Lawrence Berkeley National Laboratory

Systems Retrofit Trends in Commercial Buildings: Opening Up Opportunities for Deeper Savings

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Energy Technologies Area
February, 2020

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Acknowledgement

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, of the U.S. Department of Energy (DOE) under Contract No. DE-AC02-05CH11231.

The authors would like to thank U.S. Federal Energy Management Program (FEMP), United States General Services Administration (GSA), and a number of U.S. utilities, including Commonwealth Edison Company (ComEd), Energy Trust of Oregon, National Grid, New York State Energy Research and Development Authority (NYSERDA), Pacific Gas and Electric (PG&E), Southern California Edison (SCE), Sacramento Municipal Utilities District (SMUD), and Xcel Energy, for their participation in this project. Additionally, the authors gratefully acknowledge the input from several stakeholders including the Alliance to Save Energy, City of Palo Alto, ESource, Northeast Energy Efficiency Partnerships (NEEP), SeventhWave, The Weidt Group, and TRC Companies Inc. The authors also thank Amy Jiron in the DOE Building Technologies Office for her support and guidance, Ken Sandler from the GSA for his reviews and guidance, Juan Pablo Carvallo from Lawrence Berkeley National Laboratory (LBNL) for his assistance in analyzing the ESCO data and Ian Hoffman from LBNL for his utility program insights.

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Acronyms and Abbreviations

CBECS	Commercial Building Energy Consumption Survey
CTS	Compliance Tracking System
DER	Distributed Energy Resources
DHW	Domestic hot water
DOE	U.S. Department of Energy
EEM	Energy efficiency measure
ESCO	Energy service company
ESPC	Energy Service Performance Contract
EUI	Energy Use Intensity
FEMP	U.S. Department of Energy's Federal Energy Management Program
GSHP	Ground Source Heat Pump
GTZ	Getting to Zero
GSA	U.S. General Services Administration
HPBD	High Performance Buildings Database
HVAC	Heating, ventilation and air-conditioning
IECC	International Energy Conservation Code
LBNL	Lawrence Berkeley National Laboratory
LED	Light-emitting Diode
NAESCO	National Association of Energy Service Companies
NBI	New Buildings Institute
VAV	Variable Air Volume
VFD	Variable Frequency Drive

Executive Summary

Commercial building retrofits present a prime opportunity to improve building energy efficiency. This is increasingly happening, but usually through simple upgrades of individual building components such as equipment or lamp replacements. These equipment- or component-level retrofits, however, have been shown to have less potential for whole building energy savings as compared to comprehensive system-based approaches (Regnier et al. 2018a). A system-based approach goes beyond a single component, such as by incorporating additional elements or controls within an end use system, or leverages interactions with other building components or end use systems to achieve deeper levels of energy savings. Systems retrofits hold the potential for much greater savings and are critical to achieving aggressive energy reduction goals in the existing commercial building stock.

This study sought to answer three questions:

1. To what extent are systems retrofits taking place in the building marketplace today?
2. Are systems retrofits more prevalent in high energy saving projects?
3. What kinds of efficiency measures are most prevalent in system retrofits?

This study also solicited input from industry stakeholders on the state of system retrofits currently, as well as perceived barriers to further uptake. The results of the study revealed several findings:

Key Finding #1 *Systems retrofits are relatively uncommon, representing less than 20 percent of total projects*

Key Finding #2*: Systems retrofits show a greater occurrence in high energy saving projects*

Key finding #3*. Lighting measures are the most prevalent in all types of retrofits, while there is a higher prevalence of HVAC measures in systems retrofits than in non-system retrofits*.

Key finding #4. *Several barriers prevent wider deployment of systems, including a lack of awareness of system retrofit opportunities, perceived higher costs, ease of system design, installation and operation, and in some cases policy barriers.*

The study addressed these questions by examining commercial building retrofit data from an array of sources, including utility customer incentive programs, federal government facility retrofit programs and energy service company (ESCO) retrofit data. These were supplemented by retrofit project data from several case study repositories, including the U.S. Department of Energy's High Performance Building Database, the New Building Institute's Getting to Zero Database, and the U.S. General Service Administration's Deep Retrofit program. The final cleansed dataset included over **12,000 retrofit projects**, including over 4,500 projects that included energy savings data. A wide range of commercial building types were represented, with office and retail most prevalent.

Systems integration and systems retrofits may occur among different components within a single end use system or across multiple end use systems. Accordingly, for the purposes of this study we defined and analyzed the data in terms of three types of system retrofits:

1. *End Use System retrofits*, which involve multiple components of a single end use system (e.g., heating, cooling, lighting).

2. *Interactive System retrofits*, which involve passive interactive effects across two or more end use systems to produce a combined benefit, such as envelope or lighting improvements that reduce thermal loads for heating, ventilation and air-conditioning (HVAC) systems.

3. *Integrated System retrofits*, which employ active coordinated controls between two or more end use systems to produce efficiency gains (e.g., automated shading controlled to optimize HVAC and lighting energy use).

Notably these definitions are not mutually exclusive. A project may have occurrences of multiple system retrofit types, such as a complete HVAC system replacement (e.g. chiller, pumps, cooling tower, fan coil units) that occurred at the same time as a window upgrade (e.g. low-e or triple pane windows). In this example there is an End Use System retrofit as well as an Interactive System retrofit.

These system retrofit types are contrasted in the study by projects that did not involve a system based retrofit:

4. *Non-System retrofits*, which involve single component retrofit applications (e.g. chiller replacement by itself), or combinations of unrelated single component retrofits such as those occurring in different End Use Systems (e.g. chiller and domestic hot water heater replacement).

Retrofit projects were categorized by their whole building energy savings into those with low energy savings (defined as < 20 percent) and high energy savings (≥ 20 percent). We analyzed trends in the extent of high and low energy savings projects across different program types and retrofit types. We also analyzed the types of energy efficiency measures employed.

Key Finding #1 *Systems retrofits are relatively uncommon, representing less than 20 percent of total projects.* End Use System retrofits occurred in 17 percent of the projects, and only 6 percent of the projects had an Interactive System retrofit. Notably, there were no clear cases of Integrated System retrofits evident from the data. Systems retrofits are more prevalent in federal programs and ESCO projects than in utility programs.

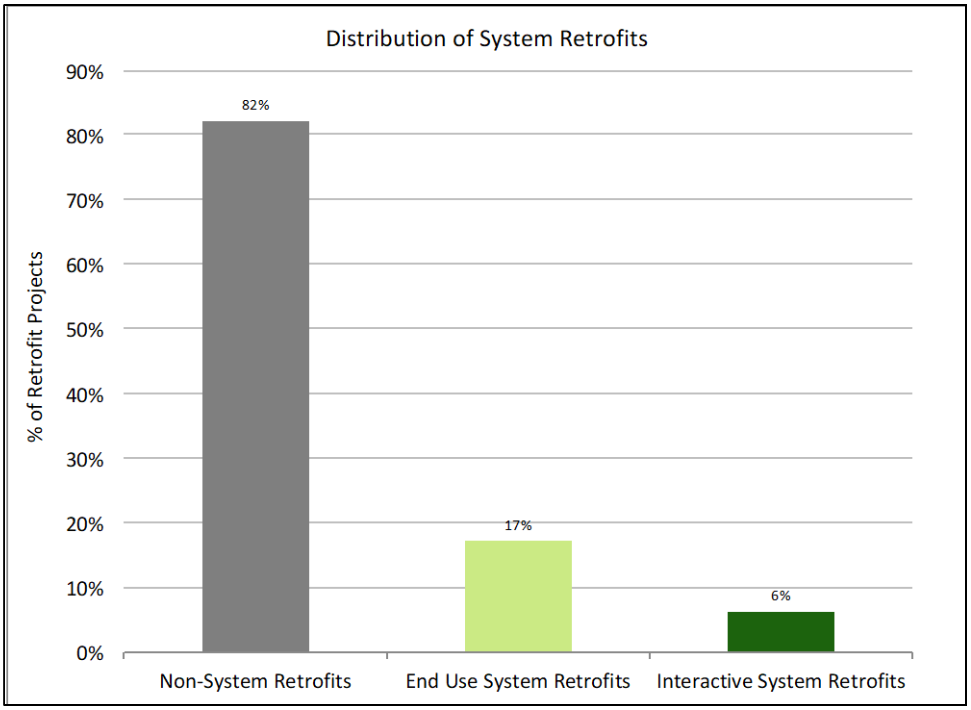

Figure ES-1. Distribution of System Retrofits

***Key Finding #2**: Systems retrofits show a greater occurrence in high energy saving projects.*

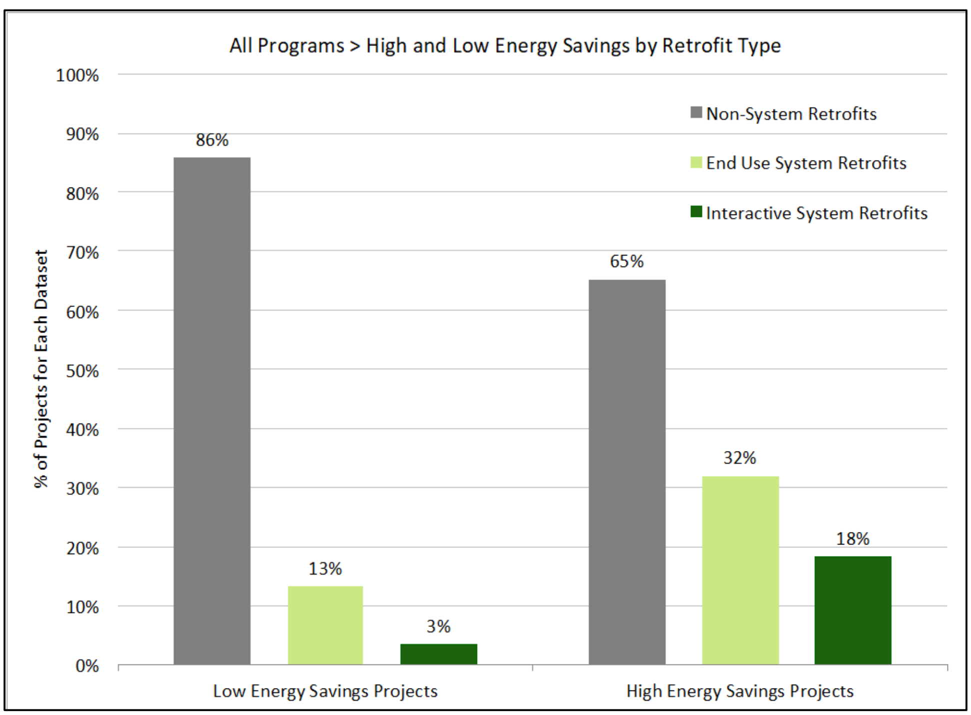

Figure ES-2. All Programs > High and Low Energy Savings by Retrofit Type

This trend varied across the different program types. Utility custom programs in particular appear to strongly favor Non-System approaches throughout, even though custom programs can support more complex systems-based approaches. ESCOs on the other hand strongly appear to favor systems-based approaches across all projects, with an increase of the prevalence in high energy savings.

Key finding #3*. Lighting measures are the most prevalent in all types of retrofits, while there is a higher prevalence of HVAC measures in systems retrofits than in non-system retrofits*. Utility programs are predominantly focused not just on component based retrofit approaches, but also heavily weighted toward lighting-dominated system retrofits. Federal and ESCO projects, however, illustrated a much broader distribution of retrofit types, with HVAC End Use System retrofits occurring most frequently, including efficient equipment replacements combined with either controls or distribution measures.

The study also sought input from an array of stakeholder organizations — utility program administrators, implementers and advocacy organizations — to understand barriers to and industry needs for wider deployment of systems-based approaches for existing commercial buildings.

Key finding #4. *Several barriers prevent wider deployment of systems, including a lack of awareness of system retrofit opportunities, perceived higher costs, ease of system design, installation and operation, and in some cases policy barriers.* A general lack of **awareness**, even within industry experts, of the relative energy efficiency opportunities and savings of systems retrofits remains a barrier. While some of the new construction market has benefited from the integrated assessment and implementation of systems solutions achieving deeper levels of energy savings, it remains the case that this has barely penetrated the existing building market, as evidenced by data from utility custom incentive programs, ESCOs, and federal retrofit program data. A **perception of higher costs** for system retrofits is also a deterrent, although improvements in cost effectiveness can be achieved through bundling with cost effective measures such as LED retrofits. Evaluating retrofits based on lifetime savings can also benefit system retrofits, as they can emphasize technologies with longer lifetimes as well as deeper savings (e.g. HVAC and envelope interactive retrofits). **Ease of design, installation, commissioning and operation** are cited by stakeholders as important factors to enable deeper levels of system retrofit application, with a focus on reducing the complexities involved.

Technology improvements can also lower barriers to system retrofit adoption, to streamline retrofit assessments, design, implementation and operation. This may include simplified assessment tools that identify systems solutions and provide cost evaluative information. System technology packages can lower the transaction costs around system specification, design and controls integration. Industry standards and protocols to develop standardized controls applications can also lower the labor costs for design and installation.

There may be **structural barriers** as well, such as for some utility incentive programs where each individual energy efficiency measure (EEM) must pass a cost-effectiveness test before program inclusion. This can considerably limit the application of system retrofits that span multiple EEMs, such as strategies that include equipment capacity reductions and cost savings (e.g., chiller replacement) as a result of the impacts of another more costly EEM (e.g., envelope insulation or glazing). Further, regulatory frameworks may emphasize short term annual savings which can favor technology upgrades with quick payback but short life time savings (such as LED lamp retrofits). System retrofits however may show substantially better life time savings (such as HVAC system retrofits).

Overall, there are numerous opportunities to advance the application of systems retrofits in commercial buildings, including technical, education, policy and regulatory advancements that enable deeper energy savings in the built environment. As energy codes and other energy and climate policies continue to drive toward deeper levels of energy efficiency, systems retrofits open up greater opportunities for savings.

1. Introduction

Building systems-based approaches have long been recognized as a way to achieve deeper levels of energy savings in buildings. By one estimate, systems level savings in the commercial market can "dwarf component-based efficiency improvements by an order of magnitude" (Elliott et al. 2012). Systems efficiency is emerging as a focus of energy policy efforts (ASE 2016). BRE Group's research report *Better Product Policy - Policy Making for Energy Saving in Systems* (Young et al. 2011) notes that:

> "Policy actions to improve the energy performance of components in isolation do not necessarily lead to corresponding improvements in the performance of the overall system. Instead it would be better (in some cases) to define the larger system, analyze its characteristics in terms of the service provided, and regulate for specified levels of system performance. If successful, the application….to systems brings greater savings than could have been obtained from individual products." (Young et al. 2011)

An analysis by Regnier et al. (2018b) compared three systems-based retrofit strategies and found that not only are deeper levels of energy savings possible (49 to 82 percent additional energy savings), but they can also pose a compelling economic case for investment in some cases, with simple payback ranging from 1.9 to 10.9 years.

