial building.

Table 3.1. Commercial Sector Building Types

Building Type	Included in MUSH Sector?*
Education	Yes
Food Sales	
Food Service	
Health Care: Outpatient	Yes
Health Care: Inpatient	Yes
Lodging	
Mercantile (Enclosed/Strip Malls)	
Mercantile (Non-Mall Retail)	
Office	Government office buildings included
Other	
Public Assembly	
Public Order and Safety	Yes
Religious Worship	
Service	
Vacant	
Warehouse and Storage	

Municipality, University, School, Hospital (MUSH) buildings include government-owned buildings and thus could include some buildings from additional building types (e.g., vacant, warehouse, and storage buildings).

3.1 Key Findings and Insights

Findings:

- Growth in electricity sales in the commercial sector has slowed significantly in the last decade, and slow growth (about 0.7% per year) is projected through 2040 (Section 3.3).
- Electricity consumption is expected to comprise a slightly higher share of energy used in the commercial sector in 2040 compared to 2015 (55% vs. 53%) (Section 3.3).

Insight: While electricity intensity (kWh/ft^2) in the commercial sector is projected to slightly decrease, overall load is still projected to increase, pointing toward the need for continued attention to electricity efficiency.

Findings:

- "Other" is the fastest growing electricity end use in the commercial sector, followed by non-PC office equipment. Electricity consumption for lighting is declining (Section 3.3).

Insight: Efficiency policies and programs targeted at the commercial sector will need to evolve to address the drivers of future electricity consumption, which are not the same as the drivers of past consumption.

Findings:

- As in the residential sector, the lighting market is transforming to much lower electricity usage due to compact fluorescent lamps (CFLs) and LEDs. A DOE-sponsored forecast projects that LEDs will grow to 82% of commercial-sector lighting market share in 2030, saving a cumulative 18% of commercial lighting electricity usage from 2013 to 2030, relative to a no-LED baseline (Section 0).

Insight: A combination of technology and policy efforts has achieved great success in the lighting market. Lighting has been a mainstay of efficiency programmatic efforts. With the market in transition, energy efficiency programs and standards will shift to LED lighting as the dominant lighting technology.

Findings:

- Energy management control systems (EMCS) for heating, ventilation, and cooling (HVAC) are installed in only 12% of buildings smaller than 25,000 ft^2. These buildings represent about 35% of overall commercial floor space (Section 0).
- EMCS for lighting are installed in only 3% of buildings smaller than 25,000 square feet (ft^2) (Section 0).

Insight: EMCS in smaller buildings offer a significant opportunity for energy efficiency improvements. Understanding and overcoming adoption barriers are critical in this market segment.

Findings:

- Best available technology for heating, cooling, ventilation, lighting, water heating, refrigeration, and PC and non-PC equipment is estimated to save 46% of building energy intensity (primary energy per unit area). Of the remaining energy intensity, almost 50% is from Other uses (Section 3.3).
- With proper design, overall costs of new zero net energy buildings (ZNEBs) in the commercial sector can fall within the same range as conventional new construction projects (Section 0).
- Buildings designed for whole-building performance using advanced system-level modeling software often outperform buildings designed using less quantitative approaches, such as prescriptive guidelines (Section 0).

Insight: The Other category is a major opportunity for energy savings. In addition, careful building design using advanced system-level modeling can achieve high performance and greater cost-effectiveness.

Findings:

- The U.S. population is aging. The fraction of the population older than 65 years of age will increase from 14.9% in 2015 to 21% in 2040 (Section 3.3).

Insight: With an aging population, healthcare-building floor space is projected to grow at a faster annual rate (1.2%) between 2015 and 2040 than average floor space growth in the commercial sector (1.0%)

Findings:

- Retail electricity prices for the commercial sector are projected to rise from about $0.102/kWh in 2014 to about $0.114/kWh by 2040 (Section 3.4).

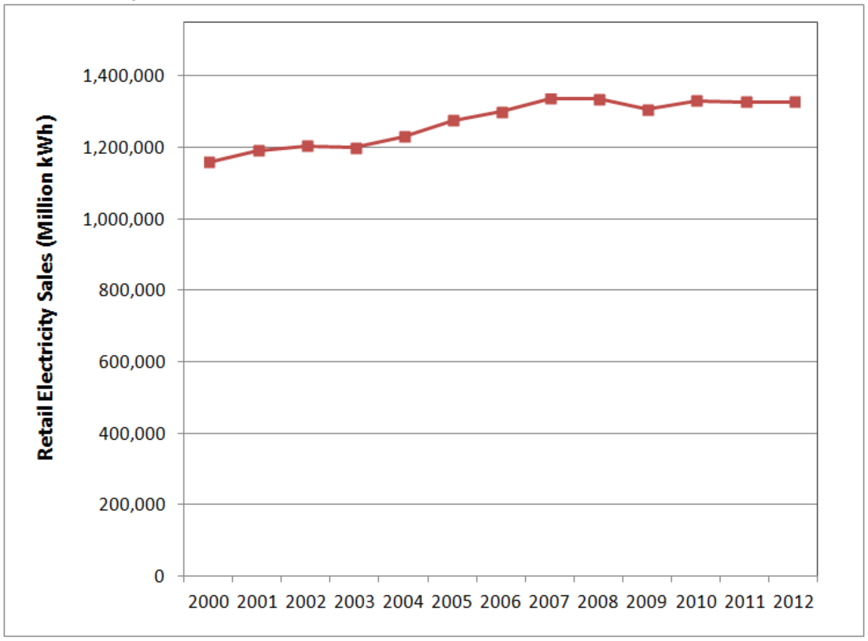
Insight: Increases in projected retail electricity prices for the commercial sector are modest, with a less than 13% increase in prices projected in 2040.

3.2 Characterization

Figure 3.1 shows retail electricity sales in the commercial sector since 2000. Sales have been flat in recent years, with higher sales growth tracking overall economic growth in the early 2000s. Recent analysis indicates that the major contributing factors to the change in commercial electricity consumption from 2008 to 2013 were savings from appliance and equipment standards and utility energy efficiency programs.[6]

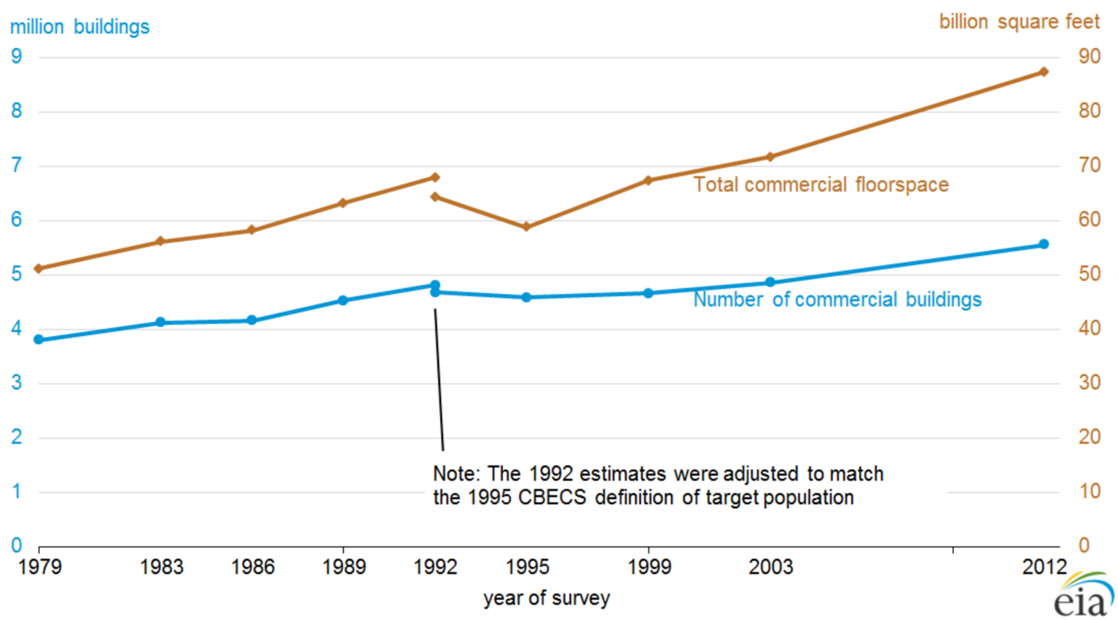
Floor space has increased more rapidly (2.2% per year from 2003 to 2012, as Figure 3.2 shows). In part, this is because new commercial buildings are larger, on average, than old commercial buildings (Commercial Appendix, Figure 7.17). Thus, overall electricity intensity (in kWh/ft^2) dropped by 8% from 2003 to 2012, largely driven by more energy-efficient end uses.

Figure 3.1. Retail electricity sales in the commercial sector from 2000 to 2012[7]



Commercial electricity sales have been fairly flat since 2007 after sharp periods of growth in the 1990s and mid-2000s.

Figure 3.2. Floor space trends and number of commercial buildings from 1979 to 2012[8]



Total floor space grew by 2.2% a year from 2003 to 2012, outpacing growth in new buildings.

3.2.1 By Building Category

Table 3.2 shows a breakdown of electricity consumption by building category and end use, highlighting the diverse nature of the commercial sector. The top row of the table shows the end-use fraction of consumed electricity for 2012, while the second row shows the same for 2003. The lower portion of the table provides the percent share of electricity consumption in 2012 for each building category and end-use pair. The right column shows the share of electricity consumption in 2012 by building category.

Office buildings and mercantile (including both malls and non-mall retail) each make up about 20% of electricity consumption, followed by education at 10%. Five building categories have between a 5% and 10% share of electricity consumption: health care (both inpatient and outpatient), lodging, warehouse and storage, food service, and public assembly (e.g., community centers, gymnasiums, and theaters).

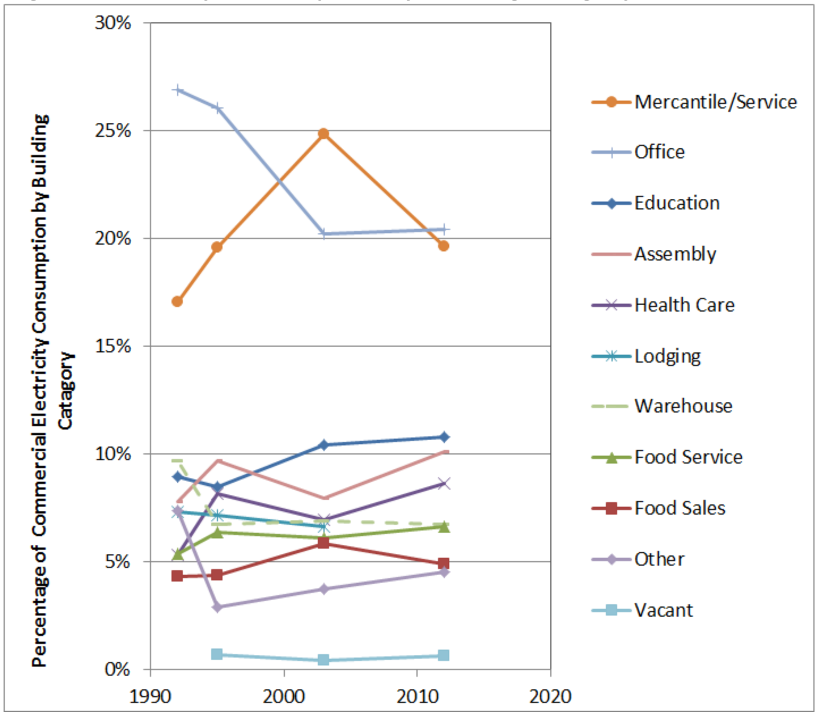
The second line of Table 3.2 shows the percentage of total consumption by end use in 2003. The share of lighting has dropped by more than 20% and space heating share by 2.7%. Lighting consumption has dropped in large part because of “increasing use of CFLs and LED bulbs as replacements for lower-efficiency incandescent bulbs,” while the large decrease in heating demand is “likely because of the warmer than average winter during the reference year (2012) and federal equipment standards."[9] Figure 3.3 shows the percentage of electricity consumption by building category from 1992 to 2012, and Commercial Appendix Table 7.6 has a summary of electricity consumption data by building category from EIA’s Commercial Buildings Energy Consumption Survey (CBECS) 2003 and CBECS 2012.**Table 3.2. Share of Electricity Consumption in the Commercial Sector by Building Category and End-Use Service, 2012**[10]

	Other	Lighting	Refriger-ation	Ventil-ation	Cooling	Compu-ters	Office Equipment	Cooking	Space Heating	Water Heating	Total by Building
% of Total Consumption (2012)	18.1%	17.1%	15.8%	15.8%	14.9%	9.5%	4.1%	2.2%	2.0%	0.5%	
% of Total Consumption (2003)	11.8%	37.8%	10.8%	12.3%	13.6%	4.4%	1.6%	0.6%	4.7%	2.4%	
% of Total Consumption, by Building Type and End Use (2012)											
Office	3.1%	3.5%	0.7%	5.0%	2.7%	3.9%	0.9%	0.0%	0.4%	0.0%	20.4%
Mercantile	2.2%	3.3%	4.5%	2.9%	2.1%	0.5%	0.4%	0.1%	0.3%	0.2%	16.6%
Education	1.6%	1.8%	0.9%	1.6%	2.1%	1.8%	0.5%	0.1%	0.2%	0.1%	10.8%
Health care	1.7%	1.4%	0.4%	1.9%	1.6%	0.8%	0.4%	0.2%	0.1%	0.0%	8.6%
Lodging	1.7%	0.9%	0.8%	1.2%	0.9%	0.1%	1.0%	0.2%	0.2%	0.1%	7.2%
Warehouse and storage	1.8%	2.0%	1.1%	0.3%	0.8%	0.4%	0.1%	0.0%	0.1%	0.0%	6.7%
Food service	0.5%	0.4%	2.7%	0.7%	0.7%	0.1%	0.2%	1.1%	0.1%	0.1%	6.6%
Public assembly	1.7%	0.8%	0.6%	0.6%	1.9%	0.4%	0.2%	0.1%	0.2%	0.0%	6.5%
Food sales	0.3%	0.4%	3.5%	0.3%	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%	4.9%
Other	1.2%	0.9%	0.4%	0.4%	0.6%	0.9%	0.0%	0.0%	0.1%	0.0%	4.5%
Service	0.9%	0.9%	0.1%	0.3%	0.4%	0.2%	0.1%	0.0%	0.1%	0.0%	3.0%
Religious worship	0.7%	0.2%	0.1%	0.3%	0.4%	0.1%	0.1%	0.0%	0.1%	0.0%	1.9%
Public order and safety	0.5%	0.4%	0.1%	0.1%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	1.7%
Vacant	0.3%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%		0.0%	0.0%	0.6%

Legend	
> 20%	1%-5%
10%-20%	0%-1%
5%-10%	

The Other end use was the largest in the commercial sector, followed by lighting, refrigeration, ventilation, and cooling. Office buildings, mercantile (including both malls and non-mall retail) and education make up almost 50% of total electricity end use.

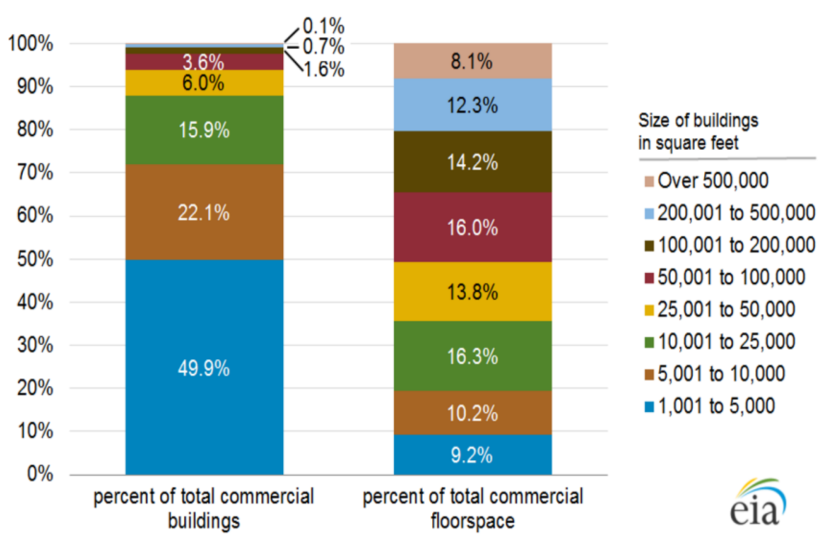
Figure 3.3. Percentage of electricity consumption by building category from 1992 to 2012[11]



Office buildings and mercantile/service buildings make up about 40% of overall consumption. Mercantile/service demand reduction from 2003 to 2012 was driven by a 14% reduction in mall floor space.

Figure 3.4 shows the distribution of buildings by floor space. Half of all commercial buildings are quite small—5,000 ft^2 or less—accounting for less than 10% of total commercial floor space. While buildings with more than 25,000 ft^2 account for almost two-thirds of commercial floor space, they make up only 12% of the total building population. [12]

Figure 3.4. Commercial building sizes, 2012 [13]



Buildings 5,000 square feet (ft^2) or less account for half of all commercial buildings but comprise less than 10% of total commercial floor space. Buildings greater than 25,000 ft^2 account for only 12% of commercial buildings but comprise about two-thirds of total commercial floor space.

Table 3.3 shows the percentage of floor space by building type and age. For several building types, 15% to 20% of floor space was built before 1946. A large fraction of building floor space for many building types was built between 1990 and 2007. In the municipalities, universities, schools, and hospitals (MUSH) category, a large fraction of building floor space (41%) in the education sector was built prior to 1969. Most health care and office building floor space was built after 1970. [14]

Table 3.3. Percentage of Total Floor Space by Building Type and Vintage.[15]

Principal building activity	Total floorspace (million square feet)										
	Before 1946	1946 to 1959	1960 to 1969	1970 to 1979	1980 to 1989	1990 to 1999	2000 to 2007	2008 to 2012	>46 yrs old	26-45 yrs old	3-25 yrs old
Education	**11%**	**12%**	**18%**	**10%**	**10%**	**14%**	**19%**	**7%**	**41%**	**20%**	**39%**
Food sales	0%	0%	0%	0%	13%	23%	0%	0%	0%	13%	23%
Food service	17%	10%	9%	13%	17%	17%	10%	0%	37%	30%	27%
Health care	**5%**	**9%**	**9%**	**21%**	**14%**	**15%**	**15%**	**13%**	**23%**	**35%**	**42%**
Lodging	6%	6%	13%	14%	20%	18%	15%	7%	26%	34%	40%
Mercantile	6%	6%	9%	14%	20%	18%	19%	8%	21%	34%	45%
Office	**16%**	**8%**	**9%**	**13%**	**25%**	**13%**	**12%**	**4%**	**33%**	**38%**	**29%**
Public assembly	18%	9%	16%	11%	11%	16%	13%	6%	43%	21%	35%
Public order and safety	**0%**	**0%**	**0%**	**0%**	**0%**	**29%**	**0%**	**0%**	**0%**	**0%**	**29%**
Religious worship	15%	13%	15%	8%	12%	14%	17%	0%	44%	20%	31%
Service	14%	7%	11%	14%	19%	17%	13%	5%	33%	33%	35%
Warehouse and storage	9%	6%	11%	11%	17%	17%	21%	8%	25%	29%	46%
Other	0%	0%	0%	0%	14%	14%	12%	0%	0%	14%	26%
Vacant	21%	11%	9%	14%	22%	14%	0%	0%	41%	36%	14%

Building types that include buildings in the MUSH sector are in bold;[a] the decades with the highest percentages are shaded. Note: Some rows do not sum to 100% because of missing data in the Commercial Buildings Energy Consumption Survey.

Municipal and State Governments, Universities, Schools, and Hospitals

The MUSH subsector includes all buildings under the control of municipal and state governments, universities and colleges, schools, hospitals, and healthcare facilities. These entities generally have control over many buildings and tend to have a longer-term perspective on investments. Some MUSH buildings (e.g., health care facilities) also are high energy users. Table 3.4 and 3.5 characterize floor area and electricity consumption in the MUSH subsector. Overall, MUSH floor space comprises an estimated 24% of total commercial floor space.[16] End-use electricity consumption is similar to the overall mix of total commercial sector end uses (Table 3.2), with lighting, ventilation, and cooling making up about two-thirds of electricity consumption. Kindergarten through 12th grade (K–12) schools, state and local government buildings, and health care facilities make up about 80% of the total floor area of large MUSH buildings in the United States (owner-occupied[b] facilities larger than 50,000 ft^2).[17]

[a] The percentages for office buildings are an approximation for the percentages of office buildings in the MUSH subsector. The CBECS data set does not split out office buildings into MUSH versus non-MUSH segments.

[b] While not owner-occupied, large public-housing projects are included.

Table 3.4. Floor Area in the MUSH Subsector for Large, Owner-Occupied Buildings More Than 50,000 square feet, 2003[18]

Market Segment	Floor area 2003 (million ft^2)	% floor area
K–12 Schools	5,113	42.3
State/Local	2,326	19.2
Health Care	2,244	18.6
Universities/Colleges	1,354	11.2
Public Housing	1,057	8.7

Table 3.5. End-Use Electricity Consumption in the MUSH Subsector, 2003[19]

End Use	% End-Use Electricity Consumption, 2003
Lighting	31
Ventilation	19
Cooling	17
Other	10
Heating	8.4
Computer Use	5.9
Refrigeration	4.2
Water Heating	3.6
Office Equipment	1.4
Cooking	0.3

Lighting, ventilation, and cooling dominate, constituting two-thirds of overall electricity consumption in the MUSH subsector.

3.2.3 By Electricity End Use

Generally, population and gross domestic product (GDP) growth are factors that drive increases in commercial-sector electricity consumption. Slower economic growth and tightened building energy codes and appliance and equipment standards have led to flat overall consumption in the past few years (Figure 3.1).