While systems strategies are critical to the advancement of low energy buildings, there has to date been little analysis of the extent of systems retrofits in the commercial buildings sector, as opposed to component level retrofits such as equipment upgrades or replacements. Toward that end, Lawrence Berkeley National Laboratory (LBNL) conducted a study sponsored by the U.S. Department of Energy (DOE) to provide insight into the different systems approaches currently used in building retrofits, as well as to highlight areas of research needed to lower barriers to better utilization of systems retrofits.

The study was conducted in two parts. The primary objective of the study was to conduct a quantitative analysis of systems level retrofits using data from energy efficiency programs. This analysis sought to address three overall questions:

1. What is the *extent of systems retrofits* compared to component retrofits?
2. Do systems retrofits *save more energy* than component retrofits?
3. What *types of measures* are used in systems retrofits?

Furthermore, the analysis sought to address these questions for different types of delivery channels (e.g., energy service companies [ESCOs], utility programs).

The second objective of the study was to obtain industry stakeholder perspectives on the current state of practice and barriers to wider deployment of systems retrofits. Toward that end, a series of structured interviews were conducted with various types of industry stakeholders to solicit input on technical, economic, market, policy and other barriers and opportunities to support deployment.

This study focused only on retrofits of existing buildings, as integrated design strategies have been well documented as supporting successful low energy systems approaches in the case of new construction (AIA 2007). Overall, this work aims to illustrate the prevalence of system retrofits, the types implemented, and their correlation to project energy savings. The results point toward areas of potential industry effort, research and growth to aid in broader application of systems approaches to achieve greater energy savings in the building stock.

This report is organized as follows:

- Section 2 defines three types of systems retrofits, each representing a different level of systems integration. These definitions are used as the basis for the analysis.
- Section 3 describes the data sources, data preparation and analysis approach for the analysis of systems retrofit data.
- Section 4 presents results from the analysis of systems retrofit data.
- Section 5 presents the approach to and findings from the stakeholder interviews about the current state of practice, barriers and opportunities.
- Section 6 concludes with industry needs and recommendations.
- The appendices provide further detailed information on the data collection and processing method (Appendix A), the energy efficiency measures studied (Appendix B), and supplementary results from the analysis (Appendix C).

2. Systems Definitions

2.1 What is a system?

Several different definitions for buildings systems can be found in the literature, such as the following:

> "A building system is a combination of equipment, operations, controls, accessories and means of interconnection that use energy to perform a specific function." (ASE 2016; ASE 2017)
>
> "A 'system' means a number of components acting together to fulfill a particular function or deliver a service." (Young et al. 2011)

Systems inherently involve the interaction and integration of components within and across various end uses. For the purposes of this study, we defined the following *end use* categories:

1. Heating
2. Cooling
3. Ventilation
4. Lighting

5. Domestic hot water
6. Plug loads (e.g., office equipment)
7. Commercial refrigeration

Other end use categories, such as process equipment, which is sometimes used to describe equipment such as elevators or other people conveyance equipment, might exist in a commercial building application. However, these were only found in very rare occurrences in the data, and have been omitted as an end use system classification for ease of analysis and presentation.

We define a building *end use system* as the *set of equipment, supporting devices, distribution, termination, sensors and controls* to maintain a desired service level, such as thermal comfort. Each end use system is characterized by technologies within each of these system elements as shown in Figure 1.

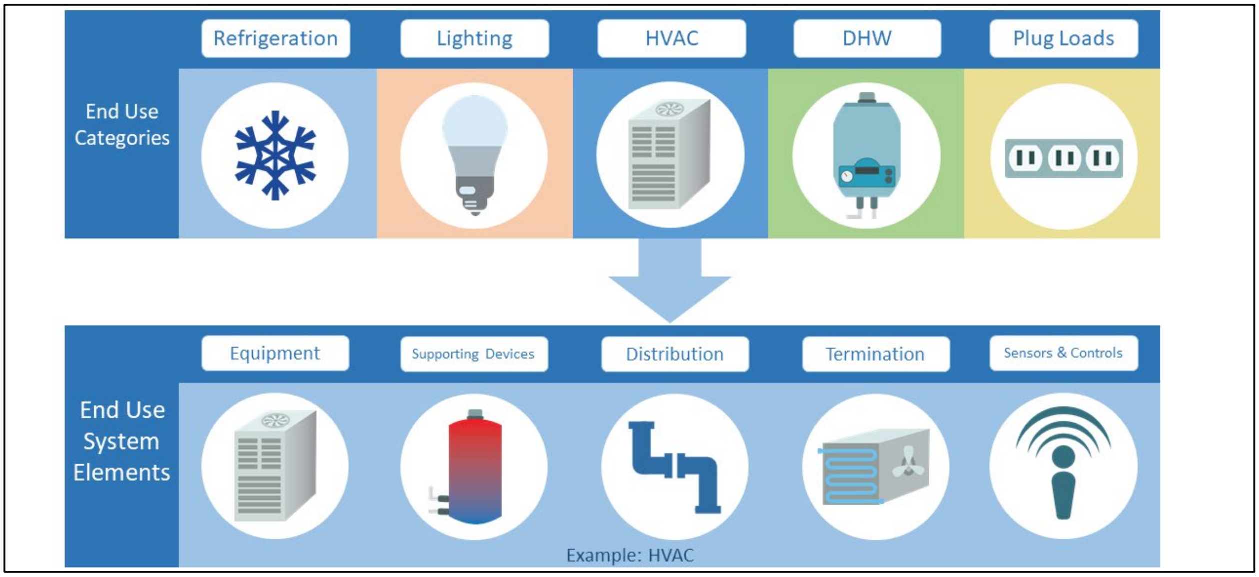

Figure 1. End Use System Categories and Elements

In Figure 1 the HVAC end use system category is broken out into its respective end use system elements of equipment, supporting devices, distribution, termination, and sensors and controls. Within and across each of the building end use system categories — heating, cooling, ventilation, lighting, refrigeration, domestic hot water (DHW) and plug loads — a range of different system approaches can deliver their respective services. Some examples are provided in Table 1, illustrating examples of each end use system element involved. When energy efficiency measures (EEMs) are applied to an end use system, each EEM applies to one of these categories, e.g., a chiller replacement affects the equipment end use system element; an application of an outside air economizer to an air handler affects sensors and controls.

Table 1. Building End Use System Examples with Elements Described

End Use System Category	End Use System Element				
	Equipment	**Supporting Devices**	**Distribution**	**Termination**	**Sensors and Controls**
Heating - Airside	Packaged heat pump rooftop unit	Enthalpy wheel for relief air heat recovery	Single zone, overhead ducting at standard pressure drop	Ceiling diffusers	Setback, scheduling, morning warm-up
Heating - Waterside	Central boiler plant	Radiant manifolds	One zone for each perimeter and core	Radiant in-slab tubing	Setback, scheduling
Cooling - Airside	Air handler with chilled water coils	—	Multiple zone, overhead ducting at reduced pressure drop	VAV terminal boxes with hydronic reheat, ceiling diffusers	Fan variable frequency drive (VFD) controls, outside air economizer
Cooling - Waterside	Central chilled water plant chiller, cooling tower, pumps	Chilled water storage tank	Primary/secondary pumps	Air handling unit coil	Pump VFD controls
Ventilation	Dedicated outside air handler	Sensible heat recovery on relief air	Dedicated outside air ducting	Control dampers and ceiling diffusers	Demand controlled ventilation via CO_2 sensors
Lighting	T5	—	Zonal	Direct/indirect overhead pendant	Occupancy, scheduling
	LED	Onboard electro-chemical battery	Workstation specific – one fixture per workstation	Overhead 2 x 4 troffer	Occupancy, daylight dimming
	LED	Reflector	Overhead ambient with workstation task lighting	Direct/indirect overhead pendant	Occupancy, daylight dimming
Domestic Hot Water	Central gas water heater and pump	Solar hot water preheating	Central distribution to fixtures	Fixture level recirculating pump	Recirculating pump controls
	Electric water heater	Low flow fixtures	—	Point of use	On-demand

Systems integration and systems retrofits may occur between different components within a single end use system or across multiple end use systems. Accordingly, for the purposes of this study we defined three types of system retrofits:

1. **End use system retrofits**, which affect a single end use system.

2. **Interactive system retrofits**, which have interactive effects across two or more end use systems.

3. **Integrated system retrofits**, which involve active integration across two or more end use systems.

Each of these three retrofit types presents a unique set of conditions relevant to their technical application and may have unique adoption barriers as well. Each can provide an opportunity for deeper energy reduction beyond a "widget" or equipment replacement of an existing technology. These system retrofit types are described further below.

2.2 End Use System Retrofits

An End Use System retrofit is defined as follows:

> **End Use System Retrofit:** The retrofit of an existing end use system including measures in at least two of the elements of *equipment, supporting devices, distribution, termination, and/or sensors and controls.*

By this definition, equipment upgrades alone, such as a chiller and pump replacements, would not qualify as a system retrofit, but an equipment replacement combined with a new controls strategy would. This definition requires that the measures must be in the different categories of the end use system, such as termination and sensors/controls, or supporting devices and sensors/controls. Two retrofits within one of these system categories would not meet the definition. The emphasis here is on *systemic planning and approaches*, i.e., recognizing interactions and coordinated strategies across the end use system, which is more likely to lead to deeper energy savings. It is recognized that there will be incremental savings from retrofits focusing on just one end use system element (e.g., controls), however the emphasis of this study is to identify retrofit trends that span strategies across the end use system elements. Some examples of End Use System retrofits, including their retrofit elements, include:

- Cooling tower replacement plus waterside economizer controls (equipment and controls)
- Light fixture replacement plus daylight dimming controls (equipment and controls)
- Central plant upgrade to include hydronic thermal storage and controls (supporting devices and controls)
- Central recirculating hot water heater retrofit to point-of-use on-demand water heaters (equipment, distribution, termination and controls)

End Use System retrofits may result in a complete change of the end use system, such as the last example of a central gas water heater with a recirculating pump being retrofit to point-of-use on-demand electric water heaters. Other end use system retrofits may result in replacements or improvements to select parts of that system, such as the installation of fan VFD controls (sensors/controls) along with low pressure drop filters (distribution) and variable flow diffusers (termination). These more incremental system improvements may not have a potential energy saving benefit as large as a complete end use system changeout, but they are important to the existing building market, as they may be less disruptive or costly to implement.

2.3 Interactive System Retrofits

Some building retrofits may have an *indirect* impact on building energy use, such as increasing or reducing internal or external heat gains and thereby affecting HVAC system energy use. This is the case for many building envelope retrofits, as well as other end use systems that produce internal heat loads such as lighting and plug load devices. Some envelope retrofits might also influence lighting energy use by increasing or decreasing available daylight to a space.

To identify when an opportunity for these increased energy efficiency (and potentially capital cost) saving strategies has occurred, we define an Interactive System retrofit as follows:

> **Interactive System Retrofit:** The modification of a building end use system or envelope component(s), intentionally leading to changes in the state of another building end use system or component, which overall results in a net energy use reduction.

All HVAC systems are interactive with the building envelope, and also with other systems that produce internal heat loads such as lighting and plug loads, as shown in Figure 2. Lighting systems also may be interactive with envelope components that provide daylight. Yet the mere presence of an interactive effect does not in and of itself make for a systems retrofit. Rather, it is a considered a systems retrofit when the affected system is *intentionally* configured to enable greater energy savings. An example would be an envelope retrofit that decreased heating or cooling needs to the point where HVAC equipment could be downsized, or changed to another more efficient system type (e.g., rooftop unit cooling and heating switched to a hydronic radiant system). Capturing when these opportunities occur can be important to improving the economics of energy efficient retrofits, as the capital cost savings of downsized equipment can be used to offset the costs of implementing the energy efficient strategies, a strategy known as “Tunneling Through the Cost Barrier” (Hawken et al. 1999).

A defining characteristic of building system interaction is that there is no active controls engagement across these elements; rather, the interaction happens through generally passive means such as heat produced by one influencing the behavior of the other. (Where there is active controls engagement among building systems, they fall into the Integrated Building System category discussed below.) It is important to note that an interactive system strategy might increase energy use in one end use system (e.g., heating) but decrease energy use in another end use system (e.g., lighting, and cooling). Interactive system retrofits aim overall to achieve a net decrease in energy use across all of the affected end use systems.

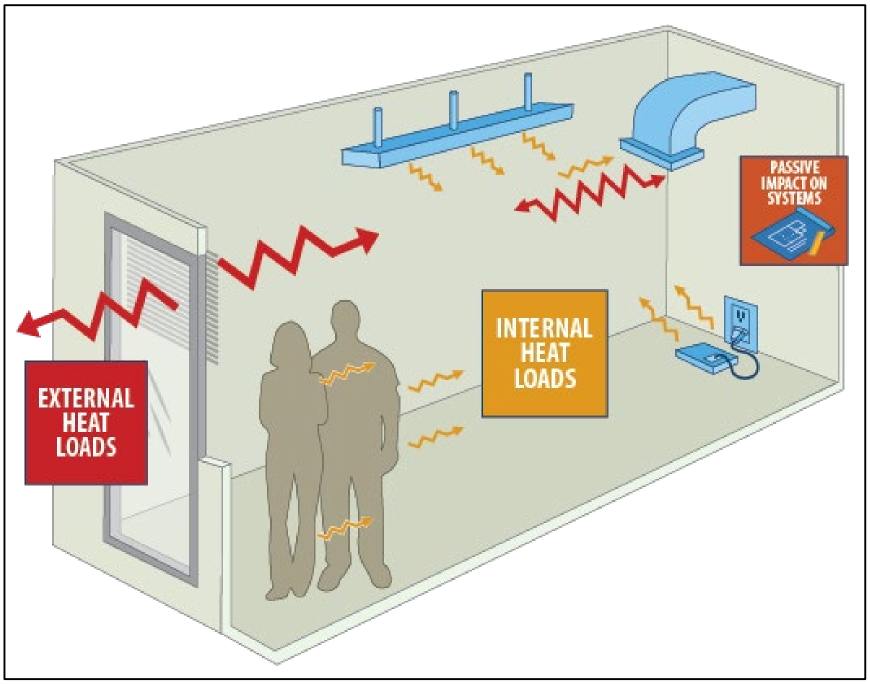

Figure 2. Interactive System Examples – HVAC with Envelope and Internal Heat Loads

An interactive building systems retrofit may involve as little as a single EEM in one end use system, along with another retrofit in the envelope or other end use system. Multiple EEMs across system elements may also occur. Some examples of interactive systems retrofits include the following:

- Envelope retrofits enabling additional lighting energy savings
  - Skylights or daylight redirecting retrofits, enabling daylighting and lighting dimming controls deeper into a building's floorplate
  - Facade solar control strategies that enable consistent daylighting (e.g., an upper window designed for daylighting, with solar controls in a lower window area)
- Envelope retrofits enabling HVAC cooling energy savings, or smaller load or capacity HVAC systems
  - Wall or roof insulation
  - Window glazing improvements
  - Cool roofs
  - Exterior shading applications

To be most effective, interactive building systems retrofits should factor interactive effects into plans for affected end use systems components, such as adjusting lighting levels based on daylight penetration or installing smaller capacity HVAC equipment in response to reduced loads. This can be an important strategy for the cost-effective implementation of energy efficient strategies.