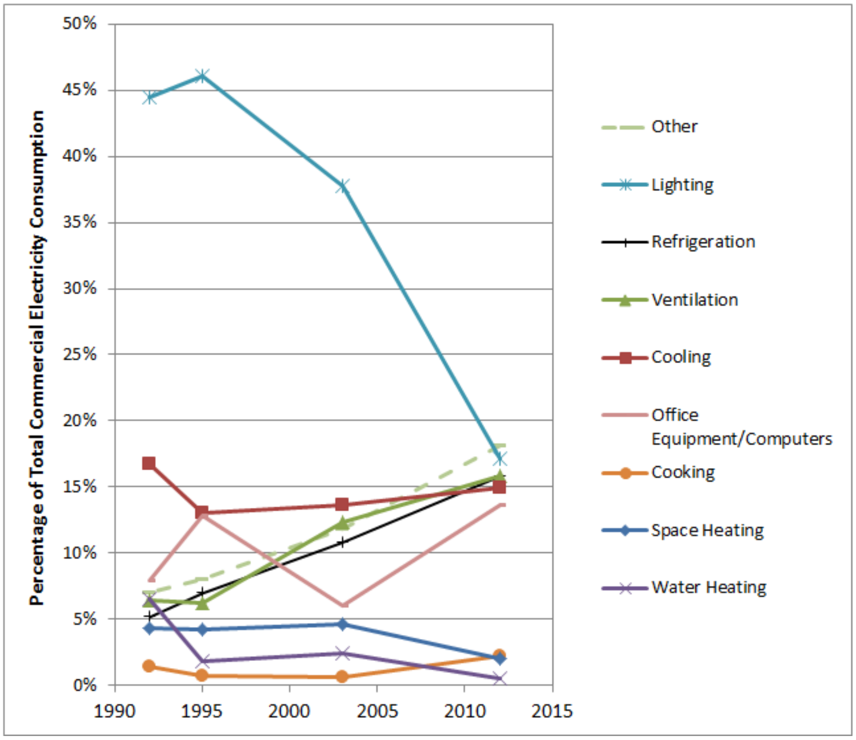
The most consumptive end uses in 2012 were Other end uses, lighting, refrigeration, ventilation, and cooling (Table 3.2). Lighting has historically been the largest end use in the commercial building sector, but the lighting share of total electricity in commercial buildings dropped from 46% in 1995 to 17.1% in 2012 (Figure 3.5) via continued improvements in lighting efficiency and controls. Electricity consumption in ventilation and Other end uses[a] has increased by 153% and 125% compared to their 1995 shares, respectively. The importance of technology development and energy efficiency standards for lighting, cooling, and Other end uses is highlighted in Section 3.34. Note that the commercial sector end use consumption data from the EPSA Side Case used in this chapter has been adjusted. The supply- and

[a] "Other" end uses include equipment such as elevators, escalators, medical and other laboratory equipment, laundry, communications equipment, security equipment, transformers, some municipal water service, non-road electric vehicles, and miscellaneous electrical appliances not counted as office equipment or computers. See Appendix Table 7.5.

consumption-side data discrepancy adjustment is separated from the Other end use category and proportionally re-allocated to the remaining end uses (see appendix 7.4.1).

Some water distribution and wastewater treatment end uses are included in the Other end-use category but are not included in EIA's CBECS. A recent study on the representation of miscellaneous electric loads in DOE's National Energy Modeling System (NEMS) found that about 0.5% of annual electricity use in the commercial sector is used for water distribution and about 3.5% for wastewater treatment.[a] [20]

Figure 3.5. Trends in electricity consumption by end use from 1992 to 2012[21]

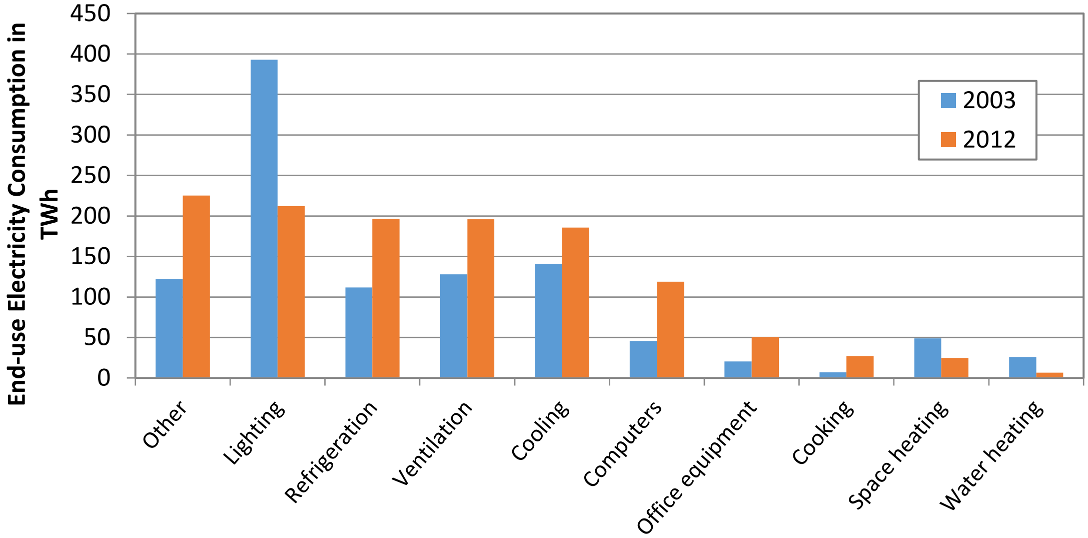


The lighting, cooling, ventilation, and Other categories made up 75% of total use, with a sharp drop in lighting share and large increase in ventilation and refrigeration.

Comparison of end-use electricity consumption in terawatt-hours (TWh) for CBECS 2003 and CBECS 2012 is shown in Figure 3.6 below. Lighting and space heating dropped by about 50% each, but they were offset by large increases in Other, refrigeration, computers, and office equipment, which increased by 84%, 76%, 160%, and 149%, respectively.

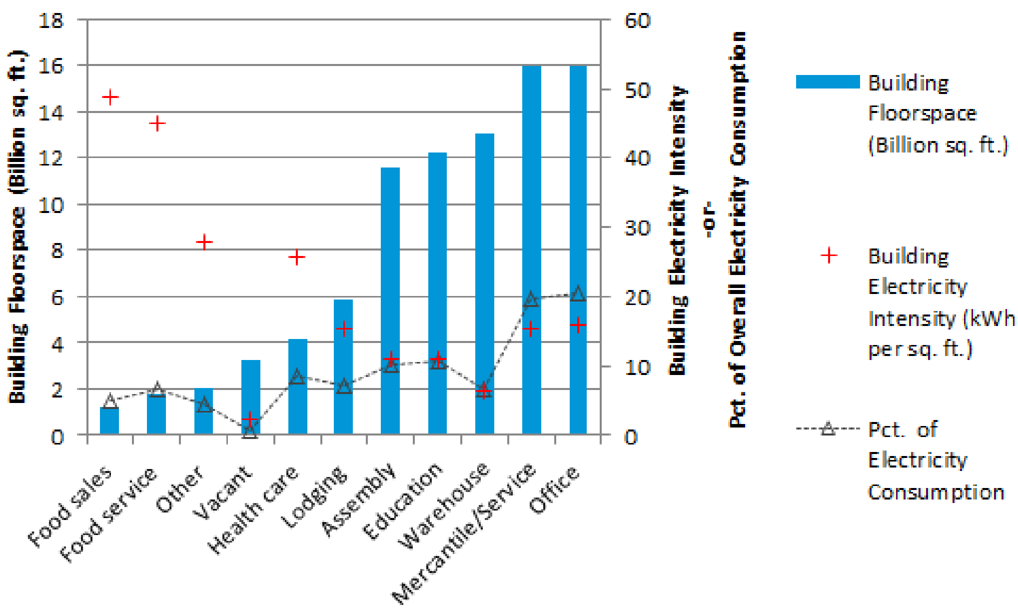
[a] While water systems may only account for a small portion of national-level annual electricity use, they may represent the largest single electricity usage (and expense) for a local government.

Figure 3.6. End-use electricity consumption in TWh, 2003 and 2012[22]



Other, computer, and office equipment end use is up sharply while lighting consumption has dropped by almost 50%. Total electricity consumption was estimated at 1,043 TWh in 2003 and 1243 TWh in 2012.

Figure 3.7. Building floor space, building electricity intensity, and overall fraction of electricity consumption in 2003 by building category[23]



Buildings with the highest electricity intensity account (food sales, food service, and health care) have less floor space; buildings with more floor space have lower electricity intensity. Mercantile/service and office buildings represent large amounts of floor space and have moderately high electricity intensity, together accounting for about 40% of overall electricity consumption in the commercial sector. "Assembly" includes three building categories: public assembly, public order and safety, and religious worship.

Figure 3.7 presents a synthesis of the above data sets. Building categories with the highest electricity intensity (food sales, food service, and health care)—due to high electricity demand for refrigeration, lighting, and plug loads around the clock—have low overall floor space, while building categories with the highest floor space (e.g., mercantile/service and office buildings) have moderate electricity intensity. This plot highlights the importance of mercantile/service, office, and health care building types, which are among the faster-growing by floor space.

3.3 Key Metrics and Trends

This section presents key metrics and trends in the commercial sector. Primary data sources are the U.S. Energy Information Administration (EIA), [a] CBECS, and EPSA Side Case.[24] Projected trends reflect the EPSA Side Case unless otherwise noted. Overall, end-use electricity consumption in the commercial sector is projected to grow about 22% from 2025 to 2040, primarily driven by Other end uses.

Figure 3.8 shows overall end-use energy consumption in the commercial sector. Electricity consumption has been increasing since 1992, while consumption of natural gas and other fuels (dominated by natural gas) has been flat. The electricity share of total energy consumption has increased from 23% in 1994 to 26% in 2012 and is projected to stay flat at 26% to 2040. Direct consumption of natural gas and other fuels dropped from 27% to 23% between 1994 and 2012 and is projected to comprise 22% of energy consumption in 2040. The increase in electricity consumption from the mid-1990s is consistent with increased use of existing types of electrical equipment and introduction of new types of equipment in commercial buildings such as computers (PCs, work stations, and servers), office equipment (printers, copiers, and fax machines), telecommunications equipment, and medical diagnostic and monitoring equipment.[25]

Note that Figure 3.8 does not take into account fuel switching from natural gas and other fuels to electricity. An example of this is moving from natural gas-fired water heaters to heat-pump water heating in small commercial buildings. If policies and technologies evolve to favor widespread fuel switching as a mechanism to achieve deep decarbonization in buildings, end-use electricity consumption in the commercial sector (blue line) could be higher than shown, and end-use fuel consumption (red line) lower, in the next 25 years.

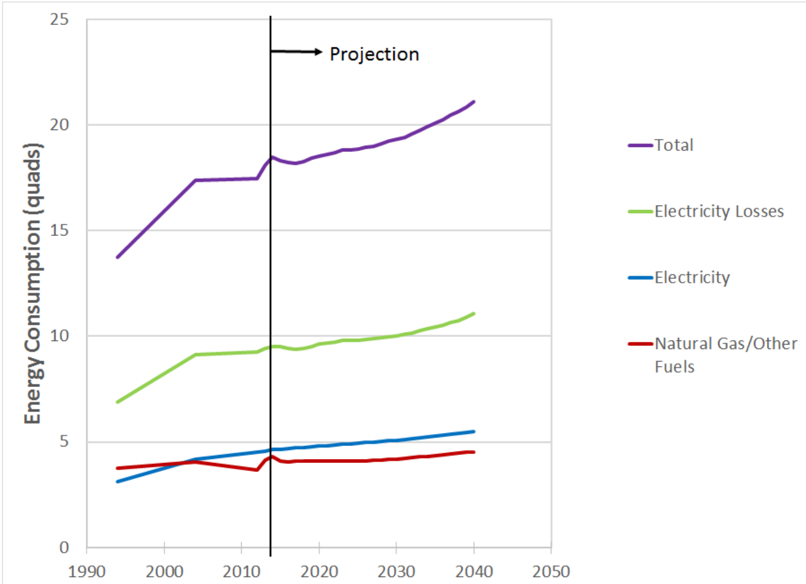
End-use electricity consumption in the commercial sector is projected to increase by 0.7% annually from 2015 to 2040, from 1.365 TWh to 1.615 TWh, a combination of a projected 0.3%-per-year decrease in electricity intensity and 1%-per-year increase in floor space (Figure 3.9). Floor space projections in the MUSH subsector are shown in Figure 7.21. End-use electricity in the sector is projected to increase by a total of about 18%. Figure 3.10 shows that the increased consumption is largely driven by Other uses.[b] Lighting and consumption continue to drop with improved technology (Section 0) and tighter federal energy efficiency standards, while non-PC office equipment, ventilation, and space cooling continue to increase. Consumption by Other end uses grows by 73% from 2015 to 2040 and by 72% for non-PC office equipment. Non-PC office equipment growth is largely driven by growth in consumption from data servers. A 2013 EIA study projected that electricity consumption from data center servers would grow 160% from 2015 to 2040, from 36 terawatt-hours TWh/year to 95 TWh/year,[26] but as noted

[a] The Commercial Demand Module (CDM) in National Energy Modeling System (NEMS) projects the reference case consumption by fuel and electricity at the Census-division level using prices from the NEMS energy supply modules, macroeconomic variables from the NEMS Macroeconomic Activity Module (MAM), and external data sources for technology characterizations and other inputs. Energy demands are projected for 10 end-use services for 11 building categories in each of the nine Census divisions. Detailed assumptions for the CDM are found in AEO 2015 CDM.

[b] An adjustment to the AEO 2015 Other end-use category was made according to the procedure described in an earlier LBNL report (Brown et al. 2008, p 2) to account for the residual electricity attributable to the commercial buildings sector but not assigned directly to specific end uses.

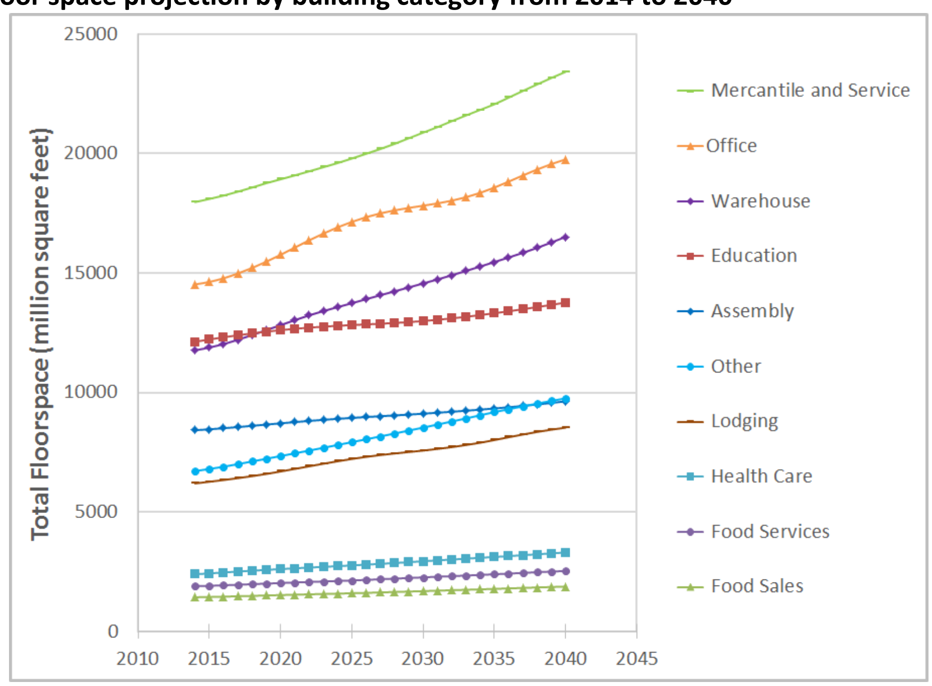
above, some large server farms would be classified in the industrial sector. The growth of data servers also increases energy requirements for building cooling and ventilation.

Figure 3.8. Energy consumption trends in the commercial building sector[27]



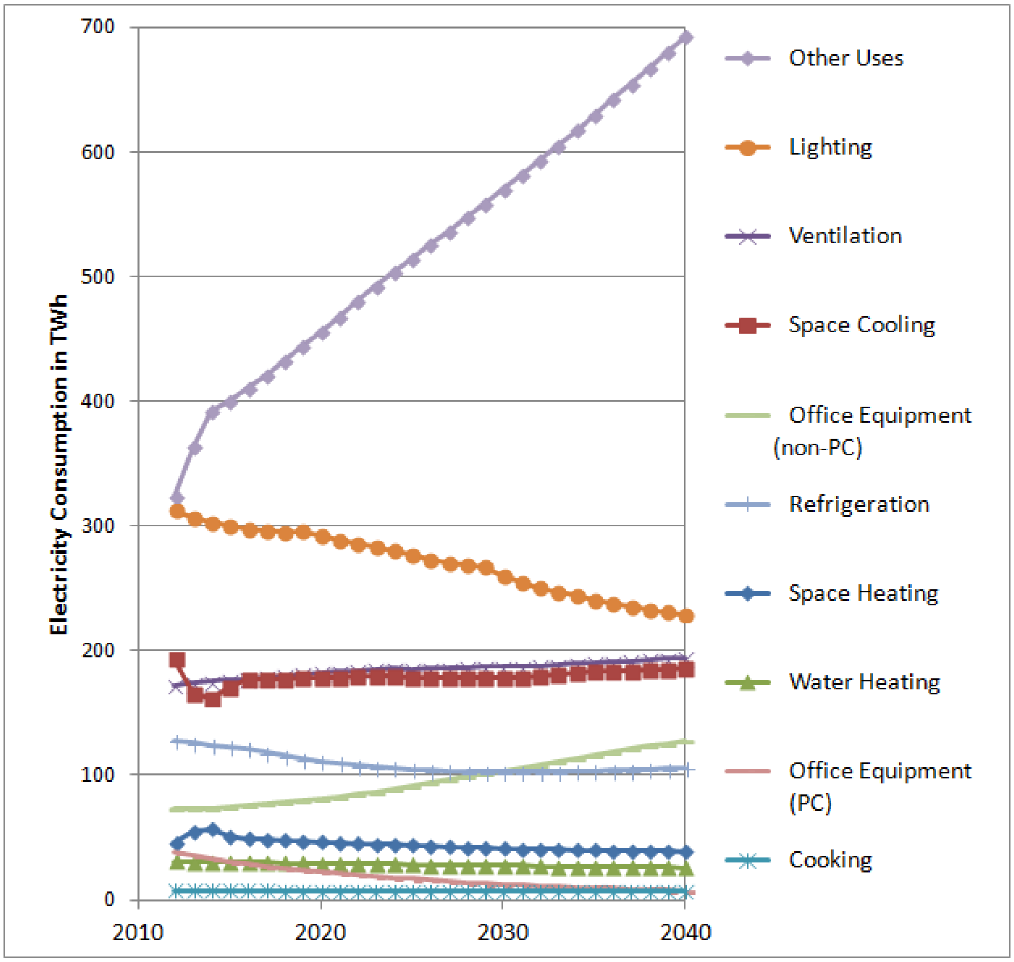
End-use electricity consumption has exceeded consumption of natural gas and other fuels since the early 2000s, largely driven by the increase in plug loads and the Other end-use category, and it is projected to grow steadily for the next several decades. "Electricity losses" refer to the thermal losses due to electricity generation, transmission, and distribution.

Figure 3.9. Floor space projection by building category from 2014 to 2040[28]



Overall, floor space in the commercial sector is projected to increase by 1.1% per year. "Other," warehouses, health care, and lodging are growing fastest, at an annual rate of 1.2% to 1.5% per year.

Figure 3.10. Projected commercial electricity consumption by end use[29] [a]



The largest demand is expected from "Other," lighting, and ventilation. Overall end-use electricity consumption in the commercial sector is expected to increase by 0.7% annually (~0.3% drop in electricity intensity in kWh/ft^2 with ~1% increase in floor space per year)—about 18% from 2015 to 2040, driven primarily by Other uses. Lighting and refrigeration consumption is expected to continue to drop. Non-PC office equipment, ventilation, and space cooling are projected to increase.

The largest demand overall comes from Other end uses, lighting, and ventilation. Future demand in the Other category may grow even more from greater workplace charging of PEVs. The growth in non-PC office equipment and Other end uses is addressed in Section 0, highlighting both direct approaches (e.g., standards for more efficient equipment and devices) and indirect approaches (e.g., management protocols) to increase energy efficiency.

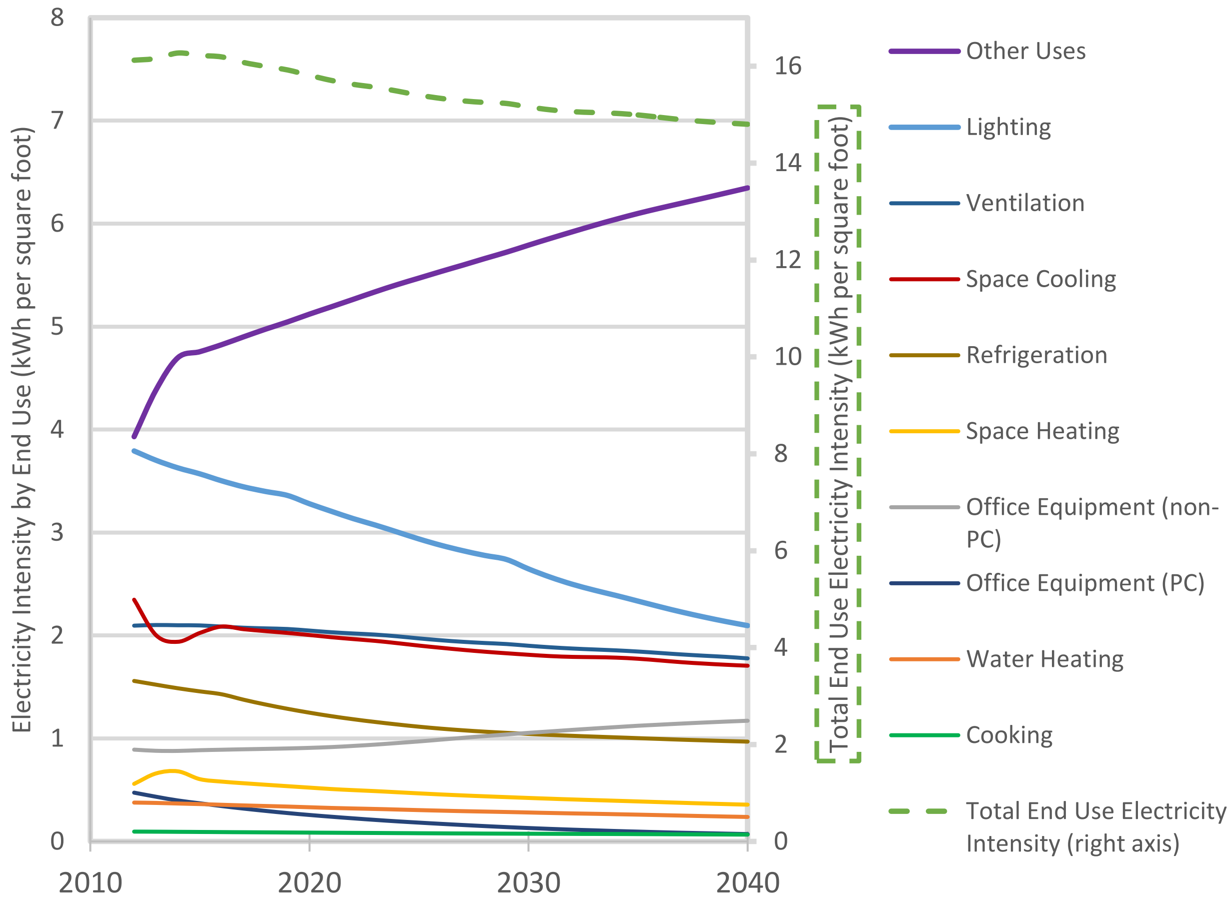
A small (8.8%) reduction in electricity end-use intensity (kWh/ft^2) from 2015 to 2040 is projected in the commercial sector (Figure 3.11). Other, lighting, ventilation, and space cooling are expected to be the most electricity-intensive end uses, making up 75% to 80% of commercial-sector electricity intensity. The intensity of Other uses is expected to trend significantly upward. Lighting is expected to trend significantly downward. Refrigeration and several other end uses also trend downward, due to more stringent appliance and equipment standards.

---

[a] Note that consumption data from CBECS 2012 was not available as an input to the EPSA Side Case. Thus the starting electricity consumption values by end use in 2012 from the EPSA Side Case are not identical to values from CBECS 2012.

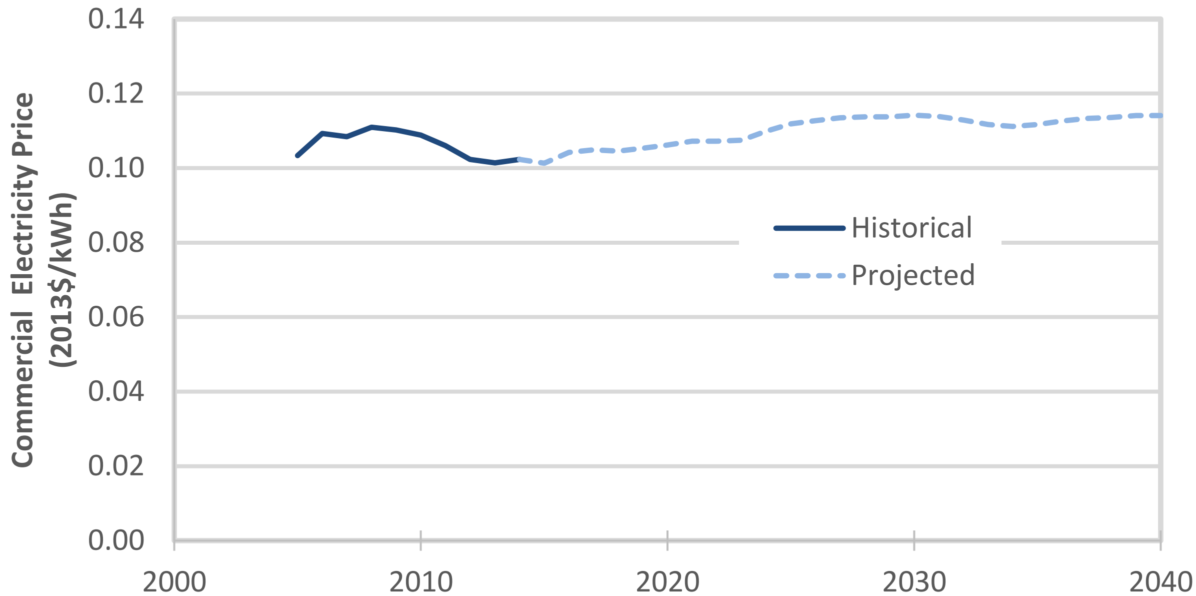
Electricity consumption for water distribution is projected to increase at a faster rate than the demand for water, as more energy is needed to distribute water from harder-to-reach places (e.g., wells of greater depth and sources of water farther away). Similarly, electricity consumption for wastewater treatment may increase at a faster rate than the increase in wastewater demand if wastewater treatment requirements are made more stringent and wastewater recycling increases.[30] Desalination could play a larger role in some coastal areas with reduced water supply from conventional sources and prolonged drought, and it could be a driver for new electricity demand. Figure 3.12 shows projected electricity prices for the commercial sector. The projected annual growth rate is a modest 0.5% per year through 2040. Between 1990 and 2014, commercial sector electricity prices increased 46%, remaining relatively stable between 1990 and 2000 at about $0.075/kWh, and then rising to $0.107/kWh by 2014. Electricity prices for the commercial sector are higher than industrial sector prices but lower than residential sector prices (Figure 7.24.).

Figure 3.11. Electricity intensity in the commercial sector by end use: Projection to 2040[31]



Electricity end-use intensity is projected to decline slightly (8.8%) from 2015 to 2040. Other, lighting, ventilation, and space cooling are expected to make up 75% to 80% of commercial sector electricity intensity. The intensity of the Other category is expected to trend significantly upward and lighting significantly downward.

Figure 3.12. Historical electricity prices and projected electricity prices per kWh in the commercial sector, 2005 to 2040[32]



Electricity prices for the commercial sector are projected to grow modestly, at 0.5% per year.

Table 3.6 shows projected population growth from 2015 to 2040. Annual growth of 0.7% is projected for the overall population, but annual growth for the population aged 65 and over is projected to grow by three times that rate—2.2% annually. Senior citizens made up about 15% of the U.S. population in 2015. This share is projected to grow to 21% in 2040. In fact, most of the growth in population from 2015 to 2030 will be from senior citizens, representing 68% of the overall population increase. This shift in the population is expected to have an impact on the distribution of commercial building types. For example, with an aging population, health care floor space is expected to increase more rapidly than the Other building type.

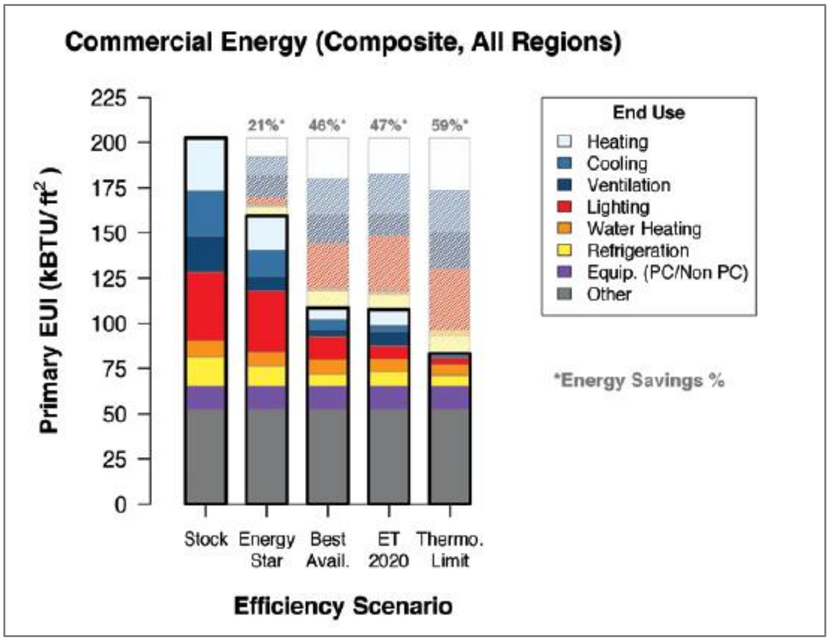
Table 3.6. U.S. Population Projections from 2015–2040[33]

Population and Employment (millions)	2015	2030	2040	Annual Growth (%)	2030 increase from 2015 (M)	2040 increase from 2015 (M)
Population, with Armed Forces Overseas	321.5	358.6	380.0	0.7	37.1	58.5
Population, aged 16 and over	255.9	287.7	307.3	0.7	31.8	51.4
Population, aged 65 and over	48.0	73.0	79.8	2.2	25.0	31.9
Employment, Non-farm	141.6	158.6	168.5	0.8	17.0	26.9
Employment, Manufacturing	12.0	10.7	9.7	-0.7	-1.3	-2.3
% of Population aged 65 and older	14.9%	20.4%	21.0%		68%	54%

3.4 Energy Efficiency Technologies and Strategies in Commercial Buildings

The 2015 QTR estimates the ultimate potential of energy savings in the commercial sector by end use (Figure 3.13). If the stock of commercial building in 2013 were improved by 20%, the savings would be approximately 3.6 quads of total energy and $36 billion in costs.[34]

Figure 3.13. Potential improvements in commercial building energy intensity[35]



For example, energy intensity can improve by an estimated 21% with ENERGY STAR equipment and 46% with best available technology. No improvement was assumed for the Other end-use category, which becomes dominant in scenarios with high levels of energy savings.

3.4.1 Lighting

Lighting in mercantile buildings, followed by lighting in office buildings, is the largest electricity end use in commercial buildings.[36] Linear fluorescent lighting is commonly used with about 72% of overall lighting energy.

LED and solid-state lighting (SSL) technology[a] through R&D programs since the mid-2000s. LEDs have a much longer lifetime than CFL or incandescent lighting and can improve the performance and value of lighting through enhanced controllability and new functionality. LEDs also are highly energy efficient and can decrease wattage by 75% or more.[37]

Solid-state lighting (SSL) sources are inherently dimmable, instantaneously controllable, and can be readily integrated with sensor and control systems. That enables additional energy savings through occupancy sensing, daylight strategies, and local control of light levels.[38]

A DOE-sponsored forecast projects LEDs will grow to 84% of market share in 2030 in the commercial sector, saving a cumulative 18% of commercial lighting electricity usage from 2013 to 2030, relative to a

[a] LEDs are a solid-state lighting technology based on semiconductor electronics to generate light, as opposed to a radiant tungsten-filament light source in incandescent lighting or a gas-discharge light source in fluorescent lighting. Solid-state lighting includes LEDs, organic LEDs, and polymer LEDs.

no-LED baseline. The same study projects that by 2030, total indoor lighting shipments (in lumen-hour units) will be 82% LED-based in 2030, compared to 2% in 2013. LED market share of lighting shipments for outdoor lighting, including parking lots and building exterior lighting, is projected at 99% in 2030, compared to 9% in 2013. The study estimates that "SSL could account for nearly half of all lighting shipments in the U.S. (measured in terms of light-production capacity in lumen-hours) and approximately 40% of the installed base (in lumen-hours) by the year 2020."[39]

Still, there are remaining market barriers to adopting advanced lighting technologies. They include first cost, with a price premium for new technologies over conventional technologies, for both new and retrofit applications. However, adoption of LED-based products in many commercial sector applications has accelerated as the payback period declines to one or two years.[40] Another market barrier is the added complexity and variation in product performance for new lighting technologies.

Organic LED or larger-area, more-diffuse, lighting technology[a] could be widely deployed in offices and other commercial buildings, offering a great variety of possible designs and product implementation. The technology is still in early commercialization but is a key area for both public and private R&D.[41]

Another priority for DOE-sponsored R&D is to capitalize the unique controllability, dimmability, and directionality of LED lighting through smart controls and sensors, including: (1) investigating interoperability of lighting control, communication, and sensor platforms, and (2) developing systems for real-time energy monitoring and feedback.[42]

3.4.2 Cooling

Cooling accounts for 15% of electricity consumption in the commercial sector, ranking as the third-highest end use.[43] Cooling systems in commercial buildings often provide humidity control, and careful system design and regular maintenance are essential for energy-efficient operation, particularly in humid climates such as the Southeast.

Traditional cooling approaches use vapor-compression heat pumps to both cool the air and remove moisture for greater comfort. Commercial central air conditioners and heat pumps (often called rooftop units) are commonly used for small and mid-sized commercial buildings. Most large commercial buildings use central chillers to cool water and transfer heat from water to air closer to the occupied spaces.[44] Activities to improve HVAC efficiency involve efforts to optimize internal loads to reduce cooling requirements, improve the efficiency of cooling systems, and develop technology that can efficiently remove moisture from air without cooling energy.[45]

Electricity consumption for cooling is projected to stay fairly constant through 2040 from its 2012 level of 200 TWh.[46] Growth in cooling demand from higher GDP and population are thus counteracted by greater energy efficiency of building shells and more energy-efficient cooling equipment. For example, updated federal standards for commercial air-cooled central air-conditioners and heat pumps issued in 2015 (and effective in 2018 and 2023, depending on product type) will yield lifetime energy savings estimated at 14.8 quads from 2018 to 2048, a savings of 24% relative to the energy use of these products in the no new standards case. Cumulative net savings are estimated at $15.2 billion to $50 billion.[47] Commercial chiller performance is addressed in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 90.1-2013, with a greater focus on part-load

---

[a] Organic LEDs (OLEDs) are made of organic compounds, while conventional LEDs are made of semiconductors. OLEDs provide thin films of material that emit light, as opposed to "point-source" lighting provided by LEDs.

performance of systems, specifically part-load “off-design” point efficiency where most of the operating hours occur. The latest version includes a 10% increase in required part-load efficiencies.[48]

Heat pump and air-conditioning systems using vapor-compression technology typically employ hydrofluorocarbon refrigerants (working fluids) that have a far higher global warming potential (GWP) than CO_2. The development of alternative, lower-GWP refrigerant substitutes is an intensive area of R&D, but current substitutes are more expensive, slightly toxic, or slightly flammable, or they require more expensive equipment.

Several promising cooling technologies can eliminate high-GWP refrigerants and increase system efficiency, but more development and demonstration is needed before these technologies can make a large impact. These include magnetocaloric, thermoelastic, electrochemical, and electrocaloric approaches. Thermally driven technologies using absorption and adsorption devices are another opportunity for performance improvement.[49]

One key source of uncertainty in cooling demand is the impact of climate change. The AEO 2015 projects a 12% increase across the United States in cooling degree days from 2012 to 2040, where “a 10% increase in cooling degree days would increase cooling consumption by about 12.5%.”[50] While the AEO takes this into account in projections, there is considerable uncertainty in future climate and, in particular, the prevalence of more extreme weather—e.g., heat waves or peak demand periods with higher frequency, duration, and intensity.

3.4.3 “Other” End-Use Sector

The Other end-use category is a key area for reduced electricity consumption in the future, with projected growth in electricity demand in the commercial sector largely driven by growth in this category. Other end uses include miscellaneous end uses, plug loads, and additional uses that do not fall into specific end-use service categories (e.g., elevators, escalators, medical/lab/security equipment). Potential improvements in the Other end-use category include improving the efficiency of vertical transportation through greater equipment efficiency, more efficient operation, and improved building design—e.g., design and location of stairways versus elevators.[51]

Importantly, electricity consumption in the Other category is not projected to drop (Figure 3.13), due to a large increase in the number of devices.[52]

Recent studies on ZNEBs and ZNEB-capable[a] buildings underscore the growing importance of improving the efficiency of plug loads. According to a recent study, plug load fractions range from 35% to 49% for California Leadership in Energy and Environmental Design (LEED)-rated projects (depending on building-use type) and 32% to 45% for ZNEB-capable California projects.[53]

Reducing electricity consumption by Other uses includes the following direct and indirect approaches:[54]

- Direct (1) improved energy-efficiency devices and appliances and (2) power-management strategies through integrated control systems with improved controllability—for example, developing a separate circuit for plug loads that can be turned off globally if there is no building occupancy, or escalator/elevator sleep modes.

[a] “ZNEB-capable” refers to a building that is capable of achieving zero net energy status with the installation of on-site renewable electricity generation but does not have on-site supply of electricity installed.

- Indirect (1) increasing the visibility of plug load energy usage to commercial building occupants and building operators,[55] (2) development of management protocols to address these miscellaneous loads, and (3) encouraging changes in behavior to minimize unnecessary power usage.

Separately metered receptacle circuits are another option to reduce plug load. The ASHRAE standard 90.1-2010 was the first to address plug loads by requiring sweep or occupancy controls on 50% of power outlets in open offices and computer classrooms.[56] States also are beginning to take action to address previously unregulated loads. For example, all new commercial buildings in California larger than 25,000 ft^2 must include separately metered receptacle circuits.[57] However, market barriers still exist in the application of plug-load savings opportunities, including lack of cost savings information, tenant/occupant buy-in, and integration with whole-building energy management and information systems.

3.4.4 Improved Controls for More Dynamic and Flexible Buildings

The market for building energy-management systems, sensors and controls, and load-management strategies for commercial buildings is large and growing.[58] A recent report by Navigant estimates the global building energy-management software market is expected to grow from $2.4 billion in 2015 to $10.8 billion in 2024.[59] Energy-management systems are increasingly able to control room temperatures, humidity, ventilation rates, plug loads, and dimmable lights, and in the future, they will control windows and louvers.[60] Similarly, lighting, windows, HVAC equipment, water heaters, and other building equipment are starting to be equipped with smart controllers and often wireless communications capabilities that enable demand response for peak load.[61]

Buildings perform most efficiently when an integrated system controls all energy-using systems. Well-designed control systems can increase building efficiency up to 23%.[62] Moreover, the greater use and effective utilization of sensors and controls will help to move today's building operations from fixed-schedule operations to more dynamic and flexible operation (e.g., for building facades, HVAC, and refrigeration systems) that is responsive to electricity price signals and utility and grid operator requests for load flexibility.

Advanced building-control systems will enable better building-to-grid integration and allow commercial buildings to participate in integrated energy efficiency and demand response programs, such as short-term frequency regulation and load shedding. Other potential benefits of advanced building-control systems include space-planning adaptation and optimization (based on occupancy, density, and scheduling), improved security, enhanced fault detection/diagnostics and response, emergency detection and management, and early identification of maintenance issues.

Sensors and controls enable valuable capabilities—greater visibility to energy usage, greater building information and control for the individual occupant at the whole-building level, and the opportunity for component-level response—i.e., exhaust fans, reheat, or one light at a time. In addition, the data enabled by these technologies can facilitate more whole-building control and potentially facilitate future building energy codes that may be based on actual energy use—e.g., requiring building monitoring for a specified period of time after the building has been occupied.[63] Key factors for the greater adoption of sensors and related equipment are interoperability, ease of installation and user interfaces, low cost, and integration with a diversity of end-use equipment.

Lighting provides an instructive example. As the largest single electricity end use in the commercial sector, lighting offers a significant opportunity for energy savings through sensors and controls. A recent meta-study on lighting controls by Lawrence Berkeley National Laboratory (LBNL) shows a wide range of potential savings—from an average of 24% using only occupancy sensors to 38% with daylighting and more sophisticated controls.[64] However, today's lighting controls can still be expensive, and it is difficult to build reliable occupancy sensors.[65] Progress is being made to make sensors more robust by coupling them with other data sources such as user activity (e.g., computer usage). Further improvements can be made to reduce cost, improve sensor quality, and enhance data algorithms.

One issue for achieving more energy efficiency and flexibility in the commercial sector is the difficulty of market adoption of EMCS[a] in small buildings. In 2012, more than 70% of all commercial buildings larger than 100,000 ft^2 had some kind of EMCS for HVAC, but only 12% of buildings smaller than 25,000 ft^2 used them.[66] Only 3% of buildings smaller than 25,000 ft^2 have EMCS for lighting. Thus, innovations are needed that greatly lower the cost and simplify the installation and operation of control systems and advanced control systems.

Other barriers and challenges to the adoption of control systems include the following:[67]

- Lack of capability to respond to price – Many commercial buildings are not capable of handling price and energy performance information.
- Lack of low-cost control networks and optimization functionality – Cost should be low enough for both large and small buildings, and systems should not disrupt the comfort of building occupants.
- Lack of accuracy and access to data – Sensors are needed to collect energy use and end-use performance data. Existing sensors may not be accurate enough or may not have the required granularity to participate in demand response programs.
- Lack of evaluation, measurement and verification (EM&V) technology – M&V technology and protocols are needed to track the performance of control systems and should be easy to install and reliable to operate. See Appendix 7.8.
- Lack of interoperability of proprietary or legacy systems with new technologies, services, tools, and DERs.

Security and privacy concerns related to increased data collection and data that are processed by external parties are another issue, and a possible barrier to the greater adoption of advanced control systems. Data-handling policies, guidelines, and protocols addressing consumer preferences and privacy concerns can remove this barrier to deploying programs that rely on more ubiquitous sensors and control systems.[68]

Prices for sensors and controls remain a barrier but are expected to come down by a factor of 10 in the next decade from lower cost, printed electronic substrates for circuits, sensors, antennas, solar photovoltaics (PVs), and batteries.[69]

Some building energy policies are expected to have an impact on facilitating the greater use of advanced controls and sensors. For example, California is developing building energy codes for net zero-energy new construction in the commercial sector for 2030. Such codes are expected to encourage builders to

---

[a] Note that the terms energy management control systems and building automation systems are synonymous and may also be referred to as smart building controls. See "Guide to the 2012 CBECS Detailed Tables," accessed January 15, 2016, http://www.eia.gov/consumption/commercial/data/2012/guide.cfm.

employ more advanced controls and sensors. Further advances in building energy codes, such as system-efficiency metrics, outcome-based energy codes, and periodic building retrocommissioning requirements, could encourage the greater use of advanced controls and sensors.

3.4.5 Zero Net Energy Buildings

The general concept of a ZNEB is that it produces as much energy on site as it consumes and, using clean generation sources, enables deep reductions in building energy use and energy-related air emissions. (See Section **Error! Reference source not found.** for more discussion on the ramifications of ZNEBs in the residential sector.)