2.4 Integrated Systems Retrofits

A third systems retrofit opportunity exists in buildings to save energy by integrating design and control between end use systems, or even between an end use system and an automated building envelope. End use systems typically operate in a "fractured environment," independently of one another, hence "system integration will be key to enabling more cost-effective operations" (ANSI 2014), including integrated controls. Therefore, we use the following definition for this third type of system retrofit:

> **Integrated System Retrofit:** The retrofit of two or more building end use systems and/or envelope components resulting in *a coordinated controls approach for systemic improvements across the end use systems.*

A defining characteristic of Integrated System retrofits is that they include active, coordinated controls across end use systems, with a goal to provide more energy savings or greater services (such as peak demand reduction) than the end use system elements in isolation. This integration may or may not include the direct sharing of data across end use systems. While many examples described below do rely on data exchange, in some cases the integration occurs by taking advantage of the design elements and performance of the second end use system or envelope component (e.g., phase change materials).

Some examples of Integrated System retrofits include the following:

- Envelope control retrofits combined with HVAC system strategies
    - Dynamic facades (e.g., automated shading and/or electrochromic glazing) combined with HVAC system controls (e.g., reduction in peak cooling, balancing daylighting with cooling reduction, demand response)
    - Phase change envelope materials (e.g., wall materials, floor tiles, ceiling plenum applications) combined with HVAC controls to store thermal energy (e.g., optimized for energy cost reduction, peak demand reduction, optimal use of onsite renewable energy production)
    - Automated operable windows combined with HVAC system controls (e.g., natural ventilation, nighttime outside air purge)
- Envelope retrofits actively combined with lighting system strategies
    - Dynamic facades (e.g., automated shading, electrochromic glazing, daylight redirecting technologies) combined with lighting controls (daylight dimming), and possibly HVAC controls as well
    - Rooftop mounted dynamic daylighting (e.g., controllable skylights, tubular daylighting devices) combined with lighting controls (daylight dimming, specular controls)
- HVAC system strategies actively combined with domestic hot water
    - Heat recovery from domestic hot water waste heat to preheat an HVAC system
- Lighting system strategies actively combined with plug loads
    - Task/ambient lighting combined with plug load occupancy controls, where the task lighting is controlled as a plug load

It should be noted that envelope components should be considered building end use systems once they become energy consumers, such as in the above examples of automated facades.

Further integration across end uses may be possible beyond these opportunities, including integration with distributed energy resources (DER) such as photovoltaics and battery storage, as illustrated in Figure 3.

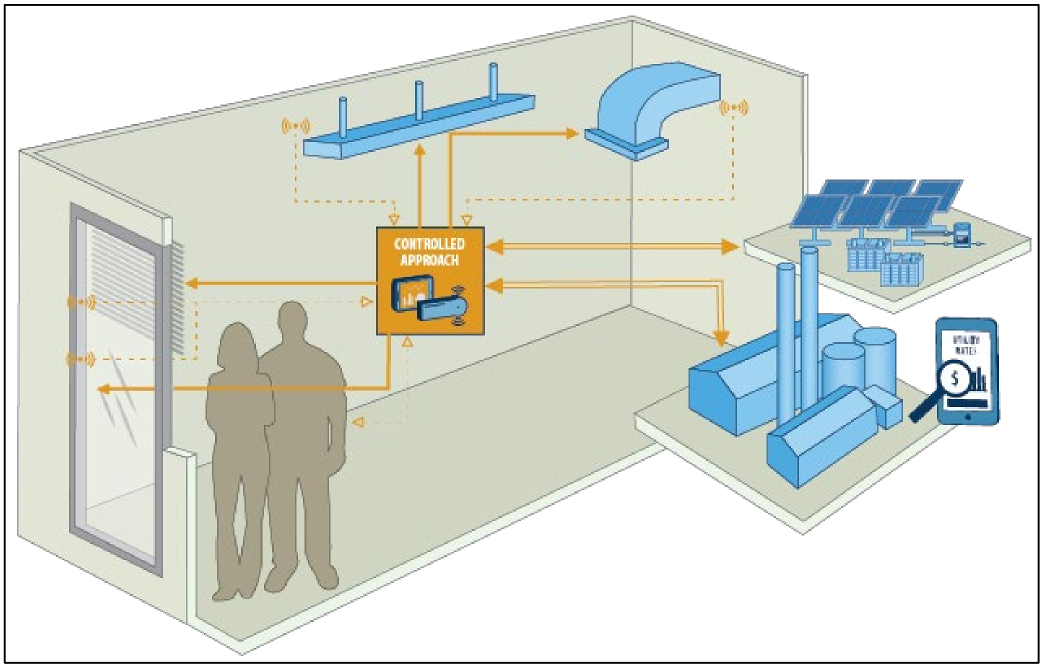

Figure 3. Integrated Systems Exchange Data between End Use Systems, and Also Integrated with DER or Utility Signals

3. Data and Methods

3.1 Data Sources

Given the empirical nature of this study, we sought energy measure data for a large number of commercial building retrofit projects from a range of programs. Data sources were targeted for:

- Relevance: Project retrofits must have been completed within about five years.
- Climatic zone representation: Data should include representation across each of the seven major U.S. climate zones (Figure 4), per the International Energy Conservation Code (ICC 2018). Differing climatic conditions may affect the types of retrofit measures employed.
- Building type: A wide range of commercial building types were included.

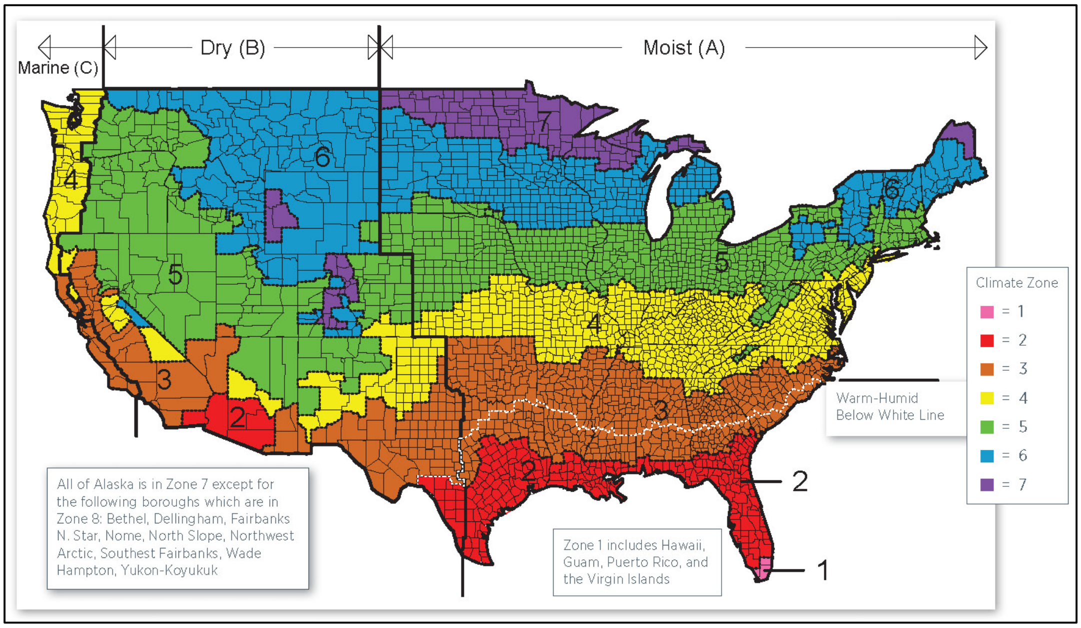

Figure 4. U.S. Climate Zone Regions (International Code Council 2018)

In addition, data sources were selected to represent a range of differing programmatic methods, to understand if adoption trends differed across these approaches. These included both public sector led programs, such as federal government agency retrofits, and private sector approaches such as custom utility incentive programs.

The following sections detail some of the basic characteristics of each dataset included in the analysis. Additional information on these data sources is provided in Appendix A.

1. Custom Utility Customer Incentive Programs

Utility customer incentive programs support a significant number of energy efficiency retrofit investments annually. An LBNL report that studied the performance of efficiency programs of 116 investor-owned utilities and other program administrators in 41 U.S. states found that between 2009 and 2015 these programs expended $13.4 billion (in 2016$) on their commercial and industrial (C&I) programs. Custom utility customer incentive programs represented 37% of the C&I sector savings, with a lifetime gross savings of 836,241 gigawatt-hours (GWh), second in savings only to the residential lighting program (Hoffman et al. 2018). Utility customer incentive programs are typically defined as either prescriptive or custom programs, with prescriptive programs more suited toward equipment upgrades or single measure approaches, and custom programs suited toward more complex applications, including the involvement of systems retrofits, multiple end use system retrofits, and generally projects involving multiple EEMs, including single measures that are in different end use systems. Custom incentive programs would be one suitable data source to assess whether system strategies have been adopted within their relevant market areas.

LBNL compiled a list of U.S. utilities that were active in the custom incentive program space, identified through industry resources (ESource 2017) and LBNL's in-house custom utility customer incentive program database (Hoffman et al. 2018). Those with the highest numbers of custom program customers and/or energy savings from custom programs were approached as potential project collaborators, also ensuring targeted utilities provided geographical and climate diversity.

Not all utilities approached were able to participate in the study, despite high interest in some cases, for a range of administrative reasons including regulatory policies that did not permit retrofit project data sharing even under anonymized conditions.

The data from the utilities included more than 9,000 projects in more than 8,000 buildings. The kinds of data available by utility varied considerably, both in terms of quantitative metrics (e.g., many projects reported different energy savings metrics, or not at all) and qualitative descriptions of EEMs (e.g., ranging from very light descriptive content to detailed case studies). For the 2,500 projects that had kilowatt-hour (kWh) savings and area details, the average energy savings were 7.52 kWh/sq. ft. per building and 5.62 kWh/sq. ft. per project.

2. FEMP Database of Federal Agency Facility Retrofits

The Federal Energy Management Program (FEMP) supports the energy efficient retrofit of U.S. federal government buildings, spanning a wide range of agencies such as the U.S. Departments of the Interior, Defense, Education, Agriculture and Energy. This dataset included 2,234 projects in 1,025 buildings either leased or owned by the U.S. federal government. The database is maintained to track energy consumption, expenditures and other metrics to evaluate program performance. Retrofit projects included a variety of different management approaches, including some energy service performance contracts (ESPCs) performed by ESCOs. It is noted that in some cases FEMP makes use of private sector ESCOs to conduct their retrofits — project records with duplicates in the National Association of Energy Service Companies (NAESCO) database have been removed in such cases.

For projects reporting energy savings and for which building square footage was known, the average electricity savings per building was about 29 kWh/sq. ft. per building, about 15 kWh/sq. ft. per project (n = 1,396).

3. NAESCO Database

This dataset included 421 projects conducted from 2012 to 2017. The majority of the projects in the LBNL/NAESCO database come from the accreditation process of NAESCO — a national trade association for the ESCO industry. As part of this process, ESCOs seeking national accreditation submit applications that include detailed project information. A small percentage of projects (< 10 percent) were provided by state agencies that manage energy efficiency programs and by FEMP. The datasets typically include at least one year of verified savings data. The complete LBNL/NAESCO database includes 6,314 projects implemented from 1982 to 2017, with the vast majority of the projects (> 98 percent) installed after 1990. This database contains projects representing more than $16 billion (2016$) in total project investment levels without financing costs. For project records that included energy data, energy savings averaged about 25 percent.

4. DOE High Performance Buildings Database

The U.S. Department of Energy maintains an online repository of example high performance buildings (https://buildingdata.energy.gov/) (DOE 2018). This dataset included 28 projects and buildings that met the study criteria for inclusion in the high performance retrofit category. Reported whole building annual energy savings averaged about 40 percent.

5. GSA Deep Retrofit Program

This dataset included 41 retrofit projects in 41 U.S. General Services Administration (GSA) buildings (GSA 2012). These projects were not included otherwise in the FEMP / Compliance Tracking System (CTS) dataset. Reported energy use intensity (EUI) savings ranged from 15 percent to 65 percent, averaging 35 percent (not including projects with negative savings evidently due to expansion of floor area usage post-retrofit).

6. NBI Getting to Zero Database

There were 21 retrofit projects and buildings in this New Buildings Institute (NBI) dataset that were not otherwise covered in other data sources, with reported whole building annual energy savings of almost 60 percent on average, and with projects achieving up to 85 percent energy savings.

3.2 Dataset Preparation

Once all the data were collected, some data cleansing was conducted. Data cleansing consisted of removing double counting of buildings and removal of a few instances where energy savings were listed as below 0 percent or above 100 percent. Other work was done to look up project site addresses to determine climate zones in some cases as well. Appendix A provides detailed information on the dataset preparation. This section provides a summary.

Energy Efficiency Measure Classification and Mapping

A standardized EEM nomenclature was developed in order to compile and analyze the data, mapping data from each retrofit project to a common reference. The standardized EEM nomenclature followed the end use system categories, and allowed for further detail within a system element. For example, in the HVAC-Heating end use system equipment element, we defined specific EEMs such as "New Boiler" and "New Air Source Heat Pump." For the Ventilation end use system controls element, we defined specific EEMs such as "Demand Controlled Ventilation," "VFD controls," etc. Similarly, specific EEMs were assigned for the other end use system categories and their elements.

In the process of mapping source information about measures implemented into our EEM nomenclature, it was necessary to make some assumptions in interpreting EEM descriptors from some data sources. For example, one of the smaller data sources listed "Lighting Retrofit" as a measure, without further information as to whether this included just equipment, or controls, or combinations thereof. Appendix A provides the data collection compilation and processing methodology for each data source. Appendix B details the complete common EEM nomenclature used, broken out by end use system category and element. In general, the mapping process tended to interpret a project's EEM descriptor, when not as descriptive as desired, as generously inclusive of system aspects. For example, the EEM descriptor labeled as "Lighting Retrofit" assumed both an equipment and a controls retrofit, and not simply a lamp (equipment) replacement. This condition occurred infrequently across the datasets, however, and was generally isolated to a few specific data sources and handful of EEMs. Contacts at the relevant data sources confirmed that this interpretation was reasonable.

All retrofit EEMs were included in the final dataset, with the omission of a few measures that were determined to not be applicable, such as maintenance efforts or retrocommissioning. Retrocommissioning by itself was not considered an EEM, as it does not consist of the application of *new* controls, equipment, etc., and is excluded from the analysis. However, retrocommissioning as a process will often identify and result in EEM recommendations that improve building performance, resulting in energy savings. In the case that those EEMs were implemented as part of a retrofit, they were identified and included in the analysis. Commissioning and retrocommissioning, however, are important energy saving processes that should be considered for all retrofit programs. They have been recognized as key strategies by energy saving programs such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) programs.