More precise definitions of such buildings depend on the treatment of site versus source energy,[a] energy imports versus exports, fuel equivalency offsets, and other factors. DOE recently defined a ZNEB as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."[70] Other definitions use site-energy-based criteria (a less-stringent definition than source-based) and time dependent valuation-based definitions,[71] which seek to assign a valuation of energy produced or consumed to better reflect the actual costs of energy, as adopted by the California Public Utilities Commission.[72]

The difficulty in meeting ZNEB criteria varies between definitions. Furthermore, the cost-effectiveness of ZNEBs is highly dependent on the type of building, location (climate), incentives (e.g., utility rebates), and the cost of renewable energy generation.

Recent studies demonstrate that many new ZNEBs in the commercial sector can be cost-effective, with overall costs falling within the same range as conventional new construction projects. The explicit goal of zero net energy throughout the design process is critical to minimizing construction costs.[73]

Table 3.7 shows key design steps toward achieving ZNEBs, including high-efficiency building envelopes, highly efficient end-use systems, building-management control strategies, energy recovery (e.g., waste heat recovery and minimizing re-heating of previously tempered air), use of sufficient renewable resources to meet remaining building load, and monitoring and management of building energy during actual building occupancy and operation.

In California, for example, many commercial buildings are technically feasible to be ZNEB using a time dependent valuation-based definition.[74] However, several building categories, such as sit-down restaurants, hospitals, and large offices cannot reach ZNEB designation using rooftop solar though they might reach that designation using parking lot PV systems. Available roof space for on-site PV often is a challenge. Contracting with off-site renewable energy systems or participation in community-scale solar projects provide greater flexibility for buildings to be ZNEB or ZNEB-ready.[b] This is an active area of policy discussion.

Other barriers to the adoption of ZNEBs are the lack of integrated design practices, cost barriers, lack of skilled and knowledgeable workforce in design and construction,[75] additional design and construction

---

[a] Site energy is energy delivered to the building; source energy includes production and line losses.
[b] A *Zero Energy Ready* home is a high-energy-performance home that enables a renewable energy system to offset all or most of the home's annual energy consumption. See "Zero Energy Ready Home," U.S. Department of Energy, http://energy.gov/eere/buildings/zero-energy-ready-home.

cost, and integration of solar PV, either as part of the building construction process or as a parallel step during that process.

Table 3.7. ZNEB Design Steps and Sample Technologies[76]

Design step	Sample technology options
1. Reduce building energy loads with improved envelopes and the use of passive systems	Superinsulation, daylighting, exterior shading, natural ventilation
2. Install high-efficiency systems to address primary building energy loads	Heating, ventilation, and air-conditioning systems (including distribution), water heating, appliances/equipment
3. Install systems to manage building energy loads with effective control strategies and other mechanisms	Energy management systems, plug-load control strategies, feedback to users and occupants
4. Incorporate energy recovery mechanisms to minimize energy losses	Energy recovery ventilation, heat-pump water heaters
5. Use renewables to meet remaining building loads	Rooftop and other photovoltaic energy systems
6. Monitor and manage building energy use post-occupancy	Monitoring-based commissioning, occupant engagement

Source: Arup et al. 2012; NBI 2014

Energy recovery mechanisms, building management, and control strategies are critical design and operation strategies beyond energy-efficient building shells, equipment, and renewable energy.

3.4.6 Integrated Design/Whole-Building Modeling for New Construction and Major Retrofits

Integrated design and whole-building modeling represent the evolution of component-level optimization to system-level design and whole-building efficiency. To do this requires advances in modeling tools, sensors and building controls, data collection, and cost-effectiveness.
Similar to ZNEBs, integrated design includes the following activities:[77]

- Minimizing plug and process loads using efficient and efficiently used equipment
- Maximizing use of natural light while minimizing the negative thermal impacts of fenestration
- Minimizing unwanted envelope heat losses and gains through both conduction and infiltration/exfiltration
- Ventilating with outside air more effectively and selectively
- Recovering heat from exhaust air and waste water
- Reusing energy within the building and exchanging energy with buildings in a complex or campus
- Using hybrid HVAC systems that reduce overall energy consumption
- Using thermal and electrical storage
- Using renewable energy sources
- Using sensing and responsive automation to provide thermal and visual comfort to meet actual rather than pre-programmed occupant demand
- Using building automation and advanced system controls and diagnostics for commissioning and continuous commissioning to maintain system health and as-designed operation.

Buildings designed for whole-building performance using advanced system-level modeling software often outperform buildings designed using less quantitative approaches, such as prescriptive guidelines.

They also often achieve this performance at a lower up-front cost because they help identify those areas where energy efficiency investments will be most effective.[78]

Whole-building energy modeling also can add value after construction, to maintain and improve building energy performance during occupancy and optimize control strategies to respond to weather forecasts, building-use predictions, and price signals from utilities, grid operators, and aggregators. Energy models can harmonize building operation between flexible load, energy storage, and on-site generation to optimize services to the grid.

Whole-building energy modeling has become more capable, robust, and application vendor-friendly, bolstered by DOE investment in the open-source modeling engine EnergyPlus and the open-source modeling software-development kit OpenStudio. Although continuous improvement is needed—especially in support of emerging building operation application, the adoption of building modeling remains another key challenge. Today, only about 55% of new commercial buildings use modeling at any time during the design process,[79] and the general consensus is that more than half of those use modeling at the end of the project for code-compliance or LEED certification, rather than early in the project for informing the design itself. Meanwhile, model-driven building commissioning and operation is an emerging area with a growing number of commercial actors but low levels of market penetration, with most activity focused on very large buildings and campuses.

Demand for integrated design could come from both regulatory and market sources. The next revision to the commercial national model energy code (ASHRAE 90.1-2016) may include system efficiency metrics that encourage more comprehensive efficiency approaches and previously unregulated loads. Outcome-based energy codes—which require absolute rather than relative energy performance levels—could also increase demand for integrated design, as well as for post-construction modeling to maintain intended performance levels.[80] Energy efficiency programs that provide incentives for whole-building design and integrated approaches to building design and operation also can drive demand. Key challenges include aligning incentives for market actors to support the integrated design and operations approach and adoption of supporting programs, regulations, and policies. Education and training in integrated design and construction is also needed.[81]

3.4.7 Some Cost Estimates for Commercial Building Energy Efficiency Retrofits

Table 3.8 summarizes cost estimates for major types of commercial building energy efficiency retrofits. Retrocommissioning can offer payback times of less than two years with source energy savings of up to 20%. Energy service company (ESCO) projects span a range of payback times, with paybacks for public buildings typically being 7 to 12 years. Retrofits with integrated design can have a similar payback period, while net zero energy retrofits are the most costly but achieve the highest energy savings. There are few data points for net zero energy retrofits, thus payback times and costs are less certain.

Table 3.8. Simple Payback Times for Various Energy Efficiency Retrofits[82]

Energy Retrofit Type	% Source Energy Savings*	Simple Payback Times from Energy Cost Savings	Cost ($/ft^2)**
Retrocommissioning	10 to 20*	4 months to 2.4 years	$0.30 –.40
ESCO	20 to 40	3 to 12 years	$2.50
Integrated Design	30 to 60	7 to 12 years	$2.50
Net Zero Energy	50 to 90	8 to 20 years?	$10?

** End-use electricity savings estimated at 2% to 5%.*
*** The cost per ft^2 varies widely among building types because the energy intensity for each type is different.*

A retrofit case study for Walmart stores[83] finds that lighting upgrades have a 3- to 5-year payback time, annual savings of 286,000 kWh, and installed cost between $72,000 and $121,000. HVAC measures utilizing waste-heat recovery have a payback greater than five years, depending on the climate, with annual savings of about 900 kWh and installed costs between $52,000 and $88,000. Refrigeration upgrades have a payback of 3 to 5 years, with annual savings of 521,000 kWh and installed costs between $208,000 and $346,000.

The decision to retrofit an existing building versus demolishing the building and constructing a new facility to achieve energy efficiency, carbon, or cost goals is generally highly building- and site-specific. Full life-cycle analysis comparing the two options typically includes operating energy as well as the embodied energy of materials and new construction. Other factors to consider include building location, density, transit proximity, infrastructure changes, occupant preferences, and other attributes such as indoor air quality and building safety.

Existing studies that compare new versus renovated commercial buildings are limited,[84] but studies generally show lifetime carbon emissions depend on operational energy efficiency and lifespan assumptions. New buildings with equivalent energy efficiency to retrofitted buildings show comparable lifetime emissions and gains of 1% to 16% for new buildings, with 30% higher energy efficiency than retrofit buildings.[85] These studies include building energy consumption and embedded energy, but do not examine cost-effectiveness and other factors such as density and transit proximity. In some cases, new buildings may be the preferred option—for example, if the existing building is too expensive to upgrade to meet current code requirements as may be the case for seismic upgrades; if technical issues prevent cost-effective energy efficiency upgrades (e.g., some older buildings cannot be easily insulated); if the older building requires a new addition that negates the cost advantage; or if the existing building cannot meet functional requirements or has a large disadvantage in another area such as density or transit proximity.

3.5 Markets and Market Actors

Market actors in the commercial sector vary according to factors such as type of building, building size, new versus existing buildings, and ownership model. Table 3.9 illustrates lists key market actors as a function of the building life-cycle phase, from pre-construction to design, modeling, and construction to building operation and building type (new and existing). In the pre-construction phase, local and state officials develop building energy codes that set minimum performance and efficiency standards, typically on a three-year cycle. For new buildings, the design, modeling and construction phase involves developers, architects, and builders, as well as financing agents. After construction, permitting entities, appraisers and, in high performing buildings, commissioning[a] agents test and measure building performance and energy efficiency. During building operation, key market actors include building owners and tenants, property management companies, real estate professionals, contractors for maintaining and replacing equipment, equipment suppliers, energy service suppliers, building auditors, and retrocommissioning[b] agents. Intelligent control system providers are emerging market actors, competing with or augmenting existing control system providers.

Table 3.9. Key Market Actors and Roles for New and Existing Commercial Buildings

<table>
<tr><th>Building Phase or Area</th><th>New Buildings</th><th>Existing Buildings</th><th></th><th></th></tr>
<tr><td colspan="3">Pre-Construction</td><td></td><td></td></tr>
<tr><td rowspan="4"></td><td colspan="2">Code officials</td><td></td><td></td></tr>
<tr><td colspan="2">Policymakers, regulators and program</td><td></td><td></td></tr>
<tr><td>Developers, architects, designers, builders</td><td>Builders/contractors</td><td></td><td></td></tr>
<tr><td>Capital providers, investors, corporate finance</td><td>Capital providers, REITs</td><td></td><td></td></tr>
<tr><td colspan="3">Construction Phase</td><td rowspan="9">Equipment/ Appliance Installation and Sales</td><td rowspan="2">Federal and state officials promulgating standards and labeling</td></tr>
<tr><td rowspan="2"></td><td colspan="2">Builders/contractors</td></tr>
<tr><td>Commissioning agents, permitting entities, appraisers</td><td>Permitting entities, retro-commissioning agents, building auditors</td><td>Administrators of utility incentive programs</td></tr>
<tr><td colspan="3">Operational Phase</td><td rowspan="2">Builders, designers, developers, and contractors</td></tr>
<tr><td></td><td colspan="2">Owners, tenants, property management firms, real estate marketing and sales professionals
Software solution providers (intelligent control systems, building management software)</td></tr>
<tr><td rowspan="5">Energy Services</td><td colspan="2">Utilities and grid operators</td><td rowspan="2">Equipment retailers and installers</td></tr>
<tr><td colspan="2">Electric industry regulators</td></tr>
<tr><td colspan="2">Distributed energy resource providers (equipment,</td><td rowspan="3">Manufacturers</td></tr>
<tr><td colspan="2">Energy Service Companies (for larger buildings)</td></tr>
<tr><td colspan="2">Energy Management System providers</td><td></td></tr>
</table>

Commercial buildings involve a diverse set of market actors and roles that vary during the life-cycle of the building (pre-construction; design, modeling, and construction; and building operation) and type of building (new and existing). REIT stands for real estate business trust.[86]

Each market actor faces various competing factors that enable or discourage energy efficiency investment in the commercial sector. See the following section (3.6) for more details on these factors. Additionally, while many of these market actors are well established, some have been growing rapidly over the past several years, and some are anticipated to grow rapidly in the coming years. The diversity and impact of these factors and the development of these market actors indicate the need for new building energy codes and equipment standards to remove barriers and align interests to increase

[a] When a building is initially commissioned it undergoes an intensive quality assurance process that begins during design and continues through construction, occupancy, and operations. Commissioning ensures that the new building operates initially as the owner intended and that building staff are prepared to operate and maintain its systems and equipment.

[b] Retrocommissioning is the application of the commissioning process to existing buildings to resolve problems that have developed throughout the building's life. In all cases, retrocommissioning improves a building's operations and maintenance procedures to enhance overall building performance.

energy efficiency of commercial buildings. In addition to new standards and codes, other evolving regulations, governmental and corporate policies, and newly available commercial technologies will continue to affect the growth of these market actors, expand the importance of building designs, and increase market adoption.

Already energy-efficient construction, maintenance, and operation of commercial buildings are on the rise. In the United States, the market share of high-performance green buildings grew from 2% of new construction starts in 2005 to 44% in 2012. In a recent survey of U.S. architecture, engineering, and real estate firms, the number of firms that report heavy engagement in green building projects (over 60% of total projects) will increase from 16% to 53% between 2009 and 2015.[87] The motives behind investment in more sustainable buildings, especially in the commercial sector, have shifted from regulation-based drivers to building owners' interest in cost and energy consumption reduction, as well as market differentiation. According to a 2013 study, 83% of leaders in the largest U.S. companies view overall sustainability practices as consistent with their profit mission. This is up from only 58% in 2006.[88] High-performance buildings are increasingly factoring into tenants' decisions about leasing space and buyers' decisions about purchasing properties.

Energy Savings Performance Contracting (ESPC)

Energy service companies (ESCOs) can integrate multiple measures and mitigate technical and performance risks for energy efficiency projects, and bundle them with other facility upgrades. Typically, these arrangements are structured as energy savings performance contracts. Performance contracting is a partnership with an ESCO to design, construct, maintain, and conduct evaluation, measurement, and verification for energy-saving projects. The client pays a percentage fee to the ESCO based on the total project cost. Performance contracting also provides a financial guarantee to the lender that the energy savings generated will cover debt service on the project. Performance contracting can pay for today's facility upgrades with tomorrow's energy savings, with service fees distributed across the term of the performance contract.

A typical performance contract reduces annual energy use by 15% to 30%.[89] Electricity accounts for an estimated two-thirds of the energy savings for public and institutional (e.g., university and hospital) ESPC projects.[90]

Municipalities, universities, schools and hospitals (MUSH) market consumers accounted for about three-quarters of U.S. ESCO industry savings during the period from 2003 to 2012.[91] Private sector projects made up only 8% of ESCO industry revenues in 2011. Private sector companies in the United States generally have higher barriers to energy efficiency investments and much shorter payback time requirements (one to two years) than the MUSH market.[92]

In 2011, 84% of ESCO revenues were from the MUSH[a] market (including the federal government) and 64% from non-federal MUSH buildings.[93] Gross revenues are projected to double from an estimated $6.4 billion in 2013 to $10.6 billion to $15.3 billion in 2020. Median estimates of market penetration in the U.S. range from 10% in health care facilities to 42% in kindergarten through 12th grade (K–12) schools. Of the remaining estimated $100 billion market potential for ESCOs, about two-thirds is in the non-federal MUSH sector, led by health care and K–12 schools.[94]

[a] Municipal and state government, university, school, and hospital sector.

3.6 Barriers, and the Policies, Regulations, and Programs That Address Them

Energy efficiency policies, regulations, and programs in the commercial sector attempt to address well-known barriers.[95] Performance contracting can address some of these barriers.

- Information/awareness and transparency – Market actors have imperfect information about the performance of energy-efficient technology and equipment, practices that can save energy, and cost effectiveness. Energy savings can be difficult to measure and separate by end use.
- First costs and short payback times – More efficient devices cost more, and typically, businesses require a short payback period (e.g., one to two years), severely restricting opportunities to invest in more energy efficient equipment.
- Risk aversion – A building owner or operator may be risk-averse to new or unfamiliar building construction technologies, new end-use technologies, new operating procedures, or business practices.
- Materiality – When energy costs are small, relative to other costs, it is hard to get building owners to pay attention to energy efficiency.
- Limited access to capital – Companies have limited capital investment budgets, and energy sometimes is not a consideration for renovations.
- Lack of monetization of non-energy benefits and price signals – Electricity prices are set to recover utility and electricity service supplier costs, not to reflect the true social cost of electricity consumption. In addition, tariff structures may discourage consumer investments in energy efficiency.
- Transaction costs – Energy efficiency improvements and building retrofits are time-consuming to understand, arrange, and execute.
- Split incentives – Commercial building owners may not have an incentive to invest in energy-efficient equipment if they do not pay utility bills, and tenants will not want to buy energy-efficient equipment if they are planning to move out soon.
- Tax treatment – Energy bills are a deductible expense, and capital costs for energy-efficient equipment may be subject to long depreciation schedules.
- Workforce development – The availability of a skilled workforce is a barrier in some regions due to inadequate training, experience, or certification (e.g., lack of technical expertise on energy-efficient technology options and lack of familiarity with various local incentive programs).
- Other market failures and imperfections – These include externalities (e.g., health and environmental costs of fossil energy production) and imperfect competition (e.g., lack of a fully competitive market for energy efficiency that may enable lower prices for products and services).

Following are key policies, regulations, and programs enacted to address these barriers in the commercial sector. Overarching policies such as an energy efficiency resource standard are discussed in Appendix 7.2 in this report. Table 3.10 summarizes the major policies, regulations, and programs enacted to encourage efficiency in commercial buildings.

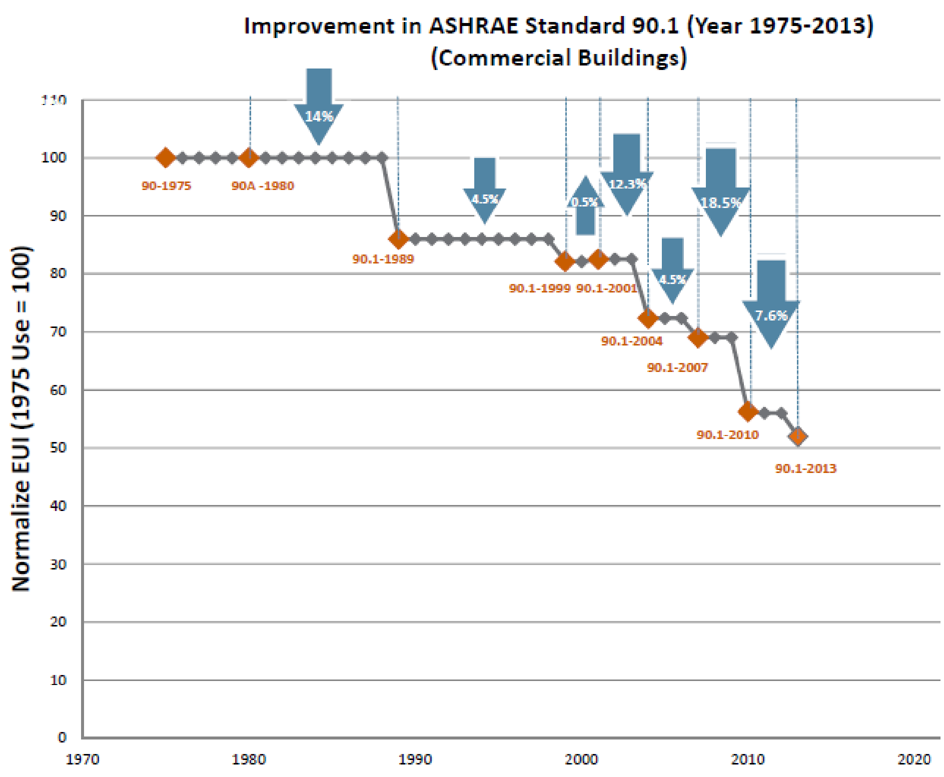
3.6.1 Building Energy Codes and Appliance and Equipment Standards

Codes and standards set a minimum level of energy efficiency performance, guarding against uninformed or inattentive purchase of inefficient devices and limiting the impact of split incentives. These policies have the goal of cost-effectively reducing energy consumption to meet long-term energy goals and to address barriers related to information and transparency, materiality, and split incentives.

- Building energy codes are mandatory prescriptive or performance-based codes that regulate building energy efficiency in new construction, major renovations, and remodels. National standards typically are updated every three years. ASHRAE 90.1-2013 is the most recent update (Figure 3.14). The ASHRAE 90.1-2010 or ASHRAE 90.1-2013 building energy code has been adopted in 22 states (Figure 3.15). Building energy codes also may include voluntary "green" or "reach" building energy codes.
- Appliance and equipment standards enact minimum performance requirements for appliances and other end-use equipment. Federal energy efficiency standards currently cover 14 types of commercial equipment (See Table 7.7), 11 of which are electricity-powered (e.g., air conditioning and refrigeration equipment). Some states have adopted additional commercial equipment standards beyond the federal standards. For example, several states have adopted standards for hot food-holding cabinets and water dispensers (California, New Hampshire, District of Columbia, Maryland, Oregon, Washington, Rhode Island, and Connecticut).