Calculation of Whole Building Energy Savings Percentage

To compare projects with lower or higher energy savings and analyze their related systems retrofit trends, projects reporting whole building percent energy savings needed to be identified. Some projects reported the whole building energy savings in this way, however, the majority of projects only reported kilowatt-hour savings, without referencing their impact on whole building energy use pre-retrofit. In some of these cases building square footage was provided, however. As a means to derive a rough approximation of whole building percent energy savings, we calculated these projects' EUI savings and compared them with the U.S. Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS) average energy use intensities for each building type and U.S. region, to obtain a rough approximation of the whole building energy savings (EIA 2012).

We recognize this approach assumes a particular building is similar to its average CBECS benchmark building for baseline energy use and other relevant characteristics. For the purposes of this study, however, a highly accurate whole building percent energy savings is not required. The analysis focuses on whether the retrofit projects are relatively *low energy saving* (defined as < 20 percent whole building savings) or *higher energy saving* (≥ 20 percent). There will inevitably be some error in the data, with some projects being characterized as low energy saving that should have been shown as high energy saving, and vice versa. As shown in Figure 8 in the Results section, with more than 55 percent of these projects having less than 5 percent energy savings, and another 12 percent at 10 percent energy savings, the representation of projects with < 20 percent energy savings is strong and not likely to be swayed substantially overall with the methodology used. Overall, this method was deemed acceptable for the purposes of broadly categorizing the buildings into those with lower and higher energy saving performance.

3.3 Dataset Characteristics

The final dataset consisted of 12,255 retrofit projects spanning 9,595 buildings, and included building areas, as depicted in Table 2.

Table 2. Projects, Buildings, and Building Size Range

Buildings – Full Dataset	No. of Projects	No. of Buildings	Project Area 5th Percentile (sq. ft.)	Project Area Average (sq. ft.)	Project Area 95th Percentile (sq. ft.)
Totals	12,255	9,595	2,000	239,476	1,067,100

Table 3 describes the building projects in the dataset for which energy savings as a percent of whole building energy use were provided or calculated.

Table 3. Projects with Whole Building Energy Savings Reported or Calculated

Buildings with Energy Savings (% of Whole Bldg)	No. of Projects	No. of Buildings	Project Area 5th Percentile (sq. ft.)	Project Area (sq. ft.) Average	Project Area 95th Percentile (sq. ft.)
Totals	4,765	3,410	2,000	228,879	1,073,400

Table 4 illustrates the distribution of the retrofit projects with whole building percent energy savings across the U.S. climate zones. Climate zone 4 (Mixed) is the most heavily represented, followed by Climate Zone 5 (Cool).

Table 4. Projects per Climate Zone, Full Dataset and with Whole Building Percent Energy Savings

IECC Climate Zone	Total No. Projects	No. Projects with Whole Building % Energy Savings
1. Very Hot – Humid (Miami, FL)	41	19
2. Hot – Humid (Houston, TX) and Hot-Dry (Phoenix, AZ)	181	111
3. Warm – Humid (Memphis, TN), Warm – Dry (El Paso, TX) and Warm – Marine (San Francisco, CA)	616	338
4. Mixed – Humid (Baltimore, MD), Mixed – Dry (Albuquerque, NM) and Mixed – Marine (Salem, OR)	9,274	3,507
5. Cool – Humid (Chicago, IL) and Cool – Dry (Boise, ID)	1,867	685
6. Cold – Humid (Burlington, VT) and Cold – Dry (Helena, MT)	197	82
7. Very Cold (Duluth, MN)	71	21
8. Subarctic (Fairbanks, AK)	8	2

IECC Climate Zone	Total No. Projects	No. Projects with Whole Building % Energy Savings
Grand Total	**12,255**	**4,765**

The building type distribution in Table 5 similarly illustrates a higher representation of office and retail retrofits, but overall a wide representation of different building types. For one data source (NAESCO data) the building types were not provided, so they are included in the "Other/Blank" category (n = 417).

Table 5. Projects per Building Type (Top 10)

Building Type	Total No. of Projects	Projects with % Energy Savings	
		Number	%
Office	1,935	992	29%
Other/Blank/Unknown	1,669	424	12%
Retail	1,522	279	8%
Trans. Infrastructure	782	0	0%
Warehouse	738	152	4%
Gas Station / Conv. Store	654	244	7%
Hospital	593	540	16%
Restaurant	542	178	5%
Education	514	354	10%
Lodging/Hotel/Motel	439	240	7%
Total	**9,388**	**3,403**	**100%**

A complete breakout of 40 building types is provided in Appendix A. Table 6 presents the breakout of building retrofit projects conducted on private sector lead programs (e.g., ESCOs, utility programs) versus public sector lead efforts (e.g., GSA, FEMP).

Table 6. Private and Public Sector Project Representation Across Climate Zones for Projects with Whole Building Percent Energy Savings

IECC Climate Zone	Public Sector Projects	Private Sector Projects
1. Very Hot – Humid (Miami, FL)	11	8
2. Hot – Humid (Houston, TX) and Hot-Dry (Phoenix, AZ)	80	31
3. Warm – Humid (Memphis, TN), Warm – Dry (El Paso, TX) and Warm – Marine (San Francisco, CA)	229	109
4. Mixed – Humid (Baltimore, MD), Mixed – Dry (Albuquerque, NM) and Mixed – Marine (Salem, OR)	398	3,109
5. Cool – Humid (Chicago, IL) and Cool – Dry (Boise, ID)	268	417
6. Cold – Humid (Burlington, VT) and Cold – Dry (Helena, MT)	65	17

7. Very Cold (Duluth, MN)	14	7
8. Subarctic (Fairbanks, AK)	2	-
Grand Total (Projects) **Grand Total (sq. ft.)**	**1,067** **680,950 sq. ft.**	**3,698** **85,405 sq. ft.**

3.4 Analysis Approach

As noted in the introduction, the analysis sought to address three questions:

1. **What is the *prevalence of systems retrofits* compared to component (i.e., non-system) retrofits?**
2. **Do systems retrofits *save more energy* compared to component retrofits?**
3. **What *types of measures* are used in systems retrofits?**

We conducted a simple statistical analysis of the dataset to identify trends by comparing the number and percentage of projects in various cohorts. The cohorts were defined based on one or more of the attributes shown in Table 7.

Table 7. Attributes Used to Define the Cohorts

Analysis Cohort Attribute	Attribute Categories
Retrofit Type	Non-System retrofits End-Use System retrofits Interactive System retrofits Integrated System retrofits
Project Savings	Low Energy Savings projects High Energy Savings projects
Program Type	Federal NAESCO Utility Other

Dataset limitations and the scope of the project precluded us from conducting more complex analysis (e.g., multivariate regression) to analyze the relationships among these attributes.

4. Results

4.1 Prevalence of Systems Retrofits

Figure 5 shows the distribution of various types of retrofits. **The three types of systems retrofits collectively represented less than 20 percent of total projects, indicating that systems retrofits are**

relatively uncommon. End Use System retrofits occurred in 17 percent of the projects while only 6 percent of the projects had an Interactive System retrofit. Notably there were no recognized instances of any Integrated System retrofits. Note that some projects with either Non-System retrofits or End Use System retrofits could also have an Interactive System retrofit (refer to the retrofit types definitions for further information), and therefore the sum of retrofit types is greater than the total number of projects.

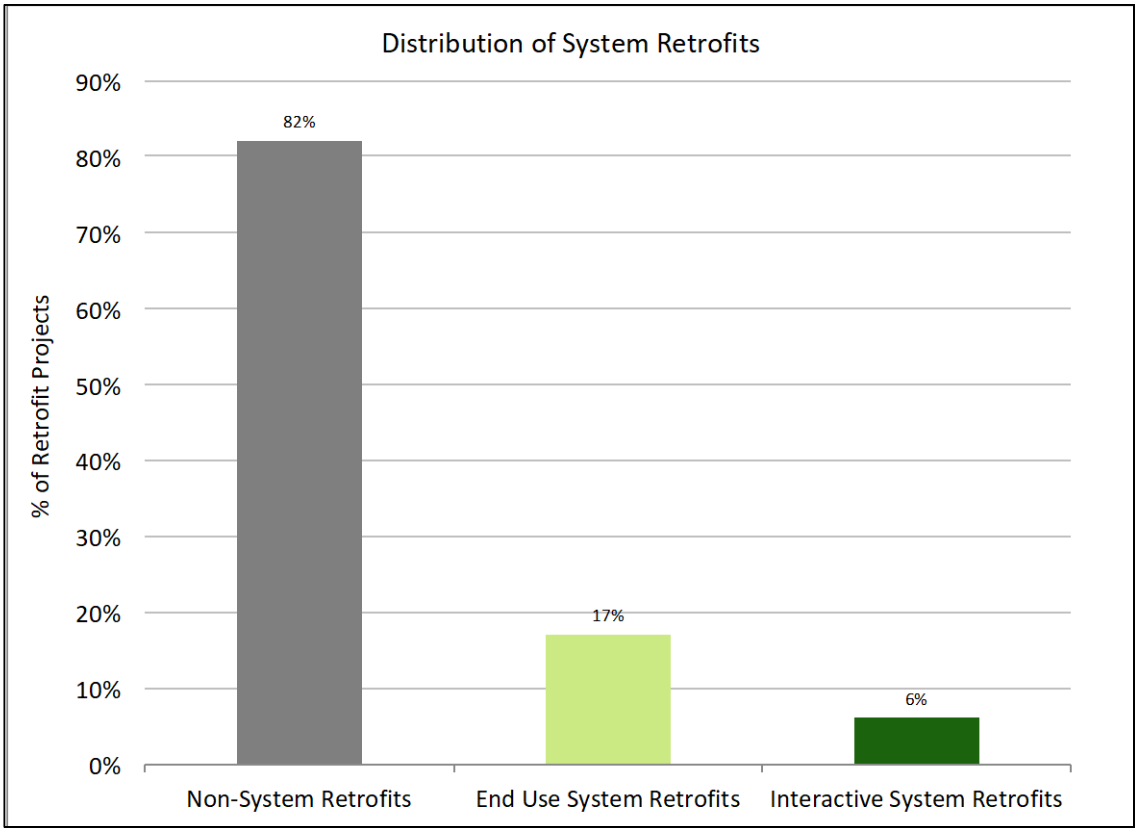

Figure 5. Distribution of System Retrofits

Figure 6 shows the distribution of system retrofits broken out by program type. It shows that systems retrofits are more prevalent in federal programs and NAESCO datasets than in utility programs. The 'Other' category includes projects sources from NBI's Zero Net Energy Buildings database, as well as the DOE High Performance Buildings Database. In both cases the retrofit buildings were all high energy saving projects.

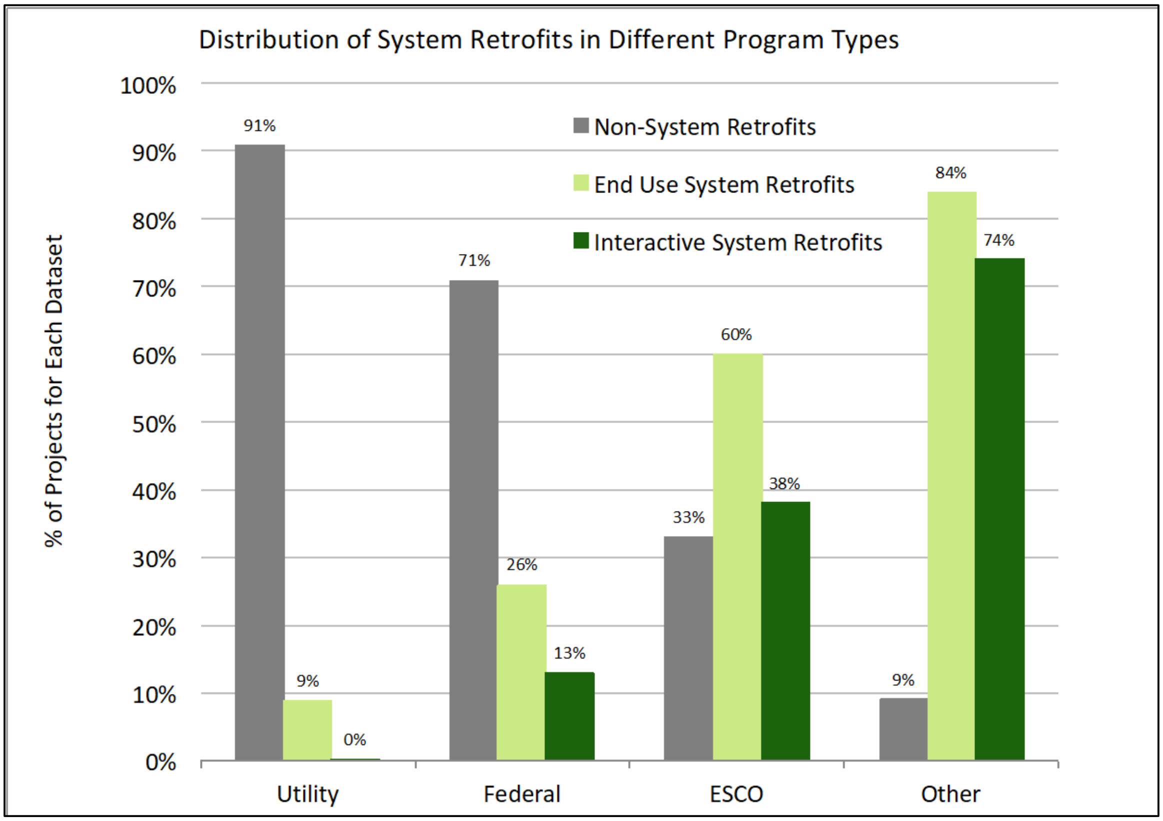

Figure 6. Distribution of System Retrofits in Different Program Types

4.2 Energy Savings of Systems Retrofits

As noted earlier, we categorized projects based on whole building energy savings as either low energy-saving (< 20 percent whole building energy savings) or high energy saving (≥ 20 percent). The vast majority of projects were low-energy savings and only about 20 percent were high energy savings projects, as shown in Figure 7.

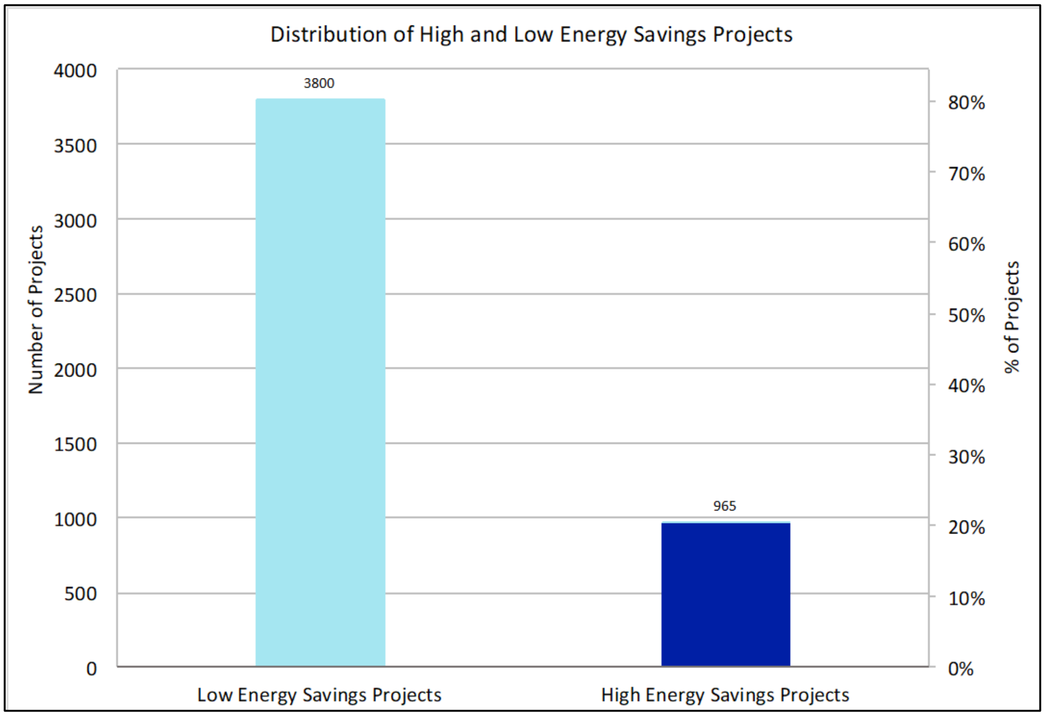

Figure 7. Distribution of High and Low Energy Savings Projects

Figure 8 illustrates the distribution of energy savings for different retrofit types across all projects.