A recent LBNL study showed that energy efficiency standards adopted from 1987 through 2014 for appliances and equipment have saved 5 quads of primary energy from commercial and industrial standards and 7.8 quads from lighting products.[a] [96]

Figure 3.14. Energy savings from commercial building energy codes relative to the 1975 base code[97]

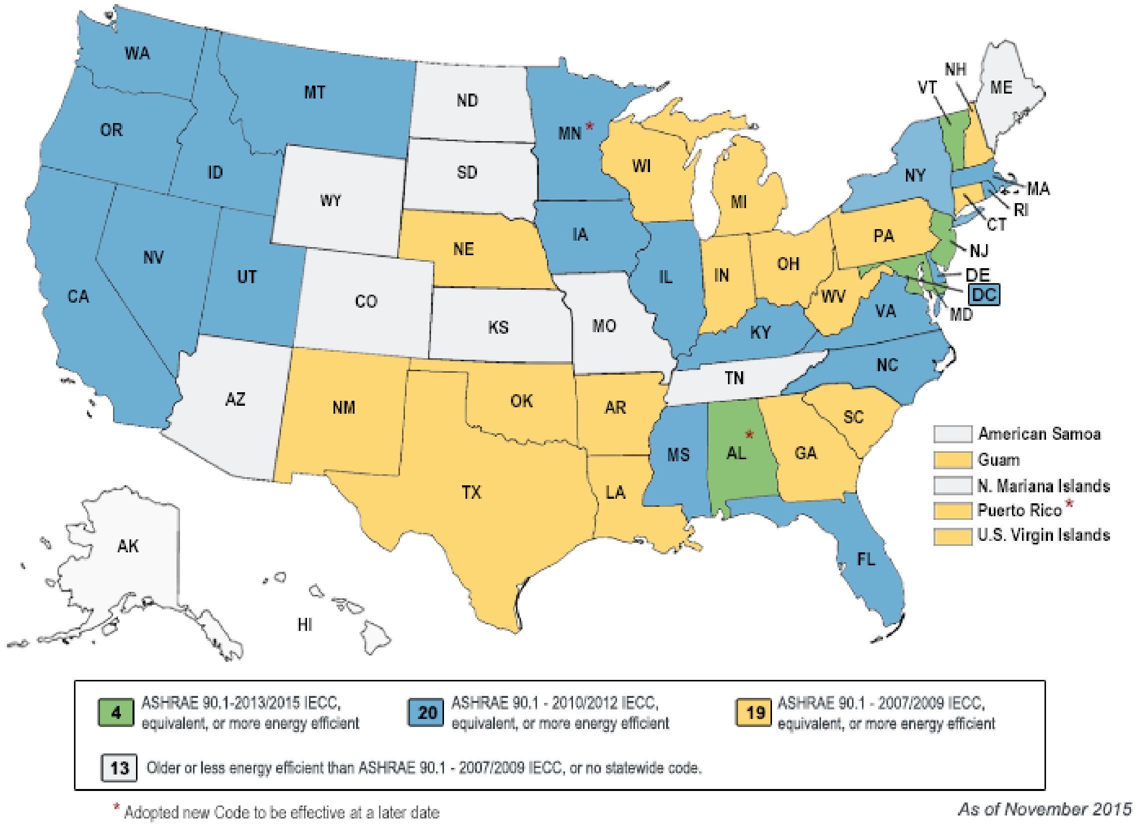


About 8% energy-use intensity savings are achieved through adoption of the ASHRAE 90.1-2013 standard compared to 90.1-2010, about 30% savings have been achieved since 2004, and almost 50% savings are achieved from the initial standard set in 1980.

---

[a] Note: the referenced study does not distinguish savings from the commercial sector alone.

Figure 3.15. Adoption of state energy codes for commercial buildings, as of 2015 [98]



Three states have adopted ASHRAE 90.1-2013, 20 states have adopted 90.1-2010, 20 states have adopted ASHRAE 90.1 – 2007/2009 IECC, and 7 states have a building energy code older than ASHRAE 90.1 – 2007/2009 IECC or no statewide code.

3.6.2 Informational Interventions

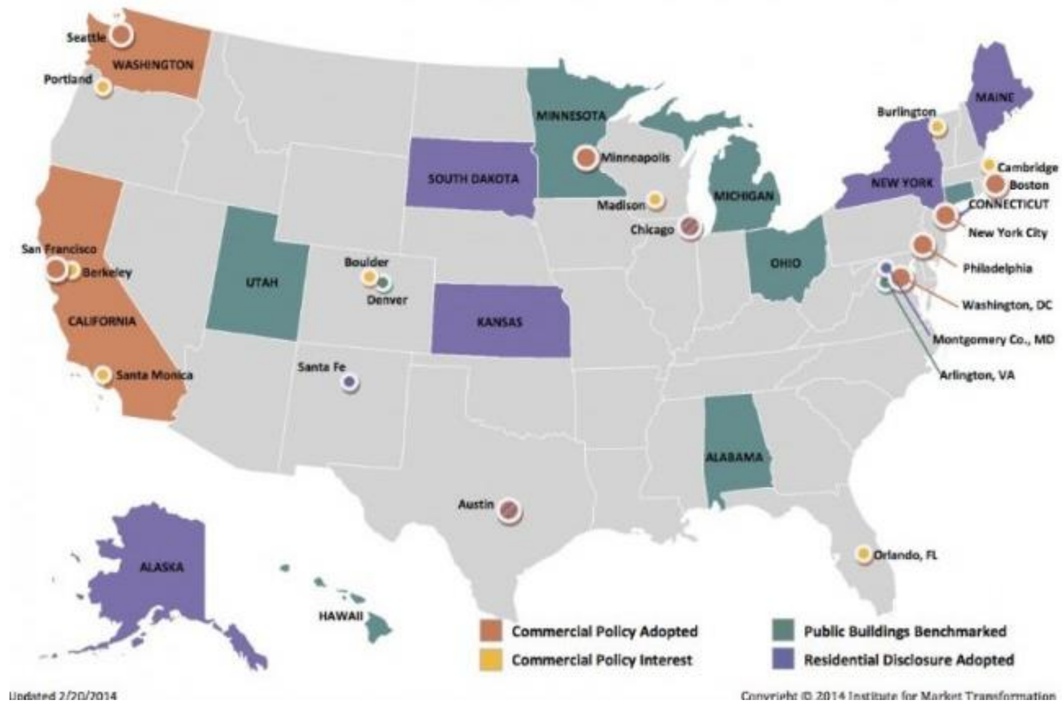
Building owners and operators often have inadequate information about the performance of high-efficiency technologies and energy-efficient operations. Stakeholders lack robust ways to assess, compare, and validate building energy performance. This leads to the perception that investing in efficiency is too expensive, complicated, or risky, making it difficult to gain access to capital. Without the appropriate information, tools, and platforms, building owners and managers are not able to accurately track their energy consumption, assess and compare their buildings, make timely decisions on upgrades and maintenance, or properly value their investments.

Inadequate information also leads to uncertainty in valuation of energy-efficient commercial buildings by the real estate community. The design, construction, appraisal, and underwriting processes do not fully account for the value that increased energy efficiency can bring to a building. When building owners are uncertain about their ability to recoup energy efficiency investments through rent or resale, they are more hesitant to make those investments. Informational interventions have been designed to alleviate or remove these barriers.

These include programs that encourage or subsidize building audits, programs promoting energy management and information systems, product labels (ENERGY STAR, EnergyGuide), or building designations (ENERGY STAR Buildings) that provide better information and disclosure about energy costs. These programs have the goal of encouraging greater energy and cost savings by addressing barriers related to information, awareness, and materiality. Building owners and occupants may lack capacity to identify opportunities for energy-saving improvements, data on energy usage may not be transparent, and consumers may lack information or focus on energy.

Building energy benchmarking and transparency policies (Figure 3.16) require reporting of building energy performance to raise building owners' knowledge base of properties' energy usage; they provide greater transparency for current and prospective tenants; they highlight cost-effective, energy-saving opportunities; and they provide market data to allow for enhanced deployment of efficiency efforts on the part of relevant agencies.[99] Building benchmarking and auditing data provide a database of information over time that support better valuation of energy efficiency measures in commercial buildings for future owners and investors. Regulations that require building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), or point of sale disclosure or upgrades (or both) for commercial buildings have been adopted by 8 states and 14 cities.

Figure 3.16. U.S. building benchmarking and disclosure policies, as of 2014[100]



A growing number of states and communities are adopting building information transparency policies. These include building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), and point of sale disclosure or upgrades (or both).

3.6.3 Incentives and Rebates

Incentives and rebates have the goal of increasing the market adoption of energy efficiency measures by lowering their incremental up-front cost. These approaches address barriers of first costs, short payback requirements, lack of monetization of non-energy benefits, materiality, and information and awareness.

Incentives and rebates are payments to end users that reduce or offset the incremental cost of energy efficient technologies, such as those offered by utility customer-funded programs. Currently, there are more than 300 of these programs nationwide targeting the commercial sector. Most programs are technology-specific; some are offered based on whole-building energy savings achieved. In December 2015, the U.S. Congress extended the commercial building tax deduction through 2016. The deduction is applicable for expenses incurred for energy-efficient building expenditures made by a building owner and is capped at \$1.80 per ft^2.[101]

3.6.4 Financing

Energy efficiency financing programs have the goal of facilitating greater adoption of efficiency measures by providing capital at attractive terms for such investments. Financing is often packaged with other programmatic offerings, such as rebates, to help drive demand. Financing programs address such barriers as lack of capital, first cost, transaction costs, and performance risk.

- Utility demand-side management financing programs – For example, for on-bill financing, the utility makes a loan to a customer for energy efficiency improvements, and the utility collects the loan payment on the customer's bill.
- Financing offered by state energy offices – According to the National Association of State Energy Officials, more than \$2 billion in state energy office-administered financing is available for energy efficiency and renewable energy projects in 44 states.[102] For example, many state energy offices administer loan programs (e.g., using general obligation bonds or revolving loan funds) offering low-interest loans for energy efficiency improvements.
- Energy investment partnerships and green banks – These entities are stand-alone public or quasi-public entities created to use existing sources of public funds (e.g., ratepayer funding, greenhouse gas allowance proceeds) to attract private capital for clean energy projects. The entities emphasize the idea of "leverage"—seeking to attract multiple dollars of private investment for every dollar of public investment—as a way to increase private market activity in energy efficiency today and ultimately transition to a model that relies solely on private investment. Rather than make direct loans with their own funds, green banks focus on strategies that attract private capital, such as offering loan loss reserves or other forms of credit enhancement. A recent report by DOE provides an overview of state energy investment partnerships.[103]
- Property-PACE programs – PACE programs finance energy efficiency improvements in the commercial sector (as well as the residential sector). Through third-party financing, local governments finance the up-front costs of these investments, and property owners repay the costs as a line item on their property tax bills.
- Energy-saving performance contracting – Performance contracting is a partnership with an ESCO to design, construct, maintain, and conduct M&V for energy-saving projects (see appendix 7.9). Performance contracting provides a financial guarantee to the lender that the energy savings generated will cover debt service on the project.
- Capacity markets for energy efficiency investments – Capacity markets offer another market for energy efficiency resources in regions of the United States with restructured electricity markets. A capacity market procures capacity resources one to three years in advance of delivery for future load-serving entity requirements. Capacity resources can include energy efficiency as well as other qualifying resources. For example, PJM's capacity market cleared 923 megawatts (MW) of energy efficiency resources for delivery in 2015-2016 (at clearing prices of \$136 to \$357/MW per day), an increase from 569 MW in 2012-2013. Energy efficiency resources in the ISO New England forward capacity market averaged 229 MW from 2011 to 2014 (at recent clearing prices of about \$130/MW per day).[104]

3.6.5 Rate Design

Electric utility tariff structures may affect customer energy consumption and investments in energy efficiency by addressing barriers such as information and materiality. Improving rate design can encourage (or at least not discourage) such investments:[105]

- Tiered (inclining block) rates – Inclining block rate structures charge a higher rate for each incremental block of electricity consumption. They are common worldwide and are based, in part, on the theory that higher usage typically is associated with consumption during times of peak demand. The effectiveness of this structure depends partly on the customers' knowledge of this rate structure and awareness of their consumption.[106]
- Demand charges – These are monthly charges based on a customer's maximum usage in an hour or shorter period of time. Charges may be based on a customer's highest load coincident with the electric system's peak demand, or the customer's non-coincident peak—the highest load during the billing period regardless of when it occurs. The theory is that the customer's own peak drives the sizing and costs of grid equipment closest to the customer, and coincident peak loads are correlated with peak needs for generation, substations, and transmission. The level and structure of demand charges can influence customer interest in energy efficiency measures, demand response programs, and on-site generation that reduce the customer's maximum demand on the grid. However, charges based on non-coincident demand may not track underlying electricity costs well and may encourage customers to shift loads in a manner that does not reduce system costs.
- Time-varying rates – The underlying costs of providing electricity vary hourly and seasonally. Tying rates more closely to the actual cost of providing electricity can give customers more economically efficient incentives to reduce usage during costly periods. In addition to encouraging energy efficiency measures that affect consumption during peak periods, time-varying rates also can increase customer use of sensors and controls and energy management systems and interest in demand response programs.

3.6.6 RD&D for End-Use Technologies

RD&D in energy efficiency is undersupplied because many energy efficiency technologies cannot find sufficient demand from transparent, robust markets. Direct support for RD&D may include incentives for manufacturer incentives, such as ongoing DOE support for SSL. The QTR provides more detail on federal RD&D activities related to end-use technologies.

3.6.7 Workforce Training

The Federal Energy Management Program provides in-person and online training for energy managers and other energy workers on how to construct, operate, and maintain facilities in an energy-efficient and cost-effective manner. Several government agencies (National Science Foundation, U.S. Department of Labor, and DOE) fund many specific training courses in energy services and manufacturing across the U.S. at community colleges and universities. In addition, DOE works with industry partners such as the National Institute of Building Sciences to develop training and certification guidelines. With the development of the Better Buildings Workforce Guidelines, a voluntary national program, DOE is helping to improve the quality and consistency of the training and certification programs offered to the buildings workforce for four key energy-related jobs: building energy auditor, building commissioning professional, building operations professional, and energy manager.

Table 3.10. Major Policies, Regulations, and Programs to Address Barriers to Energy Efficiency in the Commercial Sector

Policy, Regulation, or Program	Description and Implemented Examples	Principal Barriers Addressed
Codes and standards	• Mandatory prescriptive or performance-based energy codes that regulate building energy efficiency (ASHRAE 90.1 2010 or higher standards in 22 states) • Minimum performance standards for appliances and end-use equipment (commercial equipment federal energy efficiency standards for 14 product types, 11 of which are electric) • Voluntary "green" or "reach" codes	*Information/awareness, materiality, split incentives* • Standards set a minimum level of performance, guarding against uninformed or inattentive purchase of inefficient devices and limiting the impact of split incentives.
Clean energy mandates and target-setting	• Energy efficiency resource standards that mandate levels of savings across a sizable jurisdiction (e.g., across the entire state or all regulated utilities in a state) • Other mandates (e.g., a mandate by a state public utility commission to achieve all cost-effective energy efficiency)	*Price signals, lack of private incentive for R&D, various others* • These policies are generally enacted for clean energy policy reasons, meaning they are primarily intended to serve as a proxy for the social benefits of saving energy and other non-energy benefits.
Grants and rebates	• Payments to consumers that reduce or offset the incremental cost of efficient technologies, such as those offered by utility customer-funded programs (currently more than 300 commercial energy efficiency programs nationwide) • Most grant and rebate programs are technology-specific; some are offered based on whole-building energy savings achieved.	*First costs, short payback requirements, non-energy benefits, materiality, information/awareness* • Rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for non-priced social benefits of energy efficiency adoption.
Resource planning	• Utility integrated resource planning (IRP) to ensure system reliability at least cost and risk that appropriately factors in energy efficiency.	*Price signals, non-energy* benefits • IRPs can ensure efficiency is valued appropriately in utility planning for energy and capacity.

Policy, Regulation, or Program	Description and implemented examples	Principal barriers addressed
Informational interventions	• Programs that encourage or subsidize building audits • Programs promoting energy management systems • Regulations that require energy disclosure for comparative benchmarking (8 states and 14 cities with commercial policy adopted) • Product (e.g., ENERGY STAR, EnergyGuide), building (e.g., ENERGY STAR), and utility Demand Side Management (DSM) programs	*Information/awareness, materiality* • Building owners and occupants may lack capacity to identify opportunities for energy-saving improvements. • Data on energy usage may not be transparent. • Efficiency may not be adequately salient to consumers due to lack of information or the lack of focus on energy.
Rate design	• Tiered (inclining block) rates • Time-varying rates • Demand charges	*Price signals, non-energy benefits* • Tariff structures may discourage customer investments in energy efficiency.
RD&D for end-use technologies	• Direct support for RD&D; prizes/contests/other manufacturer incentives (e.g., ongoing DOE support for solid-state (LED) lighting through contests, product testing support, stakeholder workshops, etc.)	*Lack of private incentive for R&D* • In general, and particularly in the energy industry, RD&D is undersupplied absent policy intervention.
Financing	• Mostly utility DSM financing programs • Some financing offered by state energy offices, green banks, or by programs that are largely private (e.g., PACE programs) • Programs that facilitate and encourage energy savings performance contracting	*Lack of capital, first costs, transaction costs, performance risk* • Financing programs extend capital and often eliminate up-front cost entirely. Financing is often packaged with other programmatic offerings and potentially removes the need to seek out a source of capital, which can otherwise be a barrier to program participation. Performance contracting transfers energy performance risk to the energy services company. Performance contracting also provides technical expertise and lowers transaction costs.
Tax incentives	• Personal income tax credits (federal/state) • Sales tax incentives (state) • Property tax incentives (state or local)	*Non-energy benefits, price signals* • Like rebates, tax incentives can be a proxy for non-priced social benefits. They also alter depreciation timescales that otherwise do not accurately portray equipment lifetime and help compensate where energy cost is deductible and therefore subsidized.

3.7 Interactions with Other Sectors

Commercial interactions with the residential and transportation sectors – The commercial sector interacts with the residential sector in mixed-use developments with both residential and commercial units. The commercial sector interacts with the transportation sector in integrated land and transportation-planning policies such as SB 375 in California.[107] This policy sets regional targets for greenhouse gas (GHG) pollution reduction from passenger vehicle use in 2020 and 2035. California SB 375 is projected to save 3.0 million metric tons of CO_2 equivalent by 2020. Each region of the state must prepare an integrated land use, housing, and transportation strategy that, if implemented, would allow the region to meet its GHG emission-reduction targets. Such mixed use and transit-oriented development is designed to centralize activities, reduce passenger-vehicle miles traveled, and promote greater use of public transportation. Future commercial developments may feature more PEV-charging infrastructure and possibly better accommodation for car sharing. Recent programs in California (e.g., South Coast Air Quality Management District Rule 2202)[108] provide options for employers to reduce mobile source emissions generated from employee commutes, to comply with federal and state Clean Air Act requirements and include credits for low-emission vehicles. If adopted nationally, these types of programs may contribute to an increased demand for workplace charging infrastructure.

Development patterns and urbanization will have system-wide impacts (e.g., across economic development, construction, energy, and water), and interactions among the commercial, residential, transportation, and DER sectors. Greater urbanization affords additional opportunities for more energy-efficient systems such as district energy systems. Leading strategies include ambient heat-pump loops thermally connecting multiple urban/dense buildings and districts enabling load sharing, load diversity, and economies of scale. Microgrids and shared renewable energy resources also become more cost-effective at larger district scales.

Telecommuting and e-commerce – Greater adoption of telecommuting by office workers is expected to reduce office electricity use and increase electricity use in the residential sector. A greater degree of e-commerce could shift the distribution of buildings from retail stores to more warehouses. This could impact HVAC loads by reducing retail floor space. More e-commerce could increase the electricity demand for information technology equipment. Regular work-at-home telecommuting is projected to increase from 2.9 million workers in 2011 to 4.9 million in 2016[109] (11% annual growth), and the number of workers who telecommute at least occasionally is projected to reach 63 million in 2016.[110] E-commerce sales are projected to grow to about $450 billion by 2018 with a 10% annual growth rate.[111]

3.7.1 Distributed Energy Resources

Distributed generation – According to a recent study, the technical potential[a] for combined heat and power (CHP) in the U.S. commercial sector is 68 gigawatts (GW) by 2020, compared to 11.0 GW of CHP installed in the sector in 2012.[112] Also promising are higher-density developments or multi-building distributed heating and cooling systems. For example, a CHP system powering a nonresidential facility may provide district heating to neighboring residences, thereby lowering fuel demands for residential

[a] Technical potential is the total market potential where, in this example, CHP technologies have the capability to meet a customer's energy needs. It is not constrained by cost, capital availability, owner interest, fuel availability, or other factors. Economic potential considers three cases: (1) payback time more than 10 years, (2) payback time between 5 and 10 years, and (3) payback time less than 5 years. The Hedman et al. 2013 study does not break out economic potential by industrial and commercial sectors. The three economic potential cases are quoted at 81.7, 35.3, and 6.4 GW, respectively. A commercial sector share of about 50% of the economic potential would yield about 41, 17.5, and 3.2 GW, respectively.

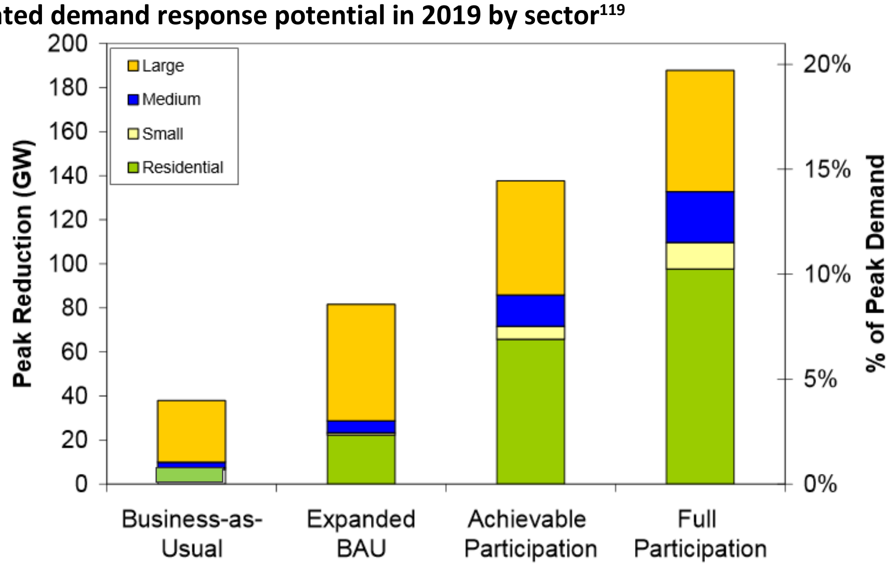
heating. Properly designed, these integrated system approaches may offer the prospect of greater efficiency and lower cost.[113]

The market for PV rooftop systems for commercial buildings is expected to grow. “Community solar” enables commercial building tenants as well as owners of commercial buildings that do not have a sufficient solar resource to buy or lease a portion of an off-site solar PV system. Shared solar is an emerging area with potential ramifications to expand the flexibility of buildings to meet ZNEB goals.[114]

Demand response and distributed energy storage (see Chapter 6 for additional information) – The commercial and industrial sectors account for 55% of total achievable potential for peak demand-reduction capacity in the United States in 2019 (Figure 3.17). Demand response in these sectors is forecast to achieve a peak demand reduction capacity in 2019 of about 8%.[115] Commercial buildings with demand-shifting using thermal mass, thermal storage, or battery storage can provide load leveling and reduce peak demand.[116] Thermal energy storage is a proven technology[117] and can be used to pre-cool buildings at times when electricity demand and prices are lower.

Distributed energy storage is rapidly expanding with declining costs. Most of the market growth appears to be in commercial buildings or for utility grid support. Current operational capacity of distribution-side storage is 180 MW, with 162 MW under construction, contracted, announced, or under repair. Median storage system capacity is 151 kW. Thermal storage (e.g., chilled water, ice) has the largest share at 37%.[118] Growth in distributed storage is in part driven by a mandate in California to add 1.3 GW of storage (both distributed and grid-connected) by 2020, compared to 2013. The growth of battery storage through sales of PEVs is another key driver in lowering the cost of distributed battery storage.

Figure 3.17. Estimated demand response potential in 2019 by sector[119]



The expanded business-as-usual (BAU) scenario represents the extension of traditional programs to states that have little to no participation. The achievable participation scenario includes dynamic prices. The full participation scenario is an estimate of how much cost-effective demand response would take place if advanced metering infrastructure were universally deployed and all customers were on dynamic pricing tariffs and use enabling technology where it is cost-effective. Large, Medium, and Small refer to commercial and industrial sites.

3.8 Research Gaps

Following are key research questions and research gaps related to electricity consumption and energy efficiency in the commercial sector:

- How will U.S. demographic and social trends, and trends in the commercial sector, affect the future distribution of commercial floor space and energy use intensity by building category and size? Demographic trends include aging population, shrinking family/household size, continuing immigration, shifts between large and medium size urban centers, changes in the distribution of income and wealth, and increasing leisure time. Commercial sector trends include increased e-commerce and flexible employment location.
- What is the opportunity to use decision and behavioral science[a] to reduce energy consumption in the commercial sector? Do existing policies, regulations, and programs (e.g., building energy codes, equipment standards, technical assistance, financial incentives) successfully address the behavior of commercial consumers and split incentives (landlord-tenant, utility-ratepayer, and builder-owner)? If not, what changes might be required? Relatedly, how should building energy codes take into account the impact of building occupants and operators on energy use? Should energy efficiency activities take advantage of social learning by emphasizing leaders (technical and financial assistance to early adopters), or should we focus more on incentives to the laggards for faster following?
- How can we better characterize commercial buildings with large opportunities for efficiency improvements? What policy and program options could better address energy efficiency in small commercial buildings?
- What analytical framework should be adopted to prioritize particular commercial sector end-use categories that offer the greatest benefits at least cost?
- How can energy-efficient commercial-sector building designs be better integrated with benefits that may be hard to quantify and monetize? These include the following:
  - Impact on primary energy[b] saved or generated from commercial sector operations
  - Impact on water consumption
  - Impact on GHG emissions, other air pollutants, and water pollutants during building operation on a life-cycle basis
  - Impact on other sectors (e.g., residential, transportation)
  - Impact on energy security
  - Impact on occupant health, productivity, and satisfaction
  - Impact of electric transportation when workplace charging systems are incorporated.
- How can we close the gap between modeled and designed building efficiency and actual performance over time? Closing this gap requires more detailed information about actual building occupancy, use, and as-built conditions, as well as advances in building energy-modeling calibration. More accurate input data could come from enhanced measurement and monitoring capabilities through sensors and data collection or from M&V for outcome-based building energy codes and outcome-based efficiency programs. Programs that achieve energy efficiency savings through operational, behavioral, and energy auditing activities are being pursued in some states.

---

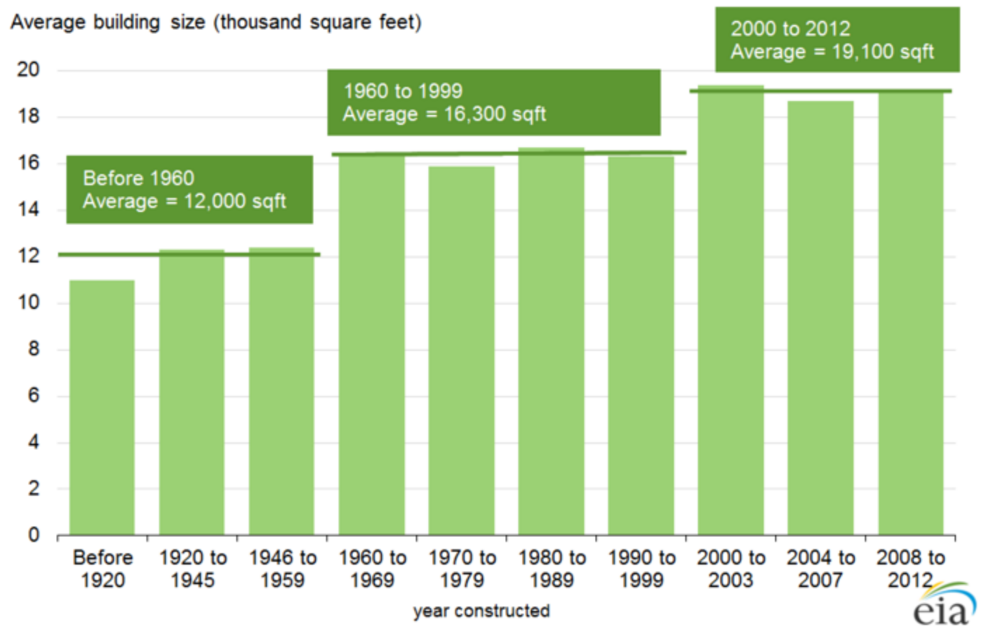
[a] Decision science involves research on how people make judgments and decisions and how they interact with one another.
[b] *Primary energy* refers to the upstream direct energy input that is required for end-use energy consumption. For example, a thermal power plant typically requires three units of energy or fuel to make one unit of end-use electricity consumed at a customer's site.

- How can the cost effectiveness of zero net energy buildings be improved, and how can greater flexibility of distributed energy supplies be achieved? More studies are needed on the cost-effectiveness of new ZNEBs considering an integrated package of energy efficiency measures rather than analysis of discrete measures, as well as a better understanding of the cost-effectiveness of ultra-low energy or ZNEB retrofits. Some of the key consumer adoption issues that need to be resolved for "shared solar" or offsite renewable generation include a lack of uniformity and standardization of consumer contracts, rate design, and program structure,[120] and the need for a framework to track and match off-site renewable resources to specific buildings claiming an offset.[121] Thus, an analysis of the policy choices, impacts, and cost implications of ZNEB generation would be helpful.

Commercial Appendix

Figure 7.17 shows that office buildings' share of electricity consumption has been falling since 1992, with a growing share from mercantile and service, education, and food sales. Figure 7.18. shows electricity intensity by building category in units of kilowatt-hours per square foot (kWh/ft^2). Total electricity intensity is highest in the food sales, food service, health care, and other[a] building categories. Mercantile and service, education, and assembly building intensity has increased by about 40%, 30%, and 20%, respectively, from 1995 to 2003. These results should be viewed as intermediate results since building-level consumption data have not yet been released from the 2012 Commercial Buildings Energy Consumption Survey (CBECS). The combination of building-level consumption data and floor space data from 2012 will provide better insight into recent consumption and electricity intensity trends by building category.

Figure 7.17. New commercial buildings are larger, on average, than older buildings[122]



Buildings constructed from 1960 to 1999 are 36% larger than buildings built before 1960, and buildings constructed from 2000 to 2012 are 59% larger than pre-1960 buildings.

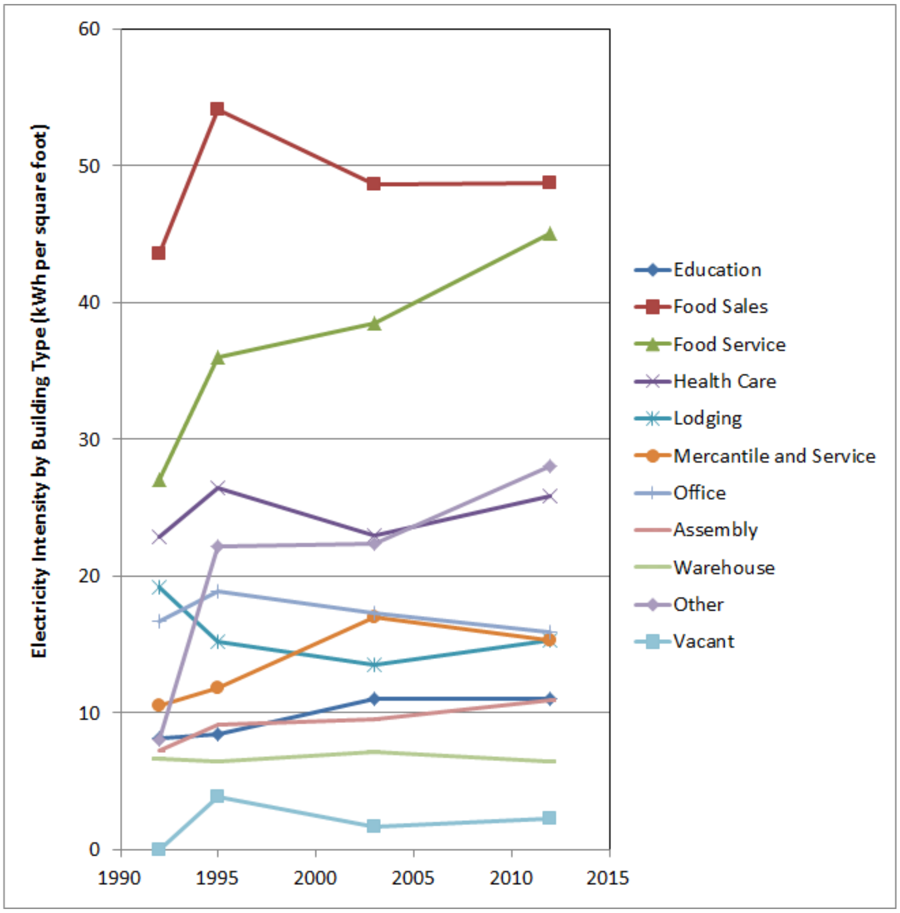
[a] "Other" buildings include data centers and server farms, airplane hangars, crematoriums, laboratories, telephone switching centers, agricultural facilities with some retail space, and manufacturing or industrial facilities with some retail space. The classification of data centers depends on the source of data: CBECs includes them in its inventory of buildings. The Annual Energy Outlook (AEO) includes data centers in the sector where their energy supplier classifies them. Thus, they could be classified in the industrial sector. Joelle Michaels, CBECS Survey Manager, personal communication, November 2, 2015.

Table 7.6. Summary of Electricity Consumption by Building Category from CBECS 2003 and 2012 [123]

Principal building activity	Building Floorspace (Billion sq. ft.)		% change 2003 to 2012	Building Electricity Intensity (kWh per sq. ft.)		% change 2003 to 2012	Electricity (TWh)		% change 2003 to 2012	% of End-Use Electricity by Building Type	
	2003	2012		2003	2012		2003	2012		2003	2012
Food sales	1.26	1.25	0%	49.4	48.7	-1%	61.0	61.0	0%	5.8%	4.9%
Food service	1.65	1.82	10%	38.4	45.0	17%	63.6	81.8	29%	6.0%	6.6%
Other	1.74	2.00	15%	22.5	28.0	24%	39.0	56.0	44%	3.7%	4.5%
Vacant	2.57	3.26	27%	2.4	2.3	-4%	4.4	7.6	73%	0.6%	0.6%
Health care	3.16	4.16	31%	22.9	25.8	12%	72.7	107.0	47%	6.8%	8.6%
Lodging	5.10	5.83	14%	13.5	15.3	13%	68.9	89.1	29%	6.5%	7.2%
Education	9.87	12.24	24%	11.0	11.0	0%	108.7	134.2	23%	10.2%	10.8%
Warehouse	10.08	13.03	29%	7.6	6.4	-16%	71.5	83.2	16%	7.2%	6.7%
Mercantile/ Service	15.24	15.96	5%	19.2	15.3	-20%	258.5	243.8	-6%	20.2%	16.6%
Office	12.21	15.95	31%	17.3	15.9	-8%	210.7	253.5	20%	19.8%	20.4%
Assembly	8.78	11.60	32%	10.9	10.1	-8%	83.8	125.7	50%	13.2%	13.1%
Total	71.65	87.09	22%	14.6	14.3	-2%	1042.8	1242.9	19%	100%	100%

Overall building electricity intensity is down slightly (-2%) with fairly stable fractions of end-use electricity by building type.

Figure 7.18. Trend in electricity intensity in kWh/ft² by building category from 1992 to 2012[124]

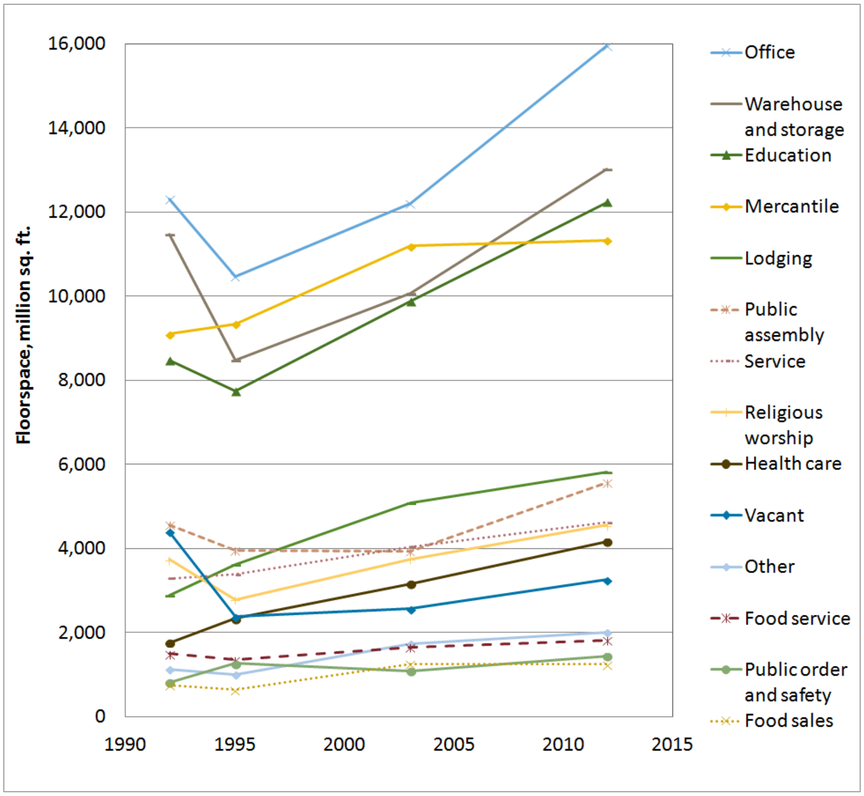


Total electricity intensity is highest in the food sales, food service, other, and health care building categories.[a]

[a] For comparison with 1992 and 1995 CBECS data, which had fewer building categories, 2003 data for some building categories are combined. Mercantile and service includes mercantile (mall), mercantile (non-mall), and services; health care includes inpatient and outpatient healthcare; assembly includes public assembly, public order, and safety and religious worship.

Figure 7.19. shows the trend in building floor space since 1992. Floor space has increased the most in public assembly, health care, office buildings, warehouses and education, with total mercantile floor space holding steady from 2003 to 2012.

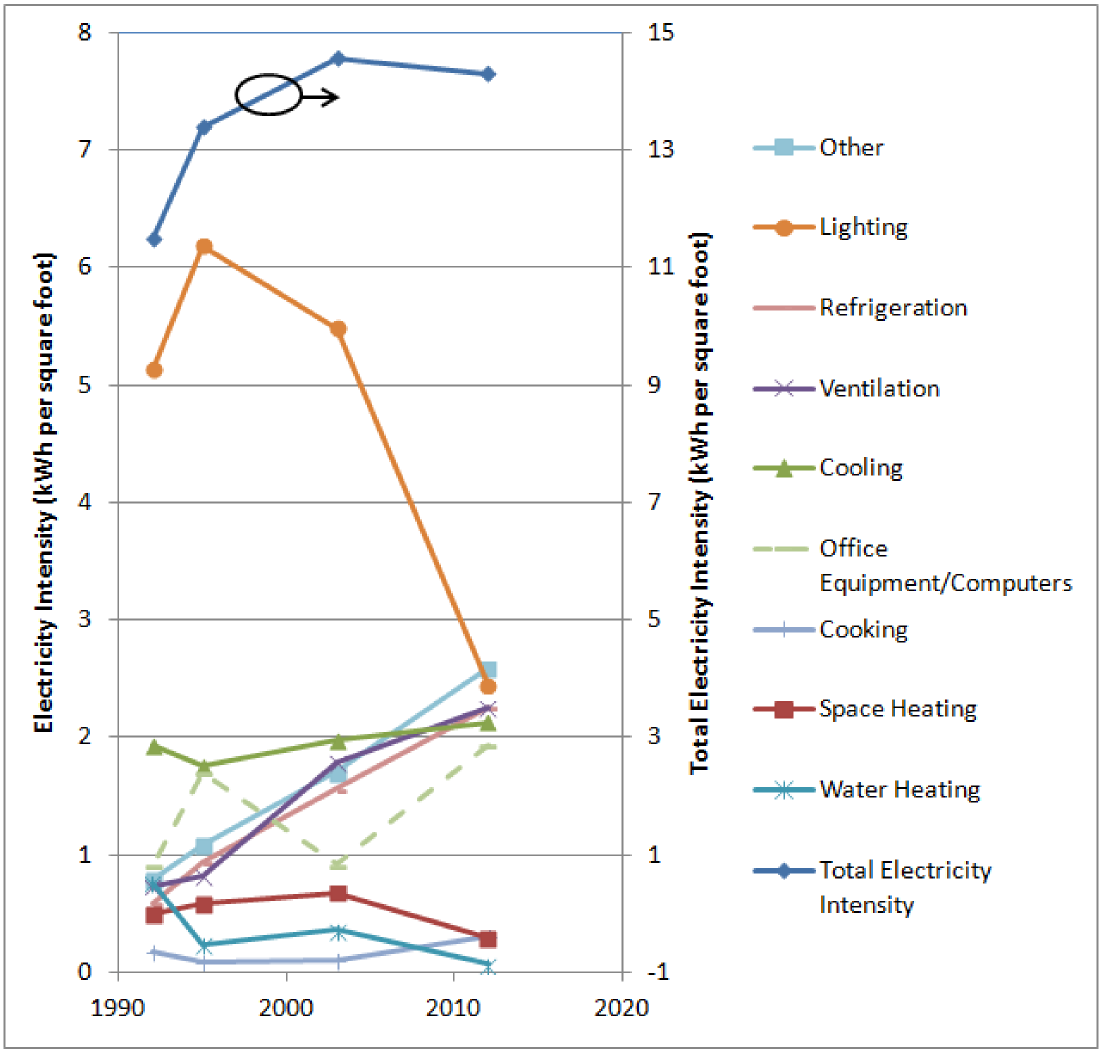
Figure 7.19. Building floor space trend from 1992 to 2012[125]



Floor space increased most rapidly in public assembly, health care (both inpatient and outpatient), office buildings, and warehouse and storage buildings from 2003 to 2012. Overall, annual growth in floor space was 2.2% over this period.

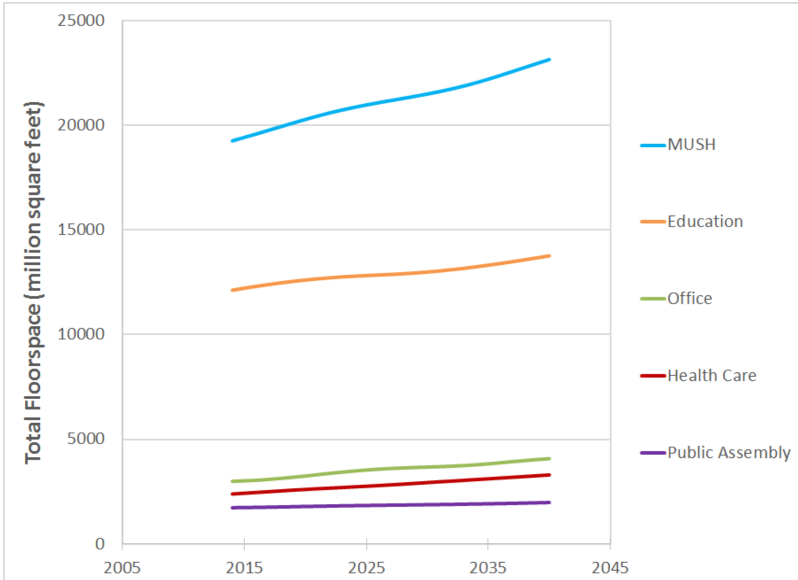
Figure 7.20. shows that total electricity intensity (kWh/ft^2) increased by 11% from 1995 to 2003 (right axis) as the demand for more services that use electricity increased. The most electricity-intensive end uses are lighting, cooling, ventilation, and other, together making up 75% of overall sector electricity intensity. Lighting intensity has been falling due to more efficient lighting and controls, but this is more than offset by increases in ventilation, refrigeration, cooling, and other end uses.

Figure 7.20. Trend in electricity intensity in kWh/ft^2 by end use from 1992 to 2012[126]



Total electricity intensity decreased slightly by 1.8% from 2003 to 2012 (right axis), led by a sharp drop in lighting intensity. Six end uses contribute between 14% and 18% of overall sector electricity intensity (other, lighting, refrigeration, ventilation, cooling, and office equipment/computers). Note: The circled data series (Total Electricity Intensity) uses the right axis.

Figure 7.21. Floor space projection in Municipal, University, School, and Hospital (MUSH) buildings for 2014 to 2040[127]



Overall, floor space in the MUSH subsector is projected to increase by 0.7% per year. Health care is growing fastest at 1.2% per year.