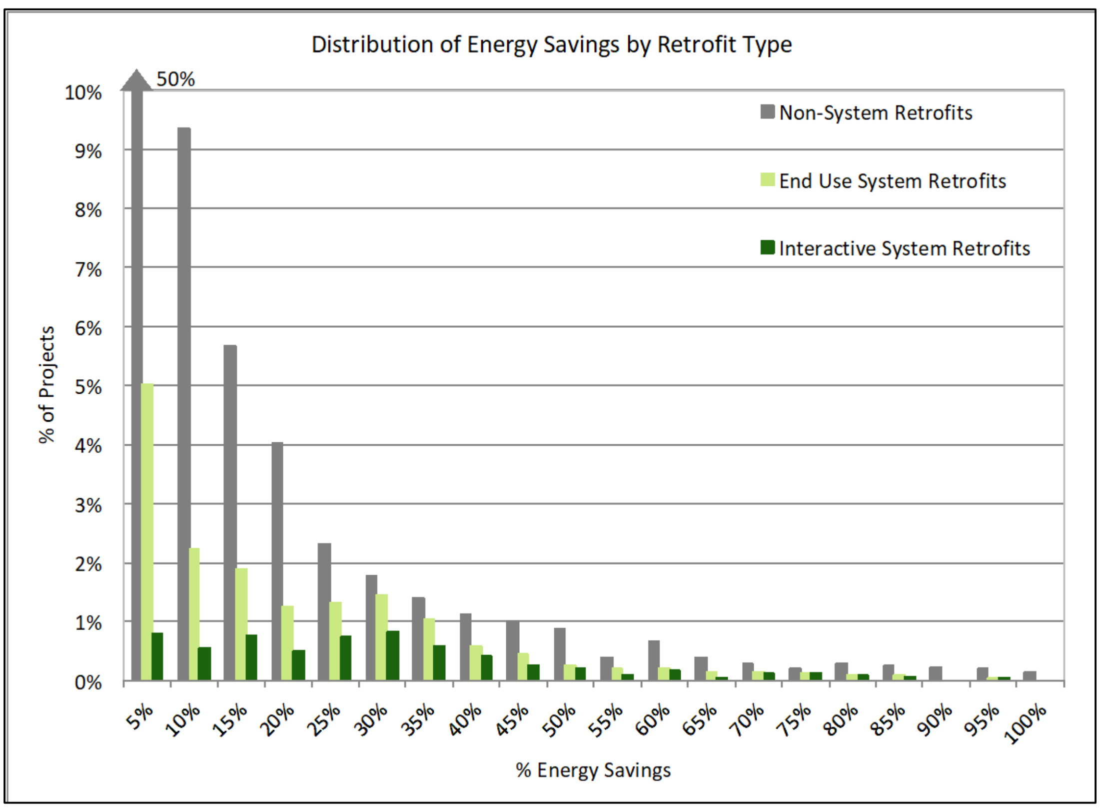

Figure 8. Distribution of Energy Savings by Retrofit Type

A first general observation is that Non-System and Systems retrofits include a wide range of energy savings. However, there are substantially fewer Non-System retrofits for projects with higher whole building energy savings. End Use System retrofits occur at increasing frequencies from lower to higher energy saving projects. It is notable that some Non-System retrofit projects are able to achieve higher levels of energy savings. Further review of data from the utility custom incentive programs, for example, indicates that some buildings may be able to achieve high energy savings through lighting retrofits, likely with an inefficient baseline. This may represent the current transition from incandescent and fluorescent lighting to high efficiency LEDs. Over time these opportunities to provide substantial energy savings through lighting replacement will become less prevalent.

Figure 9 breaks out the distribution of low and high energy savings projects for different retrofit types. End Use System retrofits and Interactive System retrofits show a greater occurrence of higher energy saving projects.

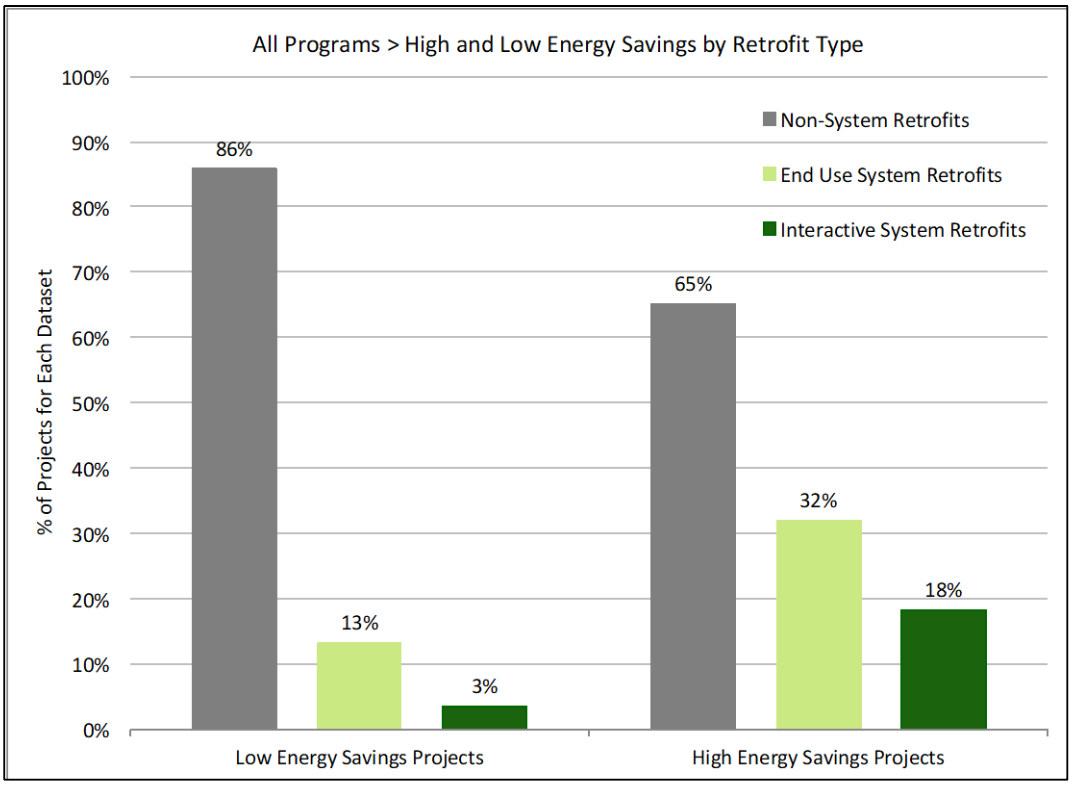

Figure 9. All Programs > High and Low Energy Savings by Retrofit Type

The distribution of retrofit types for utility, U.S. federal (FEMP and GSA) programs, and for ESCO retrofits follow in figures 10, 11 and 12. The breakout of low versus high energy savings projects is provided as well, to contrast against each other and compare with the dataset as a whole.

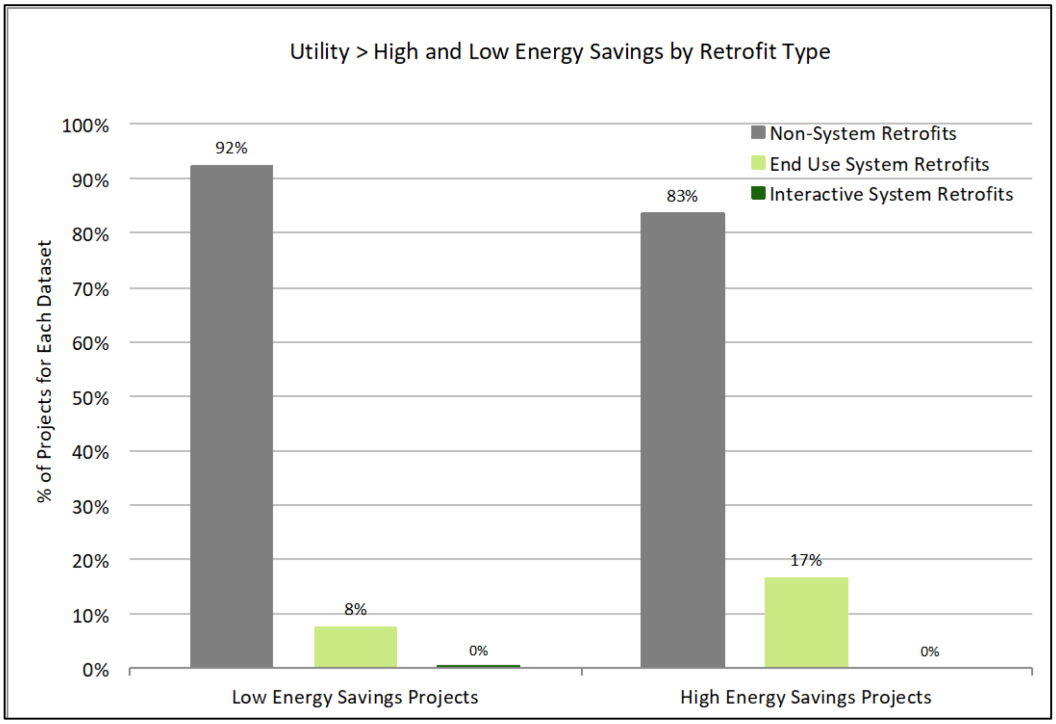

Figure 10. Utility > High and Low Energy Savings by Retrofit Type

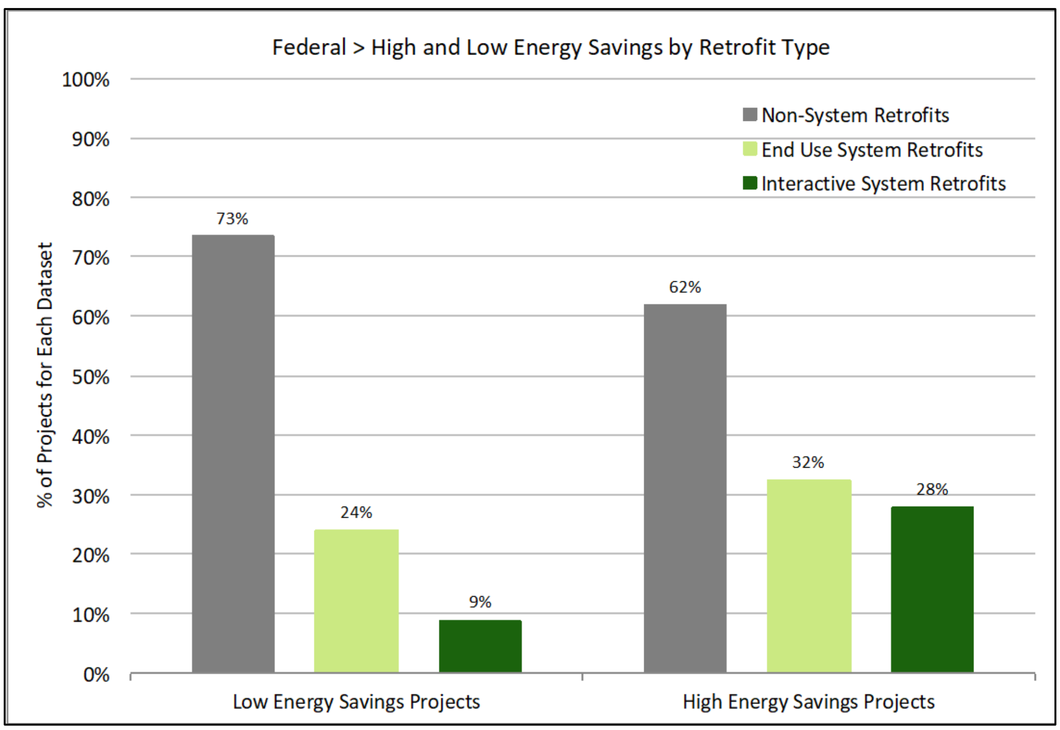

Figure 11. Federal > High and Low Energy Savings by Retrofit Type

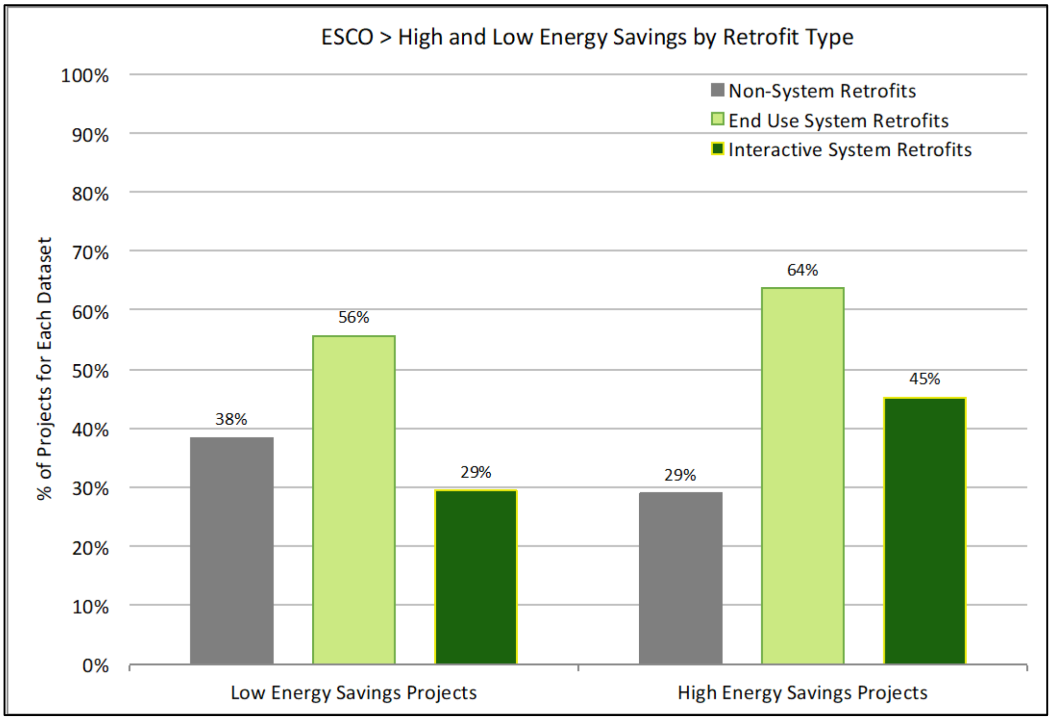

Figure 12. ESCO > High and Low Energy Savings by Retrofit Type

There is a striking difference in these three programs and their use of the different retrofit approaches. Federal programs have a much higher frequency of End Use System and Interactive System retrofits than utility programs, but ESCO projects predominantly focus on End Use System retrofits, even in lower energy saving projects. In all three cases though, End Use System and Interactive System retrofits have a greater percentage of high energy savings projects. However, the figures illustrate that there are cases where high energy savings are possible using Non-System approaches, which will be explored further in the next section. Notably, there may be programmatic differences that support the identification and application of Non-System retrofits.

Utility custom programs in particular appear to strongly favor Non-System approaches throughout, even though custom programs can theoretically support more complex systems-based approaches. The vast majority of their projects are low energy savings; only 15 percent achieve high energy savings, but in a significant number of cases these high energy saving projects are able to achieve these results using Non-System approaches. While utility projects do target more End Use System retrofits for high energy projects (17 percent of them, versus 8 percent of low energy projects), given the lower prevalence of high energy saving projects in general this is not a strong trend in these programs.

For federal programs, there is a much stronger representation of End Use System retrofits for high energy saving projects (32 percent versus 24 percent for low energy saving projects). There is a substantial showing for Interactive System retrofits, at 28 percent of high energy saving projects, suggesting a more comprehensive approach to these retrofits targeting multiple end use systems and perhaps even envelope measures at once.

ESCOs on the other hand strongly appear to favor systems-based approaches across all projects, with an increase of their prevalence in high energy saving projects. However, even the low energy saving projects more frequently applied systems-based retrofits. More than 50 percent of low energy saving projects included End Use System retrofits, and 29 percent included Interactive System retrofits. This suggests a greater level of identification of measures with a given end use, perhaps taking advantage of the labor and trade investments working in that area. Further thoughts on how each of these programs are suited to systems approaches and opportunities for improvement are explored in Section 6.

4.3 Energy Efficiency Measures in Systems Retrofits

Figure 13 shows the distribution of EEMs in the projects by end use system category. Overall, lighting was the predominant end use system affected, representing more than 70 percent of the low energy saving project EEMs, followed by heating, cooling and ventilation, which each represented about 10 percent or less of the EEMs. High energy saving projects also emphasized lighting measures, but HVAC retrofits as well, at 20–30 percent of measures. Envelope measures were also notably more frequent at the high energy savings level, although still less than 10 percent of the EEMs. Overall it appears that lighting is still a strong and important contributor to both datasets, but for higher energy saving projects HVAC is more frequently addressed.

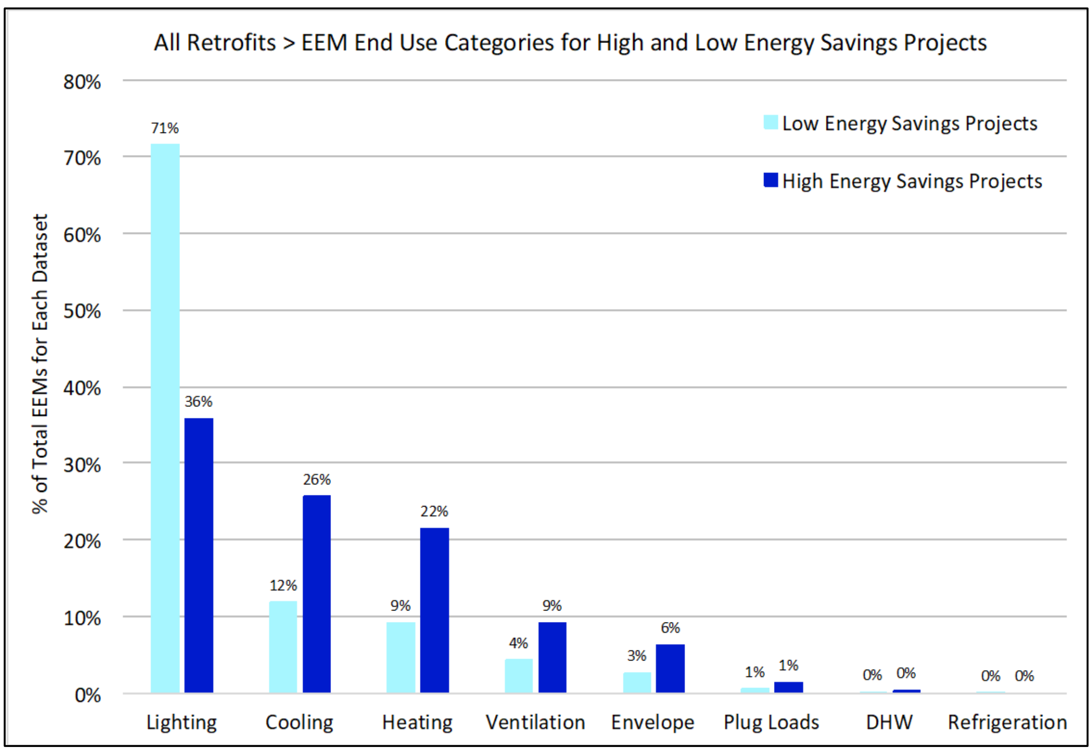

Figure 13. All Retrofits > EEM End Use Categories for High and Low Energy Savings Projects

We analyzed the EEM measures for high and low energy savings projects in each retrofit type, and for each program type. The results are discussed below for selected cohorts, focusing on the high energy savings projects. The complete results for all cohorts are presented in Appendix C.

Non-System Retrofit EEM Analysis

Given the high prevalence of Non-System retrofits, a deeper look into these projects is of interest to understand what end use system categories are most commonly affected and what measures are used. Figure 14 shows their distribution by end use type.

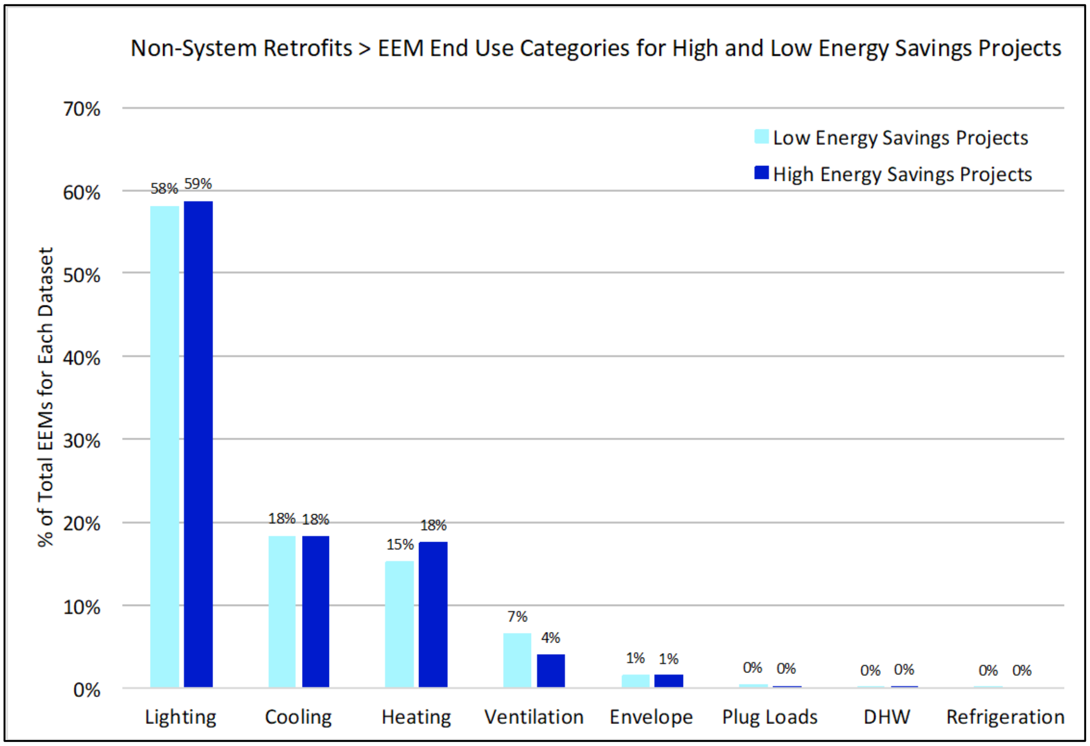

Figure 14. Non-System Retrofits > EEM End Use Categories for High and Low Energy Savings Projects

Lighting again is the predominant end use category affected, although the combination of heating, cooling and ventilation systems retrofits are nearly as substantial. There is strikingly little difference in the kinds of end use systems targeted by the low versus high energy saving projects. A deeper look into the distribution of EEMs occurring in the high energy savings datasets is presented in Figure 15.

These figures illustrate that LED lighting remains a strong energy-saving retrofit option for all projects, as do lighting fixtures, and occupancy and bi-level switching controls retrofits. Non-LED lighting retrofits are also prevalent, although considering that this set of data spans the past five years, it is conceivable that there has been less emphasis on these products in favor of LED lamps in more recent years. The frequency of Non-System retrofits for some high energy projects suggests that there can still be substantial whole building energy savings available for some buildings through use of lighting upgrades. This would most frequently occur with buildings with older T12 and non-dimming or non-occupancy based controlled lighting systems.

As these highly favorable lighting retrofit conditions begin to dwindle, other measures will be needed to achieve higher levels of savings, and these could include strategies such as End Use System retrofits.