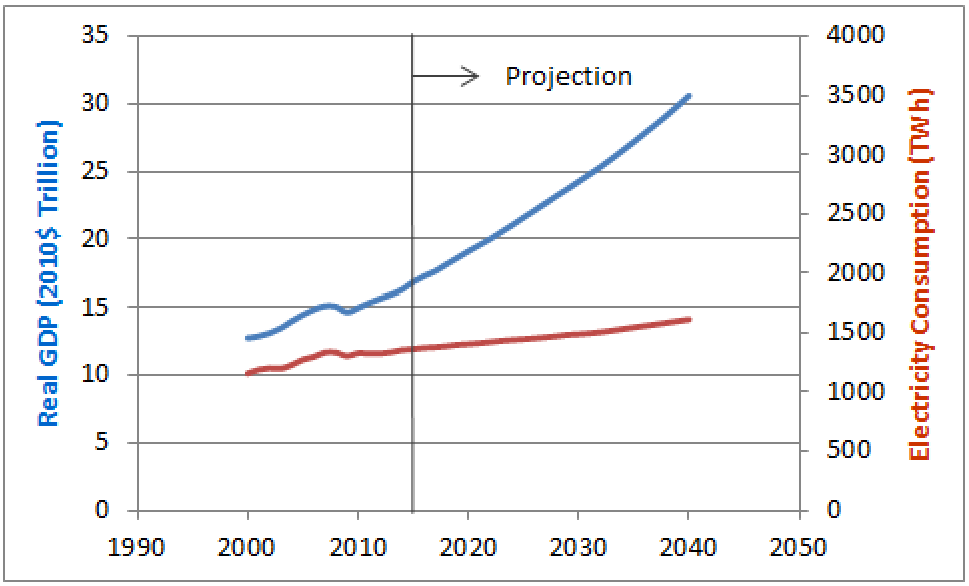
Table 7.7. Federal Appliance Standards for Commercial Products[128 129]

Product Covered	Initial Legislation	Last Standard Issued	Effective Date	Issued By	Updated DOE Standard Expected
Commercial Water Heaters	EPACT 1992	2001	2003	DOE	2016
Warm Air Furnaces, Commercial	EPACT 1992	2016	2018	DOE	2024
Water-Source Heat Pumps (HP)	EPACT 1992	2001	2003	DOE	2016
Commercial Central Air Conditioning (CAC) and HP (65,000 Btu/hr to 760,000 Btu/hr)	EPACT 1992	2015	2018/2023	DOE	2025
Commercial CAC and HP (<65,000 Btu/hr)	EPACT 1992	2015	2017	DOE	2023
Packaged Terminal AC and HP	EPACT 1992	2015	2018	DOE	2023
Single Package Vertical AC and HP	EPACT 1992	2015	2018	DOE	2023
Boilers, Commercial	EPACT 1992	2009	2012	DOE	2016
Vending Machines	EPACT 2005	2016	2019	DOE	2024
Commercial CAC and HP (Water- and Evaporatively Cooled)	EPACT 1992	2012	2013	DOE	2018
Clothes Washers, Commercial	EPACT 2005	2014	2018	DOE	2021
Commercial Refrigeration Equipment	EPACT 2005	2014	2017	DOE	2022
Walk-in Coolers and Freezers	EISA 2007	2014	2017	DOE	2016
Automatic Commercial Ice Makers	EPACT 2005	2015	2018	DOE	2023
Pumps	EPCA	2015	2020	DOE	2024

Of the 14 standards, 11 are for electricity-powered appliances. Updated standards for all products are expected by 2023.

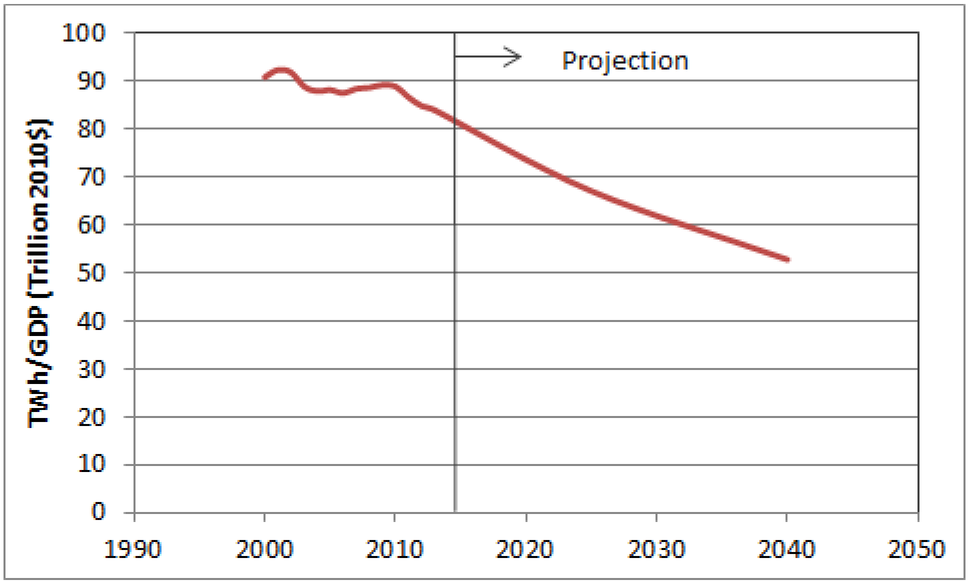
Figure 7.22. and Figure 7.23. show commercial electricity use relative to economy-wide gross domestic product (GDP). Gross domestic product is projected to grow 2.4% annually from 2012 to 2040, but commercial electricity consumption is projected to grow at a much lower rate (0.7% per year). This represents a 26% higher GDP growth rate than in the past 15 years (1.9% annual growth), but closer to the 50-year historical average of 2.8%. Conversely, projected growth in commercial-sector electricity use to 2040 is about 40% lower than the 1.1% annual growth rate since 2000. The net result is a projected 1.7% annual reduction in the ratio of electricity consumption to GDP through 2040 (Figure 7.23.).

Figure 7.22. Trend of real GDP and commercial electricity sector consumption[130]



Real GDP is projected to grow at about three times the rate of electricity consumption (2.4% per year vs. 0.8% per year, respectively).

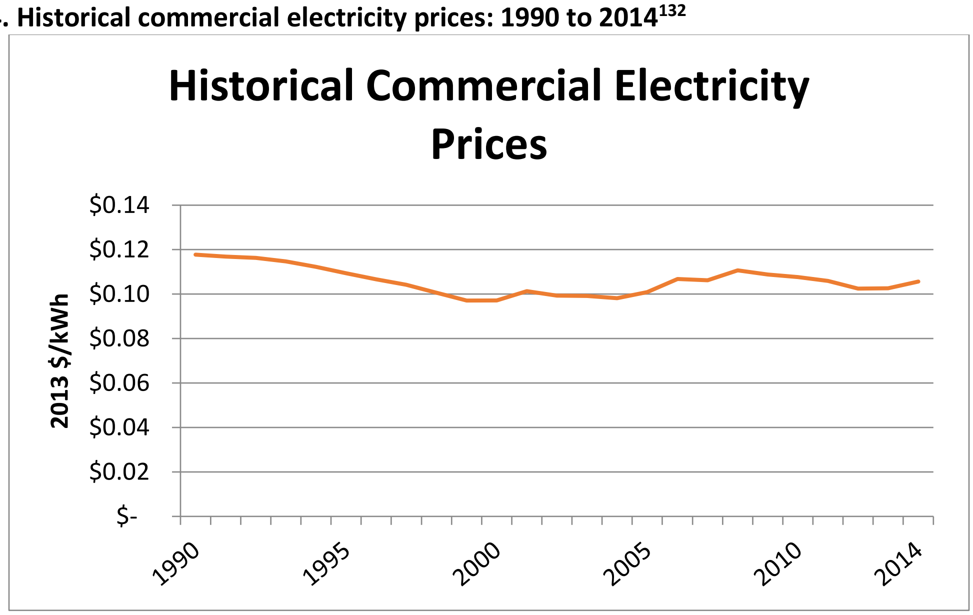
Figure 7.23. Commercial electricity end-use energy per unit of GDP (GDP units in US$ trillion (2010), CO_2 in million metric tons, and electricity in terawatt-hours [TWh]) [131]



The ratio of TWh per unit of GDP is projected to drop by 35% from 2013 to 2040, and commercial CO_2 per unit of GDP to drop by 42%.

As Figure 7.24. shows, between 1990 and 2014, commercial sector electricity prices decreased 10% in real terms (constant 2013 dollars), from 11.8 cents/kWh to 10.6 cents/kWh. Electricity prices for the commercial sector are higher than industrial sector prices but lower than residential sector prices.

Figure 7.24. Historical commercial electricity prices: 1990 to 2014[132]



Electricity prices in the commercial sector decreased by 10% in real terms (constant 2013 dollars) between 1990 and 2014.

7.4.1 Characterization of "Other Uses"

As characterized by NEMS in the EPSA Side Case, the "Other uses" category includes an adjustment to relieve discrepancies between supply- and consumption-side data sources. Figures 7.25 and 7.26 below present an alternative characterization of commercial end-use consumption in 2014 and 2040. These figures re-allocate this adjustment proportionally to the other end uses, rather than including it together with the "Other uses" category. "Other uses" remain the largest end use in 2014 and 2040.

Figure 7.25. Commercial electricity consumption by end use, with adjustment re-allocation, 2014

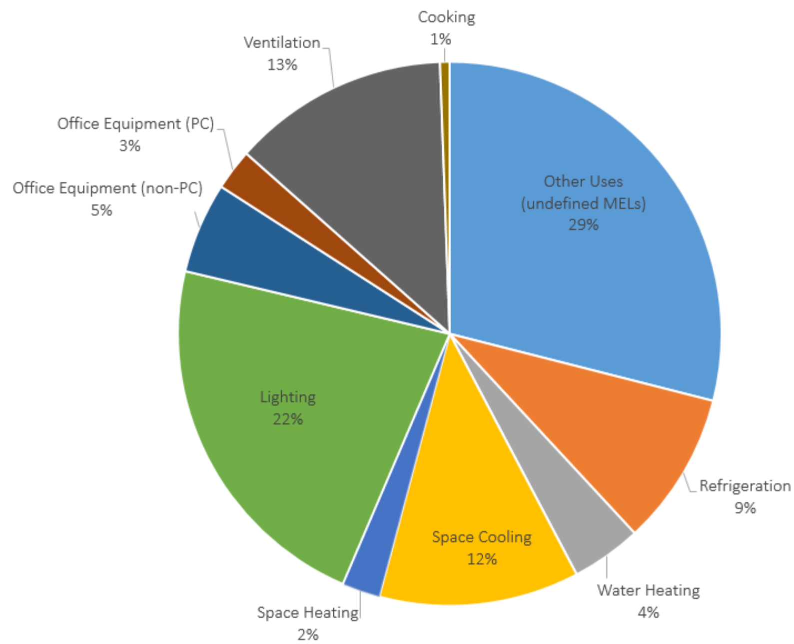
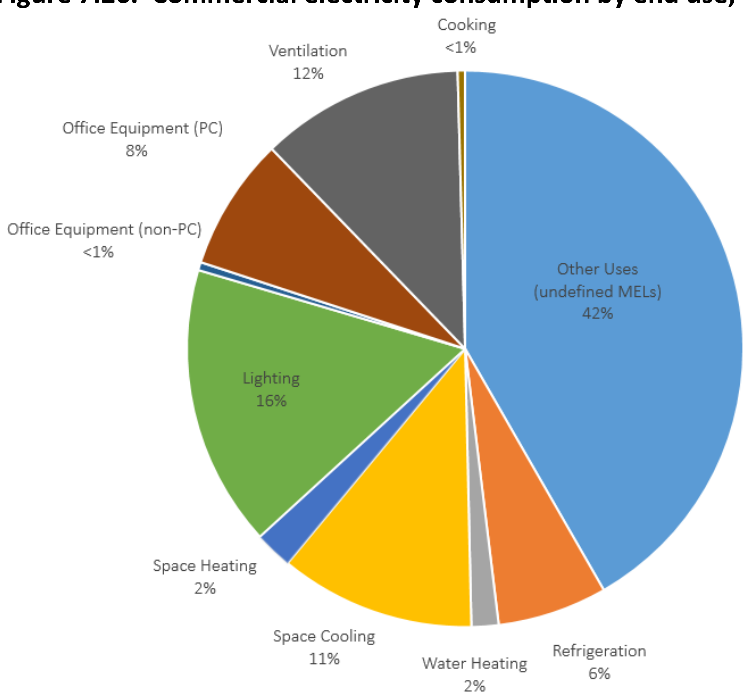


Figure 7.26. Commercial electricity consumption by end use, with adjustment re-allocation, 2040



References

[1] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey Survey Data*. Table B1. 2012. https://www.eia.gov/consumption/commercial/data/2012/#b3.

[2] U.S. Energy Information Administration. *Annual Energy Outlook 2014: With Projections to 2040*. Tables IF-47, MT-5, A-3, A-35. 2014. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

[3] U.S. Energy Information Administration. *Annual Energy Outlook 2015: With Projections to 2040*. Table A3. April 2015. DOE/EIA-0383(2015). http://www.eia.gov/forecasts/archive/aeo15/.

[4] U.S. Energy Information Administration. *2012 Residential Energy Consumption Survey Data*. Table HC1.1. 2009. http://www.eia.gov/consumption/residential/data/2009/

[5] Department of Energy Building Technologies Office. *History and Impacts*. http://energy.gov/eere/buildings/history-and-impacts. Accessed January 25. 2016.

[6] Steven Nadel. *Electricity Distribution & End Use: Challenges & Opportunities.* American Council for an Energy-Efficient Economy. 2016. http://energy.gov/sites/prod/files/2016/02/f29/Panel%202%20Steve%20Nadel.%20Executive%20Director.%20American%20Council%20for%20an%20Energy%20Efficient%20Economy_0.pdf.

[7] U.S. Energy Information Administration. *Annual Energy Review*. Table 9.8 - Average Retail Prices of Electricity. 2014. http://www.eia.gov/totalenergy/data/annual/index.php. Accessed September 15. 2015.

[8] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey Preliminary Results*. Table B1. 2012. https://www.eia.gov/consumption/commercial/reports/2012/preliminary/. Accessed March 17. 2016

[9] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 20, 2016.

[10] U.S. Energy Information Administration. *2003 Commercial Building Energy Consumption Survey*. Table 2. 2003. http://www.eia.gov/consumption/commercial/data/2003/; U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*. Table 6. 2012. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17. 2016.

[11] U.S. Energy Information Administration. 1992 *Commercial Building Energy Consumption Survey*. Table 3. 1992. http://www.eia.gov/consumption/commercial/data/1992/; U.S. Energy Information Administration. *1995 Commercial Building Energy Consumption Survey Data*. Table 3. 1995. http://www.eia.gov/consumption/commercial/data/1995/; U.S. Energy Information Administration. *2003 Commercial Building Energy Consumption Survey Data*. Table 2.11. 2003. http://www.eia.gov/consumption/commercial/data/2003/; U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*. Table 6. 20120. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17. 2016.

[12] U.S. Energy Information Administration. *1992 Commercial Building Energy Consumption Survey Survey Data*. Table 3. 1992. http://www.eia.gov/consumption/commercial/data/1992/; U.S. Energy Information Administration. *1995 Commercial Building Energy Consumption Survey Survey Data*. Table 3. 1995. http://www.eia.gov/consumption/commercial/data/1995/; U.S. Energy Information Administration. *2003 Commercial Building Energy Consumption Survey Data*. Table 2.11. 2003. http://www.eia.gov/consumption/commercial/data/2003/; U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*. Table 6. 2012. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Acessed March 17. 2016.

[13] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Preliminary Results.* Table 6. 2012. https://www.eia.gov/consumption/commercial/reports/2012/preliminary/. Accessed March 17, 2016

[14] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Preliminary Results.* Table B9. 2012. https://www.eia.gov/consumption/commercial/reports/2012/preliminary/.

[15] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Preliminary Results.* Table B9. 2012. https://www.eia.gov/consumption/commercial/reports/2012/preliminary/.

[16] U.S. Energy Information Administration. *Electricity Sector Data - Sales (consumption), revenue, prices & customers.* Table B7. 2015. http://www.eia.gov/electricity/data.cfm#sales.

[17] Elizabeth Stuart, Peter H. Larsen, Charles A. Goldman, and Donald Gilligan. *Current Size and Remaining Market Potential of the U.S. Energy Service Company Industry*. Lawrence Berkeley National Laboratory. Table 4. 2013. LBNL-6300E. https://emp.lbl.gov/sites/all/files/lbnl-6300e_01.pdf.

[18] Elizabeth Stuart, Peter H. Larsen, Charles A. Goldma, and Donald Gilligan. *Current Size and Remaining Market Potential of the U.S. Energy Service Company Industry*. A-4. Lawrence Berkeley National Laboratory. 2013. LBNL-6300E. https://emp.lbl.gov/sites/all/files/lbnl-6300e_01.pdf.

[19] U.S. Department of Energy. *Buildings Energy Data Book* (based on 2003 CBECS data). http://buildingsdatabook.eren.doe.gov/CBECS.aspx. Accessed December 10, 2016.

[20] U.S. Energy Information Administration. *Analysis and Representation of Miscellaneous Electric Loads in NEMS.* 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf.

[21] U.S. Energy Information Administration. *1992 CBECS Survey Data*. Table 3; U.S. Energy Information Administration. *1995 CBECS Survey Data*. Table 3; U.S. Energy Information Administration. *2003 CBECS Survey Data*. Table 2.11; U.S. Energy Information Administration. 2*012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary.* Table 6. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17. 2016.

[22] U.S. Energy Information Administration. 2003 Commercial Buildings Energy Consumption Survey Data. Table E5A, 2003. https://www.eia.gov/consumption/commercial/data/archive/cbecs/cbecs2003/detailed_tables_2003/2003set19/2003html/e05a.html. Accessed March 17, 2016.; U.S. Energy Information Administration. 2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary. Table 6. 2012. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17. 2016.

[23] U.S. Energy Information Administration. *2003 Commercial Buildings Energy Consumption Survey Data*. Table 2, 2003. U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*. Table 6. 2012. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17. 2016.

[24] U.S. Energy Information Administration. *Assumptions to the Annual Energy Outlook 2015 - Commercial Demand Module*. 2015. http://www.eia.gov/forecasts/aeo/assumptions/pdf/commercial.pdf.

[25] U.S. Energy Information Administration. *Commercial Building Energy Consumption Survey - Overview of Commercial Buildings.* 2003. http://www.eia.gov/consumption/commercial/data/archive/cbecs/cbecs2003/overview2.html.

[26] U.S. Energy Information Administration. *Analysis and Representation of Miscellaneous Electric Loads in NEMS*. P. 37. 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf.

[27] U.S. Energy Information Administration. *Electricity Sector Data - Sales (consumption), revenue, prices & customers.* Table A5. 2015. http://www.eia.gov/electricity/data.cfm#sales; EPSA Side Case

[28] EPSA Side Case.

[29] EPSA Side Case.

[30] U.S. Energy Information Administration. *Analysis and Representation of Miscellaneous Electric Loads in NEMS*. P 38–40. 2013. http://www.eia.gov/analysis/studies/demand/miscelectric/pdf/miscelectric.pdf.
[31] EPSA Side Case.
[32] U.S. Energy Information Administration. *Electricity Sector Data - Sales (consumption), revenue, prices & customers.* 2015. http://www.eia.gov/electricity/data.cfm#sales.; U.S. Energy Information Administration. *Annual Energy Outlook 2015 with Projections to 2040*; EPSA Side Case.
[33] U.S. Energy Information Administration. *Annual Energy Outlook 2015*. Table A20. 2015. http://www.eia.gov/outlooks/archive/aeo15/.
[34] U.S. Energy Information Administration. *Annual Energy Outlook 2015*. Table C-2. Table C-3. 2015. http://www.eia.gov/outlooks/archive/aeo15/.
[35] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. Figure 5.3. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[36] EIA. "2003 CBECS Survey Data." Table 2-11.
[37] "LED Lighting." Department of Energy. http://energy.gov/energysaver/articles/led-lighting. accessed December 10. 2015.
[38] Norman Bardsley. Stephen Bland. Lisa Pattison. Morgan Pattison. Kelsey Stober. and Mary Yamada. *Solid-State Lighting R&D Plan*. Department of Energy. May 2015. P. 3. http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf.
[39] U.S. Department of Energy Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. Table 3.1. August 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf.
[40] Norman Bardsley, Stephen Bland, Lisa Pattison, Morgan Pattison, Kelsey Stober, and Mary Yamada. *Solid-State Lighting R&D Plan*. p. 4. Department of Energy. May 2015. http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf.
[41] Bardsley Norman, Stephen Bland, Lisa Pattison, Morgan Pattison, Kelsey Stober, and Mary Yamada. *Solid-State Lighting R&D Plan*. p. 5, 83. U.S. Department of Energy. May 2015. http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf.
[42] Bardsley Norman, Stephen Bland, Lisa Pattison, Morgan Pattison, Kelsey Stober, and Mary Yamada. *Solid-State Lighting R&D Plan*. p. 6. U.S. Department of Energy. May 2015. http://energy.gov/sites/prod/files/2015/06/f22/ssl_rd-plan_may2015_0.pdf.
[43] EPSA Side Case.
[44] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 153. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[45] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 152. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[46] EPSA Side Case.
[47] U.S. Department of Energy. *Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces.* Direct final rule. Jan 15, 2016. https://www.regulations.gov/document?D=EERE-2013-BT-STD-0007-0113.
[48] Kimberly Schwartz. "New Standards Focus on Chiller Efficiencies: HVAC Industry Embracing Holistic Approach as ASHRAE 90.1 Continues to Evolve." *Air Conditioning. Heating and Refrigeration News.* May 11. 2015. http://www.achrnews.com/articles/129574-new-standards-focus-on-chiller-efficiencies.