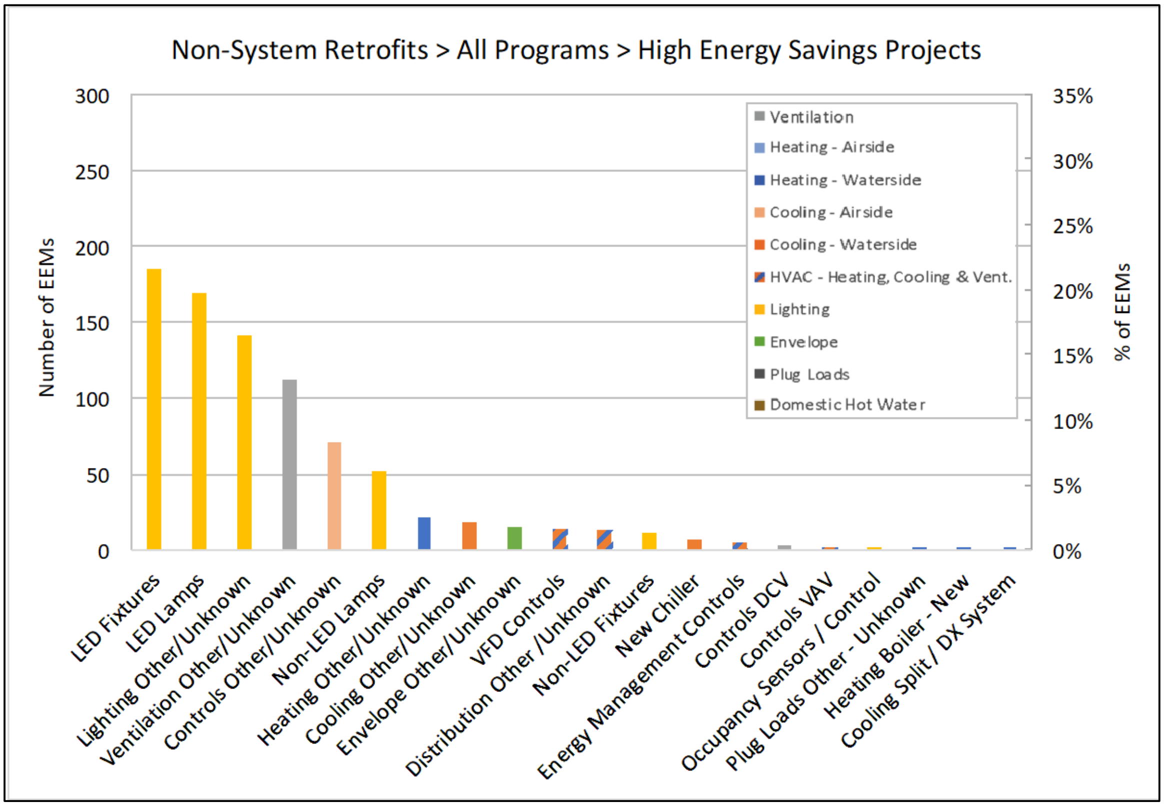

Figure 15. Non-System Retrofits > All Programs > High Energy Savings Projects

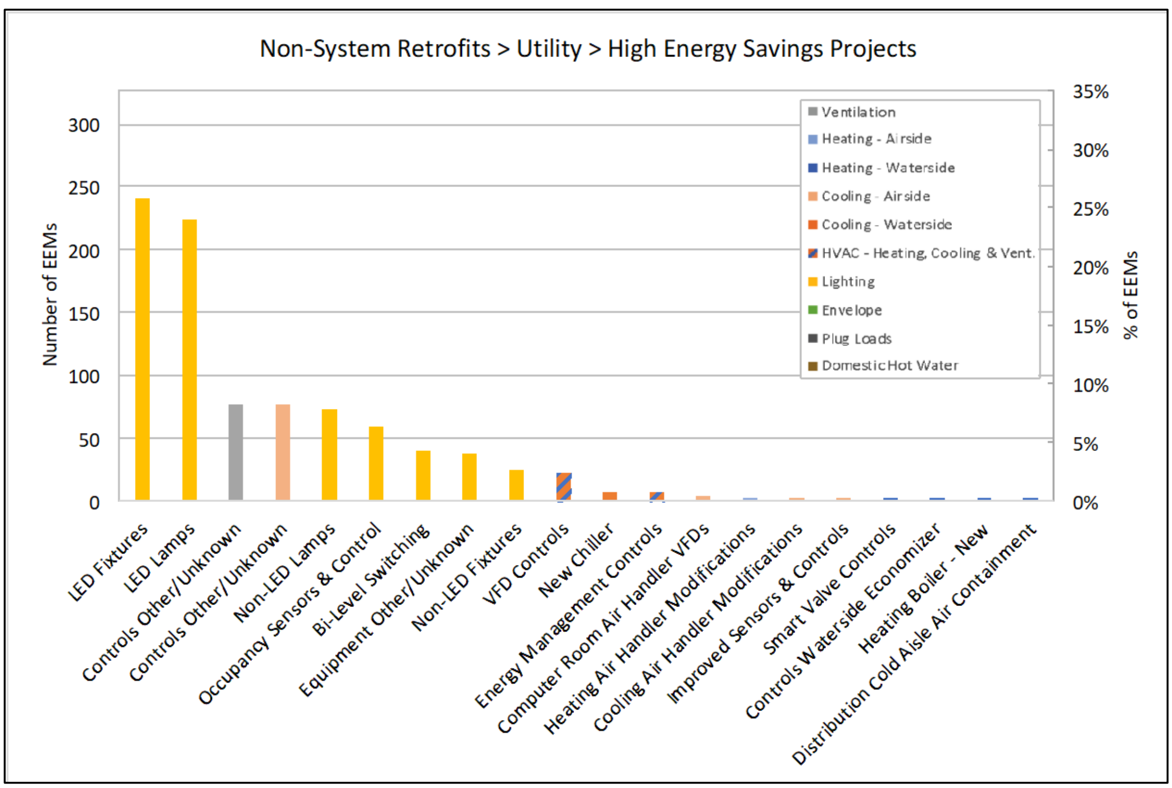

Figure 16. Non-System Retrofits > Utility > High Energy Savings Projects

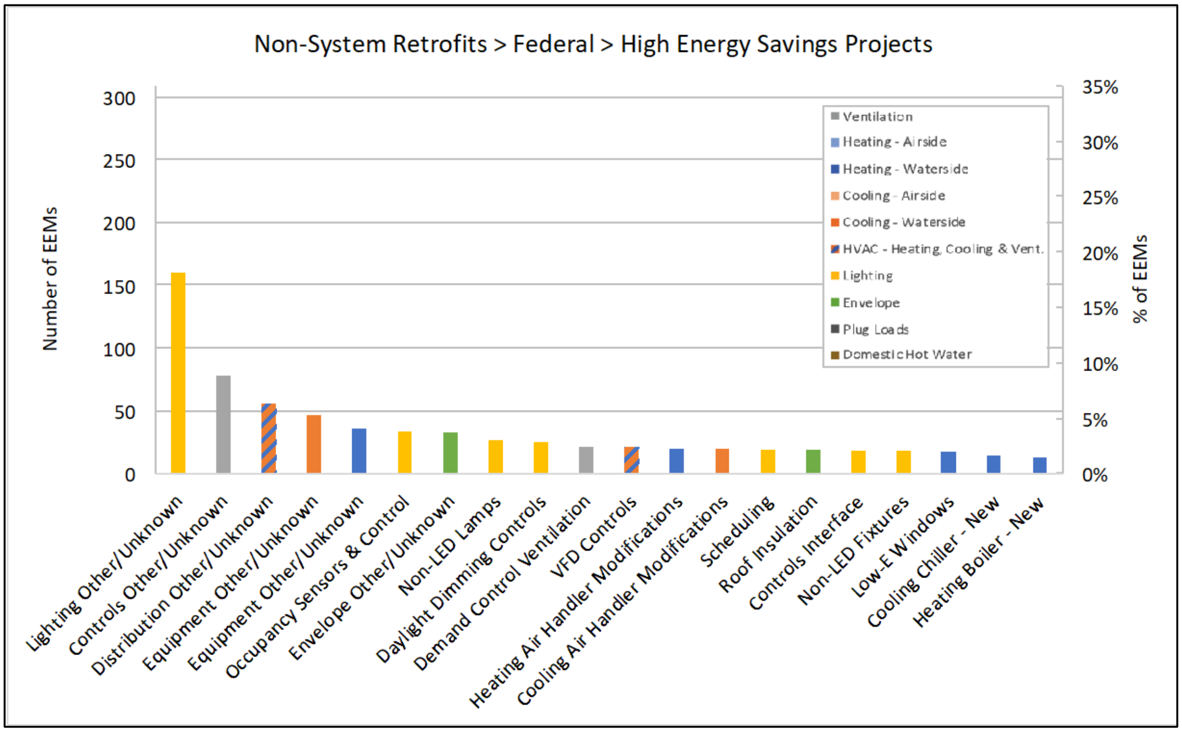

Figure 17. Non-System Retrofits > Federal > High Energy Savings Projects

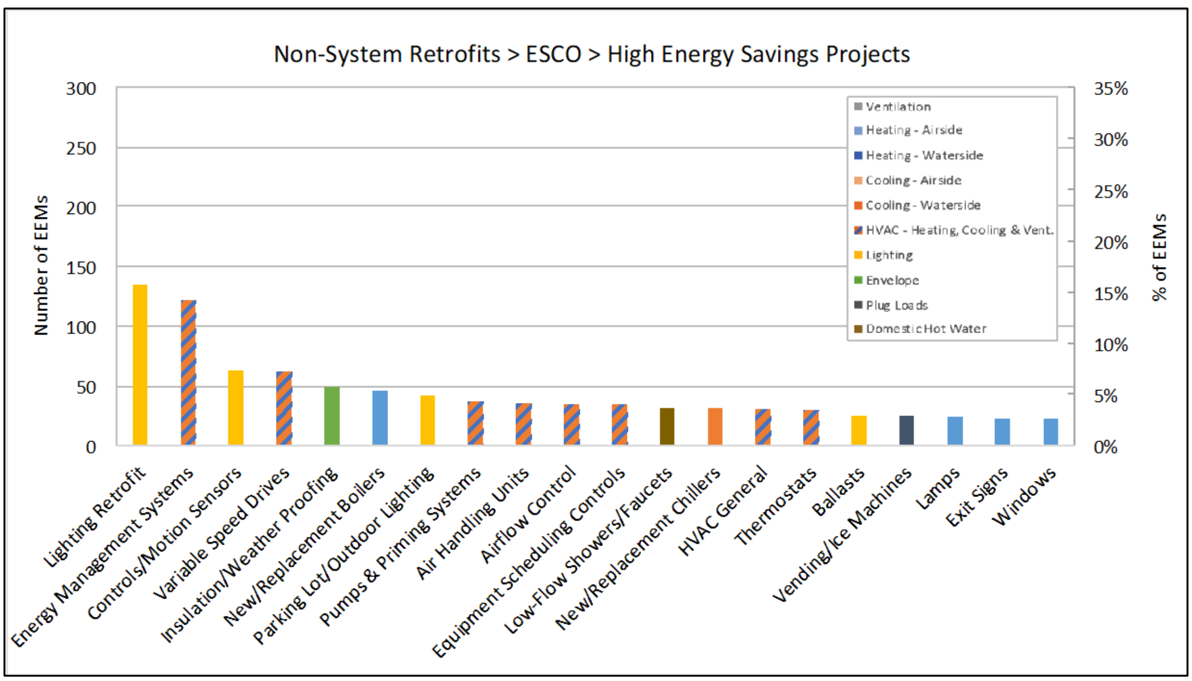

Figure 18. Non-System Retrofits > ESCO > High Energy Savings Projects

Overall, 65 percent of the high energy saving projects and 66 percent of the low energy saving projects used lighting measures. Ventilation also contributed significantly to the higher energy savings projects, although the measure descriptions available did not provide sufficient additional detail on the strategies implemented. In some cases, it may be that a combination of Non-System approaches, such as single EEMs implemented across different end use categories might have resulted in the higher energy savings (e.g., light fixtures and other non-lighting measures, likely in HVAC).

Figures 16 through 18 present further analysis of the Non-System retrofits, splitting out EEM distributions by program type for the high energy savings projects (again, see Appendix C for low energy savings projects). The following are key takeaways:

- Utility custom incentive programs strongly trend toward lighting measures as the predominant Non-System approach to savings (Figure 16).
- Federal programs have a much broader range of strategies used in both low and high energy saving projects, with no one end use category dominating. Heating, cooling, ventilation, lighting and even envelope have made significant contributions. Lighting, heating (waterside) and ventilation, though, are the most common retrofit targets for low energy projects, comprising 15 percent of EEMs each. For high energy saving projects, the distribution of measures is much flatter, indicating a broader array of strategies. Here lighting is most prevalent, at 18 percent of EEMs, but ventilation, cooling (waterside) and heating (waterside) trail at < 10 percent each (Figure 17).
- ESCO project Non-System EEMs are even more broadly distributed than the federal project cases, with lighting, HVAC and envelope the highest contributors. Notably, the most frequent HVAC EEMs are controls related strategies that could have impacts across heating, cooling and/or ventilation. These strategies include VFDs, energy management system controls, and air handler upgrades (Figure 18).

End Use System Retrofit EEM Analysis

Overall, 17 percent of all projects with whole building percent energy savings data included at least one End Use System retrofit. Figure 19 shows the distribution of End Use System retrofits by end use system category.

Among End Use System EEMs, lighting measures were still the most prevalent, but heating, cooling and ventilation measures occurred at about twice the rate they did in the Non-System retrofit projects. The main differences in End Use System retrofits between the low and high energy saving projects centered on a greater number of lighting retrofits in the low energy saving projects, and a significantly higher number of envelope retrofits in the high energy saving projects. Notably, the frequency of other HVAC related retrofits was similar in both datasets. It should be recalled, however, that only 13 percent of the low energy saving projects had End Use System retrofits, compared with 32 percent of the high energy saving projects (Figure 9). At this level there is not a striking difference in the frequency that certain end use system categories are targeted by high and low energy saving projects.

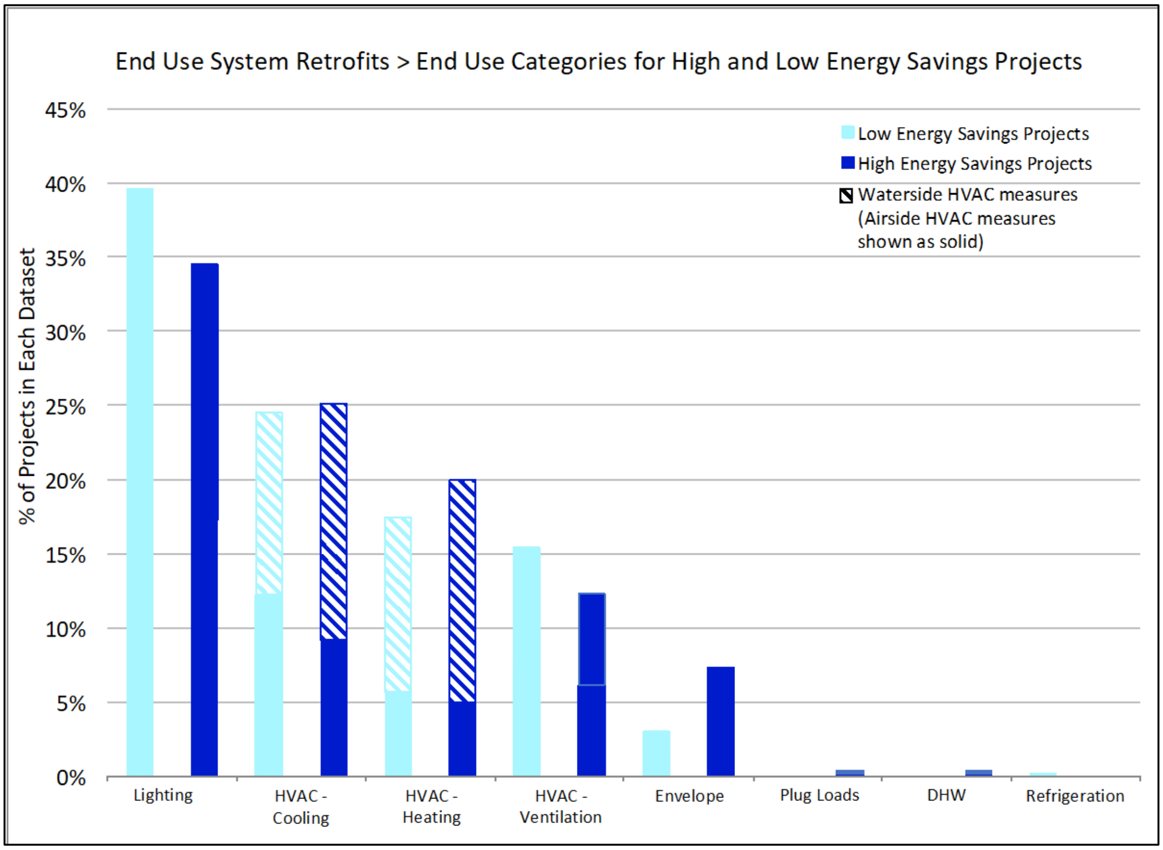

Figure 19. End Use System Retrofits > End Use Categories for High and Low Energy Savings Projects

Figure 20 shows the top 20 EEM combinations present in the End Use System retrofits for high energy saving projects.

Fourteen of the top combinations for the high energy saving projects focus on lighting — showing a greater range of equipment (lamp, fixture, LED, non-LED) and controls (occupancy, bi-level switching, daylighting dimming, scheduling) combinations. VFD controls and HVAC equipment replacements with higher efficiency products were a common trend in the top EEM combinations for the low energy saving projects. The high energy saving projects show several additional measures being used, including demand-controlled ventilation, dedicated outside air systems, and air handler upgrade combinations.

The lower energy saving projects applied fewer kinds of End Use System retrofits, with the top 20 EEM combinations representing 63 percent of the total EEMs implemented. In contrast, the top 20 EEM combinations for the high energy saving projects represent only 36 percent of their EEMs implemented. A much broader number of EEM combination types were employed by the higher energy saving projects (302) than those found in the low energy saving projects (179).

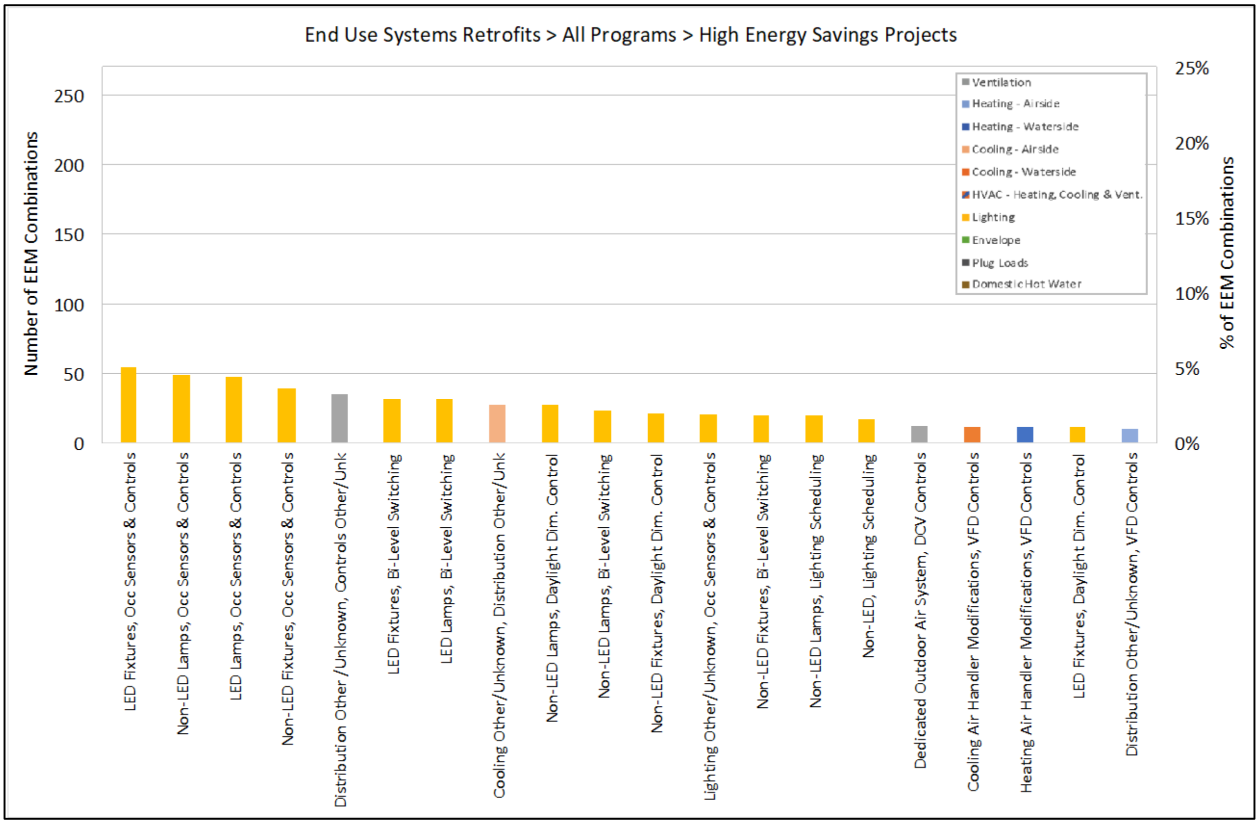

Figure 20. End Use System Retrofits > All Programs > High Energy Savings Projects

Some further trends are apparent from the EEM combinations. It is interesting to note for the high energy saving projects, non-LED lighting occurred with the most frequency among lighting retrofits. This is likely an artifact of some of these projects being of slightly older vintage, so LED pricing may not have been as advantageous as it currently is.