[49] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 152. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[50] U.S. Energy Information Administration. "Commercial Demand Module." *Assumptions to the Annual Energy Outlook 2015*. EIA. 2015. http://www.eia.gov/forecasts/aeo/assumptions/pdf/commercial.pdf.
[51] ARUP North America Ltd.. *The Technical Feasibility of Zero Net Energy Buildings in California*. P 8. Pacific Gas and Electric. 2012. http://www.energydataweb.com/cpucfiles/pdadocs/904/california_zne_technical_feasibility_report_final.pdf.
[52] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 146. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[53] Heschong Mahone Group. *The Road to ZEB: Mapping Pathways to ZEB Buildings in California: Main Report*. P 132. Pacific Gas and Electric. 2012. http://www.energydataweb.com/cpucFiles/pdaDocs/899/Road%20to%20ZNE%20FINAL%20Report_withAppendices.pdf.
[54] Jim Edelson and Mark Lyles. *Commercial Plug Load Energy Use Policy: What's in Place, Pending and Possible*. P 6. New Buildings Institute for California Energy Commission. 2013. http://newbuildings.org/sites/default/files/Plug_Load_Policy_Paper.pdf; Michael Sheppy, Chad Lobato, Shanti Pless, Luigi Gentile Polese, and Paul Torcellini. *Office Buildings: Assessing and Reducing Plug and Process Loads in Office Buildings*. P 2. National Renewable Energy Laboratory. 2013. http://www.nrel.gov/docs/fy13osti/54175.pdf.
[55] Jim Edelson and Mark Lyles. *Commercial Plug Load Energy Use Policy: What's in Place, Pending and Possible*. P 6. New Buildings Institute for California Energy Commission. 2013. http://newbuildings.org/sites/default/files/Plug_Load_Policy_Paper.pdf.
[56] Jennifer Thorne Amman. *Energy Codes for Ultra-Low-Energy Buildings: A Critical Pathway to Zero Net Energy Buildings*. American Council for an Energy-Efficient Economy. P 19. 2014. ACEEE-A1403. http://aceee.org/research-report/a1403.
[57] California Energy Commission. *2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24)*. 2013. http://www.energy.ca.gov/title24/2013standards/index.html.
[58] Jennifer Thorne Amman. *Energy Codes for Ultra-Low-Energy Buildings: A Critical Pathway to Zero Net Energy Buildings*. American Council for an Energy-Efficient Economy. P 13. 2014. ACEEE-A1403. http://aceee.org/research-report/a1403.
[59] Navigant Consulting. *Building Energy Management Systems.* https://www.navigantresearch.com/research/building-energy-management-systems. Accessed December 10, 2015.
[60] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 168. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[61] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 167. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.
[62] Kurt W. Roth, Detlef Westphalen, Michael Y. Feng, Patricia Llana, and Louis Quartararo. *Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization. Energy Impact of Building Faults and Energy Savings Potential*. P 2–6.Prepared by TIAX. LLC. for Department of Energy. Building Technologies Program. 2005. NTIS PB2006-100567. http://s3.amazonaws.com/zanran_storage/www.tiaxllc.com/ContentPages/42428345.pdf.

[63] New Buildings Institute. *Outcome-Based Energy Codes*. http://newbuildings.org/outcome-based-energy-codes. Accessed December 10. 2015.

[64] Alison A. Williams, Barbara A. Atkinson, Karina Garbesi, Francis M. Rubinstein, and Erik Page. *A Meta-Analysis of Energy Savings from Lighting Controls in Commercial Buildings*. Lawrence Berkeley National Laboratory. 2011. LBNL-5095E. http://eetd.lbl.gov/sites/all/files/a_meta-analysis_of_energy_savings_from_lighting_controls_in_commercial_buildings_lbnl-5095e.pdf.

[65] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 160. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.

[66] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey Data*. 2012. http://www.eia.gov/consumption/commercial/data/2012/.

[67] Sila Kiliccote, Mary Ann Piette, and Mahabir Bhandari. *Buildings-to-Grid Technical Opportunities: From the Buildings Perspective*. P 4. Department of Energy Office of Energy Efficiency and Renewable Energy. 2014. http://energy.gov/sites/prod/files/2014/03/f14/B2G_Tech_Opps--Building_Perspective.pdf.

[68] See. for example: Mikhail Lisovich, Stephen Wicker. "Privacy Concerns in Upcoming Residential and Commercial Demand-Response Systems". 2008 Clemson University Power Systems Conference, Clemson University, March, 2008. P 10.

[69] U.S. Department of Energy Building Technologies Office. *Low-Cost Wireless Sensors for Building Applications*. http://energy.gov/eere/buildings/downloads/low-cost-wireless-sensors-building-applications. Accessed October 25. 2015.

[70] U.S. Department of Energy Building Technologies Office. *DOE Releases Common Definition for Zero Energy Buildings, Campuses, and Communities*. September 16. 2015. http://energy.gov/eere/buildings/articles/doe-releases-common-definition-zero-energy-buildings-campuses-and.

[71] Snuller Price, Amber Mahone, Nick Schlag, and Dan Suyeyasu. *Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2013 Time Dependent Valuation (TDV) Data Sources and Inputs*. P 3. Energy and Environmental Economics. Inc.. 2011. http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/Title24_2013_TDV_Methodology_Report_23Feb2011.pdf.

[72] Cathy Fogel and Martha Brook. *Defining ZNE Buildings and ZNE Building Goals in California*. Presented at Integrated Energy Policy Report Workshop on Zero Net Energy. July 18, 2013. http://www.energy.ca.gov/2013_energypolicy/documents/2013-07-18_workshop/presentations/04_Brook_and_Fogel_Defining_ZNE_Buildings.pdf. 6.

[73] New Buildings Institute (NBI). *2014 Getting to Zero Status Update*. P 4, 21. 2014. http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf.

[74] ARUP North America Ltd.. *The Technical Feasibility of Zero Net Energy Buildings in California*. P 8, 25. Pacific Gas and Electric. 2012. http://www.energydataweb.com/cpucfiles/pdadocs/904/california_zne_technical_feasibility_report_final.pdf;

[75] Commercial Buildings Consortium (CBC). *Next Generation Technologies Barriers & Industry Recommendations for Commercial Buildings*. P 10. 2011. https://www.naseo.org/data/sites/1/documents/publications/CBC-Technologies-Report-2011.pdf.

[76] ARUP North America Ltd.. *The Technical Feasibility of Zero Net Energy Buildings in California*. P 8, 25. Pacific Gas and Electric. 2012. http://www.energydataweb.com/cpucfiles/pdadocs/904/california_zne_technical_feasibility_report_final.pdf; New Buildings Institute (NBI). *2014 Getting to Zero Status Update*. P 21. 2014. http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf.

[77] Drake Erbe, Richard Lord, and Robert Wilkins. "A Whole-Building Systems Approach to Energy Efficiency." *Air Conditioning. Heating and Refrigeration News.* June 3. 2013. http://www.achrnews.com/articles/123361-a-whole-building-systems-approach-to-energy-efficiency.

[78] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 170. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.

[79] U.S. Department of Energy. *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities*. P 170. 2015. http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.

[80] For example, see: New Buildings Insitute. *Outcome-Based Energy Codes*. http://newbuildings.org/outcome-based-energy-codes. accessed December 10. 2015; Institute for Market Transformation. *Outcome-Based Pathway Is Voted Into the 2015 IgCC*. http://www.imt.org/news/the-current/outcome-based-pathway-is-voted-into-the-2015-igcc. Accessed December 10. 2015

[81] ARUP North America Ltd.. *The Technical Feasibility of Zero Net Energy Buildings in California*. P 8, 25. Pacific Gas and Electric. 2012. http://www.energydataweb.com/cpucfiles/pdadocs/904/california_zne_technical_feasibility_report_final.pdf;

[82] L. Nock and Clint Wheelock. *Energy Efficiency Retrofits for Commercial and Public Buildings - Energy Savings Potential, Retrofit Business Cases, Financing Structures, Policy and Regulatory Factors, Demand Drivers by Segment. and Market Forecasts*. P 1. Pike Research. 2010. http://srmnetwork.com/pdf/whitepapers/Energy_Efficiency_Retrofits_Jul10.pdf; Evan Mills. *Building Commissioning – A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions*. P 6. California Energy Commission. Public Interest Energy Research. 2009. http://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf.

[83] National Renewable Energy Laboratory. "Walmart — Saving Energy. Saving Money Through Comprehensive Retrofits."p 4. 2015. http://www.nrel.gov/docs/fy15osti/63782.pdf.

[84] Athena Sustainable Materials Institute and Morrison Hershfield Limited. *A Life Cycle Assessment Study of Embodied Effects for Existing Historic Buildings*. Parks Canada. 2009. http://www.athenasmi.org/wp-content/uploads/2012/01/Athena_LCA_for_Existing_Historic_Buildings.pdf; Preservation Green Lab. *The Greenest Building: Quantifying the Environmental Value of Building Reuse.* 2011. http://www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf.

[85] Preservation Green Lab. *The Greenest Building: Quantifying the Environmental Value of Building Reuse. P 62-64*. 2011. http://www.preservationnation.org/information-center/sustainable-communities/green-lab/lca/The_Greenest_Building_lowres.pdf.

[86] LBNL analysis, based in part on: Arent, D., R. Benioffo, G. Mosey, L. Bird, J. Brown, E. Brown, J. Aabakken, et al. *Energy Sector Market Analysis*. P 8, 25.National Renewable Energy Laboratory, 2006. NREL/TP-620-40541. http://www.nrel.gov/docs/fy07osti/40541.pdf.

[87] McGraw Hill Construction. *World Green Building Trends: Business Benefits Driving New and Retrofit Market Opportunities in Over 60 Countries*. P 13. 2013. http://www.worldgbc.org/files/8613/6295/6420/World_Green_Building_Trends_SmartMarket_Report_2013.pdf.

[88] McGraw Hill Construction. *Green Outlook 2011: Green Trends Driving Growth*. P 41. 2010. http://aiacc.org/wp-content/uploads/2011/06/greenoutlook2011.pdf.

[89] Ashley Patterson and Chris Hessler. *Energy Efficiency Case Study: Performance Contracting.* Slide 4. Presented at 3N 111(d) Meeting. December 4. 2014. http://111d.naseo.org/Data/Sites/5/media/events/2014-12-04/espc-patterson-hessler.pdf.

[90] J. P. Carvallo, P. Larsen, and C. Goldman. "Estimating Customer Electricity and Fuel Savings from Projects Installed by the US ESCO Industry." *Energy Efficiency* 8. no. 6 (2015): 1251–1261. 1. doi:10.1007/s12053-015-9405-8.
[91] J. P. Carvallo, P. Larsen, and C. Goldman. *Estimating Customer Electricity Savings from Projects Installed by the U.S. ESCO Industry*. Lawrence Berkeley National Laboratory. 2014. LBNL-6877E. 6. https://emp.lbl.gov/sites/all/files/estimating_customer_electricity_savings_25nov2014_final.pdf.
[92] Eizabeth Stuart, Peter H. Larsen, Charles A. Goldman, and Donald Gilligan. *Current Size and Remaining Market Potential of the U.S. Energy Service Company Industry*. Lawrence Berkeley National Laboratory. 2013. LBNL-6300E. 19. https://emp.lbl.gov/sites/all/files/lbnl-6300e_01.pdf.
[93] Eizabeth Stuart, Peter H. Larsen, Charles A. Goldman, and Donald Gilligan. *Current Size and Remaining Market Potential of the U.S. Energy Service Company Industry*. Lawrence Berkeley National Laboratory. 2013. LBNL-6300E. 19. https://emp.lbl.gov/sites/all/files/lbnl-6300e_01.pdf.
[94] Eizabeth Stuart, Peter H. Larsen, Charles A. Goldman, and Donald Gilligan. *Current Size and Remaining Market Potential of the U.S. Energy Service Company Industry*. Lawrence Berkeley National Laboratory. 2013. LBNL-6300E. 37. https://emp.lbl.gov/sites/all/files/lbnl-6300e_01.pdf.
[95] H. Granade, Jon Creyts, Anton Derkach, Philip Farese, Scott Nyquist, and Ken Ostrowski. *Unlocking Energy Efficiency in the US Economy*. McKinsey & Company. 2009. http://www.mckinsey.com/client_service/electric_power_and_natural_gas/latest_thinking/unlocking_energy_efficiency_in_the_us_economy.
[96] Stephen Meyers, Alison Williams, Peter Chan, and Sarah Price. *Energy and Economic Impacts of U.S. Federal Energy and Water Conservation Standards Adopted From 1987 through 2014*. Lawrence Berkeley National Laboratory. Environmental Energy Technologies Division. 2015. LBNL-6964E (rev). http://eetd.lbl.gov/sites/all/files/lbnl-6964e.pdf.
[97] Pacific Northwest National Laboratory. *Update on Energy Codes and Standards for Commercial Buildings*. P 13. 2014. https://www.energycodes.gov/sites/default/files/becu/CSI%2012-16-14%20PPT%20PNNL%20%20107200.pdf.
[98] U.S. Department of Energy. *Status of State Energy Code Adoption*. https://www.energycodes.gov/status-state-energy-code-adoption. Accessed January 10, 2016.
[99] U.S. Department of Energy. *Benchmarking & Transparency Policy and Program Impact Evaluation Handbook*. P v. 2015. http://energy.gov/eere/slsc/downloads/benchmarking-and-transparency-policy-and-program-impact-evaluation-handbook.
[100] Institute for Market Transformation. *Map: U.S. Building Benchmarking and Transparency Policies*. *http://www.imt.org/resources/detail/map-u.s.-building-benchmarking-policies*. Accessed January 20, 2016.
[101] Efficient Buildings. *Commercial Building Tax Deduction Coalition*. http://www.efficientbuildings.org. Accessed January 25, 2016.
[102] SEE Action and the National Association of State Energy Offices. *State Energy Loan Fund Database*. http://www.naseo.org/state-energy-financing-programs. Accessed December 15, 2015.
[103] U.S. Department of Energy. *Energy Investment Partnerships: How State and Local Governments Are Engaging Private and Public Capital to Drive Clean Energy Investment*. P 3. 2015. http://energy.gov/sites/prod/files/2015/12/f27/Energy%20Investment%20Partnerships.pdf.
[104] Terri Esterly. *Energy Efficiency in PJM Capacity Market*. Webinar. U.S. Department of Energy. 2012. P 17, 35. http://energy.gov/sites/prod/files/2013/12/f6/bbnp_webinar11-15-12.pdf.
[105] Jim Lazar. *Rate Design Where Advanced Metering Infrastructure Has Not Been Fully Deployed.* P 9. Global Power Best Practice Series. Regulatory Assistance Project. 2013. www.raponline.org/document/download/id/6516; Jim Lazar and Wilson Gonzalez. *Smart Rate Design for a Smart Future*. P 5. Regulatory Assistance Project. 2015. www.raponline.org/document/download/id/7680.

[106] William Prindle. *Customer Incentives for Energy Efficiency through Electric and Natural Gas Rate Design*. P 13. National Action Plan for Energy Efficiency. 2009. https://www.epa.gov/sites/production/files/2015-08/documents/rate_design.pdf.
[107] For example, see: *CA senate Bill 375*. http://www.arb.ca.gov/cc/sb375/sb375.htm. Accessed March 15. 2016.
[108] South Coast Air Quality Management District. *Rule 2202 On-Road Motor Vehicle Mitigation Options.* http://www.aqmd.gov/home/programs/business/business-detail?title=rule-2202-on-road-motor-vehicle-mitigation-options. Accessed March 15, 2016.
[109] Kate Lister and Tom Harnish. *The State of Telework in the U.S.: How Individuals, Business, and Government Benefit*. P 4. Telework Research Network. June 2011. http://www.workshifting.com/downloads/downloads/Telework-Trends-US.pdf.
[110] Forrester Research. *U.S. Telecommuting Forecast, 2009 to 2016*. March 11, 2009. https://www.forrester.com/US+Telecommuting+Forecast+2009+To+2016/fulltext/-/E-res46635.
[111] Internet Retailer. *U.S. E-Commerce Sales, 2014–2018*. https://www.internetretailer.com/trends/sales/us-e-commerce-sales-2013-2017. Accessed November 1. 2015.
[112] Bruce Hedman, Anne Hampson, and Ken Darrow. *The Opportunity for CHP in the United States*. ICF. International for American Gas Association. 2013. A-3 and ES-1. http://www.iipnetwork.org/opportunity-chp-united-states.
[113] Lauren T. Cooper and Nicholas B. Rajkovich. *An Evaluation of District Energy Systems in North America: Lessons Learned from Four Heating Dominated Cities in the U.S. and Canada*. P 1. American Council for an Energy-Efficient Economy Summer Study on Energy Efficiency in Buildings. 2012. http://aceee.org/files/proceedings/2012/data/papers/0193-000354.pdf.
[114] David Feldman, Anna M. Brockway, Elaine Ulrich, and Robert Margolis. *Shared Solar: Current Landscape. Market Potential. and the Impact of Federal Securities Regulation*. P 4. National Renewable Energy Laboratory. 2015. NREL/TP-6A20-63892. http://www.nrel.gov/docs/fy15osti/63892.pdf.
[115] Federal Energy Regulatory Commission. *A National Assessment of Demand Response Potential*. P 29. June 2009. https://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf.
[116] M. C. Kintner-Meyer, J. C. Molburg, K. Subbarao, N. Prakash Kumar, G. Bandyopadhyay, C. Finley, V. S. Koritarov, J. Wang, F. Zhao, L. Brackney et al.. *The Role of Energy Storage in Commercial Building:* A *Preliminary Report*. Pacific Northwest National Laboratory. 2010. Report PNNL-19853. 1.2. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-19853.pdf.
[117] M. C. Kintner-Meyer, J. C. Molburg, K. Subbarao, N. Prakash Kumar, G. Bandyopadhyay, C. Finley, V. S. Koritarov, J. Wang, F. Zhao, L. Brackney et al.. *The Role of Energy Storage in Commercial Building:* A *Preliminary Report*. Pacific Northwest National Laboratory. 2010. Report PNNL-19853. 1.2. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-19853.pdf.
[118] Sandia Corporation. *DOE Thermal Storage Database*. http://www.energystorageexchange.org/projects. Accessed October 20, 2015.
[119] Federal Energy Regulatory Commission. *A National Assessment of Demand Response Potential*. P xiv, 29. June 2009. https://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf.
[120] David Feldman, Anna M. Brockway, Elaine Ulrich, and Robert Margolis. *Shared Solar: Current Landscape. Market Potential. and the Impact of Federal Securities Regulation*. P 12. National Renewable Energy Laboratory. 2015. NREL/TP-6A20-63892. http://www.nrel.gov/docs/fy15osti/63892.pdf.
[121] Cathy Fogel. *Update on Statewide ZNE Residential Goals*. P 7. Presented at PG&E ZNE Residential Consultations Meeting. March 27. 2014. http://static1.squarespace.com/static/54d6ffd1e4b0cd7c8af30f57/t/550763d9e4b025f5e868f1c5/1426547673149/5_Res+ZNE+Presentations_CPUC+presentation_Fogel_2014-03-27.pdf.

[122] U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey Preliminary Results*. Figure 7. 2012. http://www.eia.gov/consumption/commercial/reports/2012/preliminary/index.cfm. Accessed March 23, 2016.

[123] U.S. Energy Information Administration. 2012 Commercial Buildings Energy Consumption Survey Preliminary Results. Table 6. 2012. http://www.eia.gov/consumption/commercial/reports/2012/energyusage/. Accessed March 17, 2016.

[124] U.S. Energy Information Administration. *1992 Commercial Buildings Energy Consumption Survey*. Table 4. 1992. http://www.eia.gov/consumption/commercial/data/1992/.; U.S. Energy Information Administration. *1995 Commercial Buildings Energy Consumption Survey*. Table 4. 1995. http://www.eia.gov/consumption/commercial/data/1995/.; U.S. Energy Information Administration. *2003 Commercial Buildings Energy Consumption Survey*. Table E4A. 2003. http://www.eia.gov/consumption/commercial/data/2003/.; U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey*. Table 6. 2012. http://www.eia.gov/consumption/commercial/data/2012/. Accessed March 16, 2016.

[125] U.S. Energy Information Administration. *1992 Commercial Buildings Energy Consumption Survey*. Table A2. 1992. http://www.eia.gov/consumption/commercial/data/1992/.; U.S. Energy Information Administration. *1995 Commercial Buildings Energy Consumption Survey*. Table 9. 1995. http://www.eia.gov/consumption/commercial/data/1995/.; U.S. Energy Information Administration. *2003 Commercial Buildings Energy Consumption Survey*. Table E4A. 2003. http://www.eia.gov/consumption/commercial/data/2003/. U.S. Energy Information Administration. *Annual Energy Outlook 2015*. Table B7. http://www.eia.gov/outlooks/archive/aeo15/

[126] U.S. Energy Information Administration. *1992 Commercial Buildings Energy Consumption Survey*. Table 4. 1992. http://www.eia.gov/consumption/commercial/data/1992/.; U.S. Energy Information Administration. *1995 Commercial Buildings Energy Consumption Survey*. Table 4. 1995. http://www.eia.gov/consumption/commercial/data/1995/.; U.S. Energy Information Administration. *2003 Commercial Buildings Energy Consumption Survey*. Table E4A. 2003. http://www.eia.gov/consumption/commercial/data/2003/.; U.S. Energy Information Administration. *2012 Commercial Buildings Energy Consumption Survey*. Table 6. 2012. http://www.eia.gov/consumption/commercial/data/2012/. Accessed March 16, 2016.

[127] EPSA Side Case.

[128] Appliance Standards Awareness Project. http://www.appliance-standards.org/national. Accessed February 1, 2016.

[129] U.S. Department of Energy. *Energy Department Announces Largest Energy Efficiency Standard in History*. December 17, 2015. http://energy.gov/articles/energy-department-announces-largest-energy-efficiency-standard-history.

[130] U.S. Energy Information Administration. *Annual Energy Outlook 2015: With Projections to 2040*. 2015. http://www.eia.gov/forecasts/aeo/pdf/0383%282015%29.pdf; U.S. Energy Information Administration. *Electricity Sector Data - Sales (consumption), revenue, prices & customers.* 2015. http://www.eia.gov/electricity/data.cfm#sales

[131] U.S. Energy Information Administration. *Annual Energy Outlook 2015*; U.S. Energy Information Administration. *Electricity Sector Data - Sales (consumption), revenue, prices & customers.* 2015. http://www.eia.gov/electricity/data.cfm#sales

[132] U.S. Energy Information Administration. *EIA 826 Data - Average Price (Cents/kilowatthour) by State by Provider*, *1990–2014*. Last updated November 29, 2016. http://www.eia.gov/electricity/data/state/avgprice_annual.xls.