Figures 21 through 23 illustrate the distribution of the End Use System retrofits for high energy savings projects in the utility, federal and NAESCO projects. Disaggregating by program illuminates some distinct differences between the programs. These include the following:

- Utility programs' top EEM combinations show an even greater proportion of lighting-based measures across all of their retrofit projects. Lighting combinations represent the top 10 strategies for both low and high energy saving projects, with top measures occurring at rates of 21 percent and 18 percent (LED fixtures with occupancy controls), respectively. However, lighting retrofits are slightly less common among the high energy saving projects, with HVAC measures slightly more common. The lighting measures used are similar across all projects (lamps/fixtures, bi-level switching, occupancy controls).

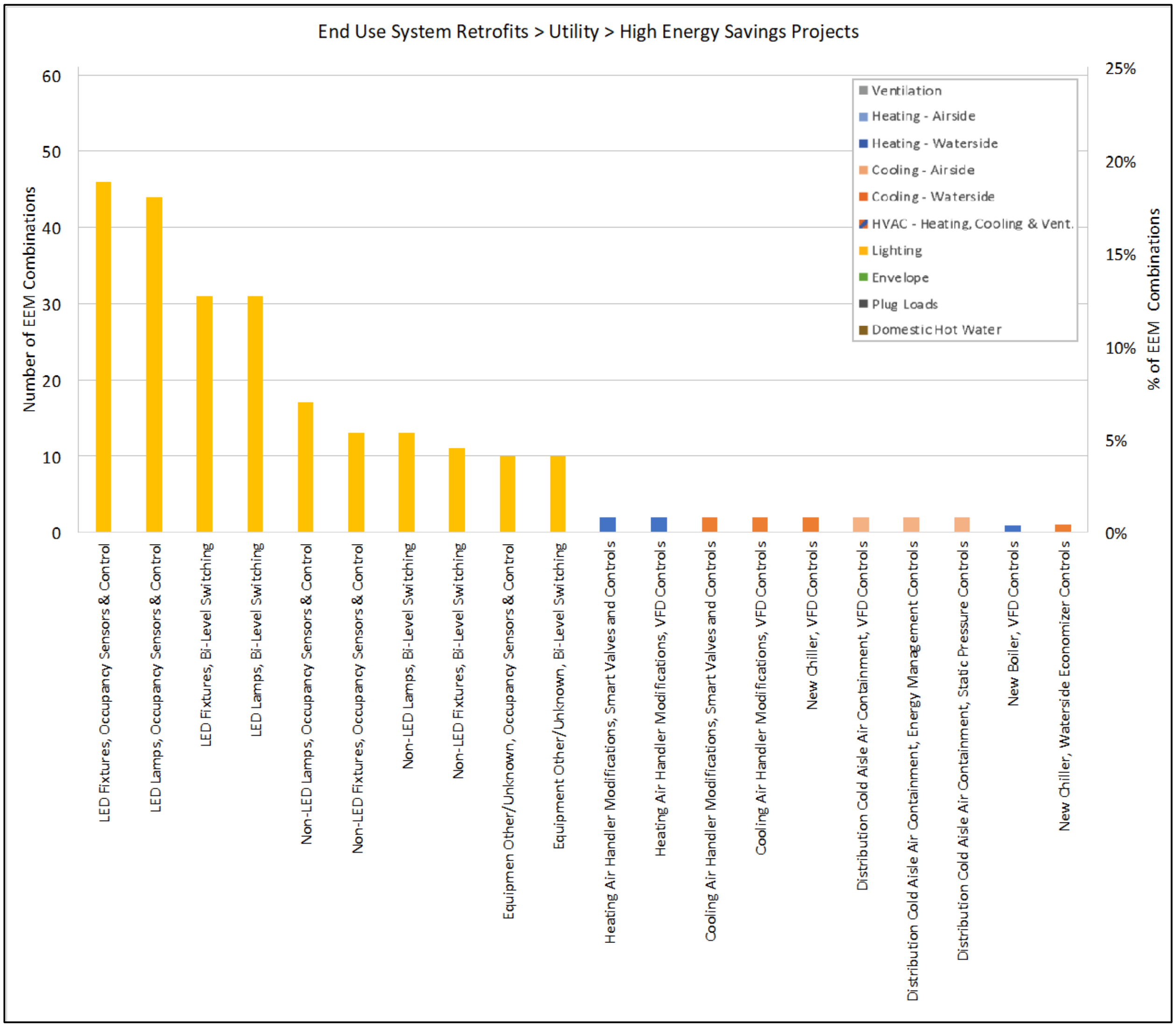

Figure 21. End Use System Retrofits > Utility > High Energy Savings Projects

- (con't) The most common combinations of HVAC measures for low energy saving projects include controls with new equipment (chiller), air distribution, or heat recovery, although none constituted more than a 1 percent. In contrast, high energy saving projects included controls combined with air handler modifications, new equipment (chiller or boiler), and a few air distribution cases related to data centers (cold aisle containment).

- Federal programs demonstrate a notable difference in the kinds of End Use System retrofits. They appear to use a much wider range of strategies in all cases. The highest combinations for both low and high energy saving projects, at rates of 9 percent and 6 percent respectively, was a combination of ventilation distribution “other/unknown” and controls “other/unknown.” Ventilation, lighting, heating airside and cooling airside systems are most prevalent in the low energy saving projects. High energy saving projects, however, have lighting for 8 of the top 10 combinations. In general, however, most of the top 20 combinations represent only 1 to

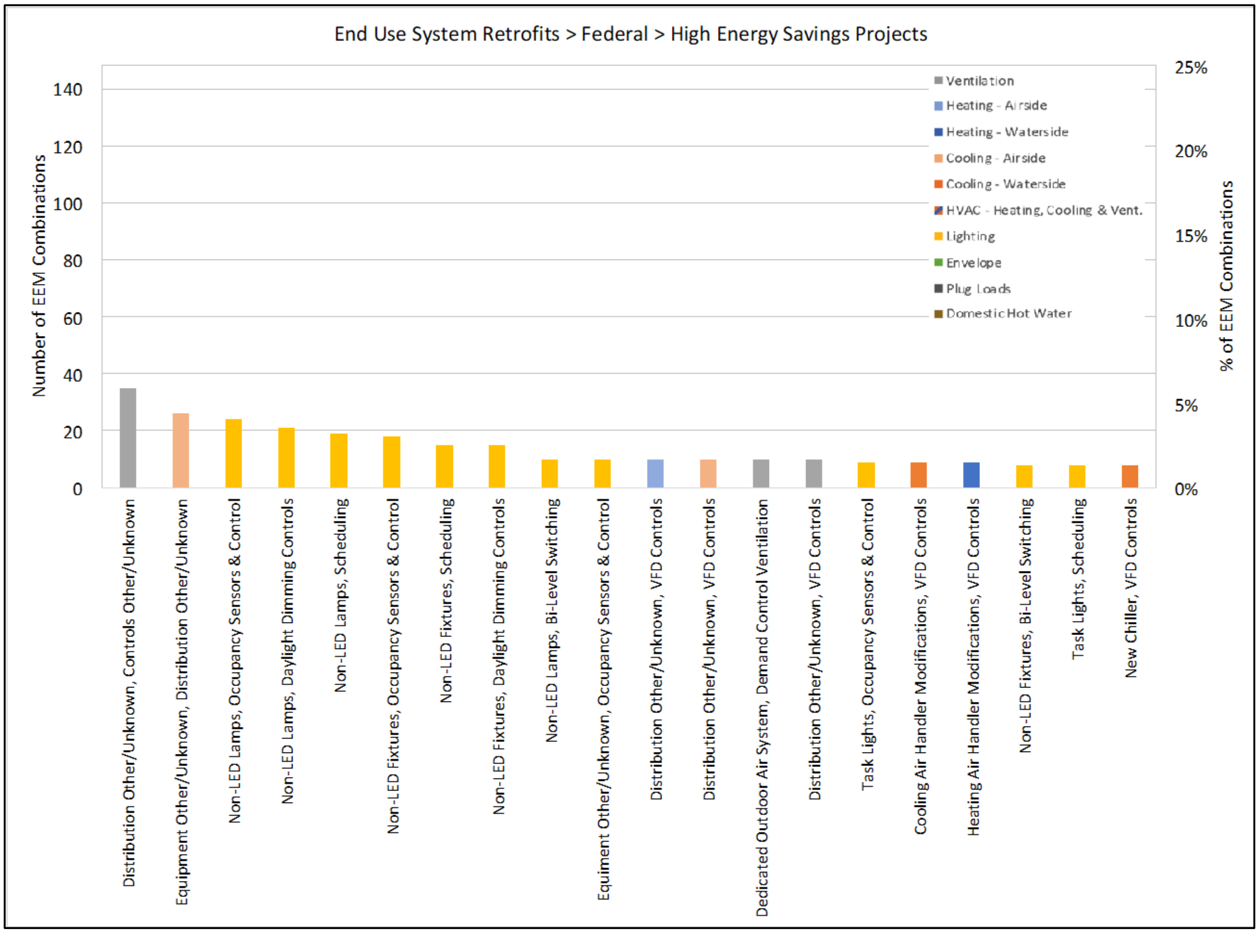

Figure 22. End Use System Retrofits > Federal > High Energy Savings Projects

- (con't) 4 percent of cases each, so a strong pattern is not apparent, other than a wide number of types of End Use System retrofits.

- ESCO projects have an even wider distribution of End Use System retrofits than the federal projects do. The top EEM combinations for ESCO projects occurred in only 3 percent and 2 percent of projects (low and high energy saving projects respectively). The top 20 measures in each case included combinations that only occurred in 1 percent of projects, so at these rates additional trend analysis is limited. However, it is interesting to note that heating waterside and cooling waterside element combinations are the most prevalent in the Top 20 for both the low and high energy saving projects. Element combinations here included equipment (pumps, chillers, boilers, air handler modifications) and controls (VFDs, energy management system).

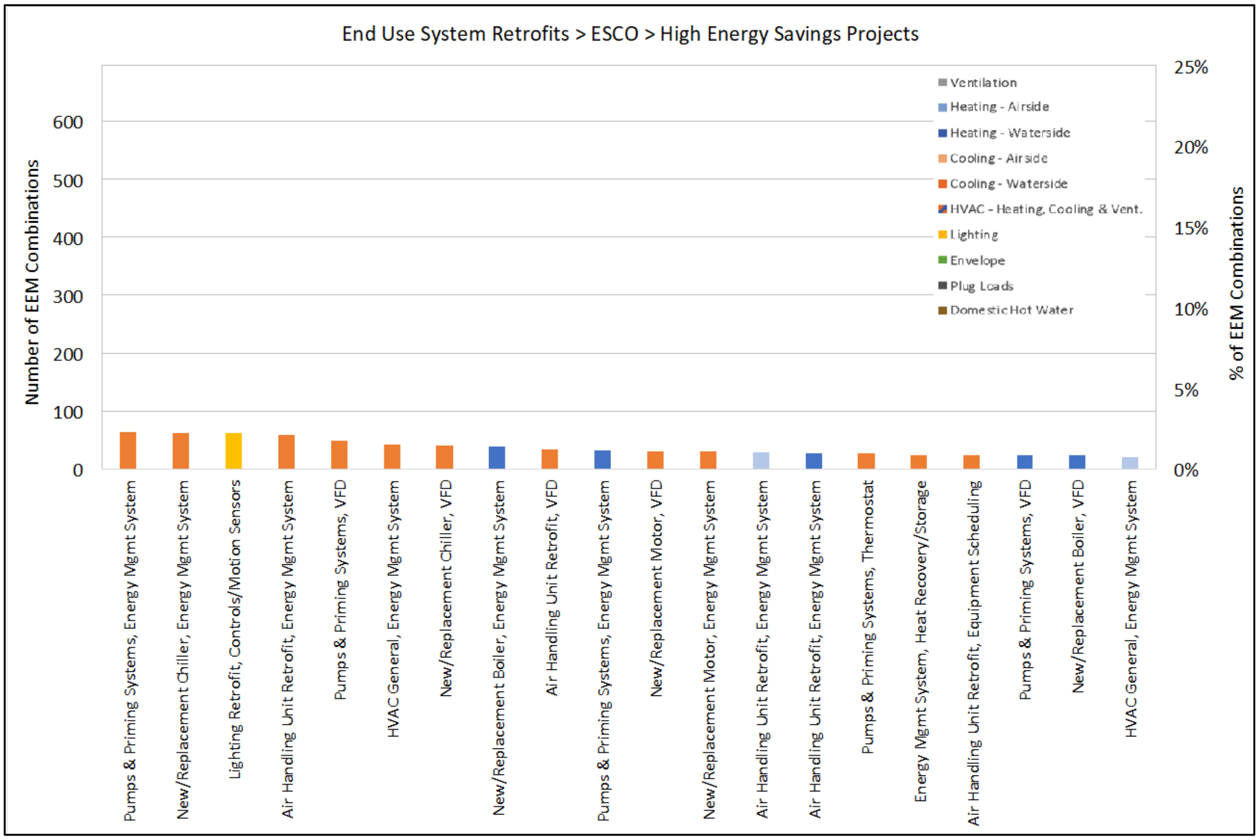

Figure 23. End Use System Retrofits > ESCO > High Energy Savings Projects

EEM combinations favoring equipment and controls retrofits were ubiquitous across the most common strategies used by all end use systems. This may point toward an understanding of relative ease of implementing retrofits in these areas, compared to some other End Use System retrofit strategies that could be more costly and disruptive to implement (i.e., distribution and termination measures). Supporting devices appear to be infrequently used across the programs, pointing perhaps to reduced technical opportunities for savings in this area, or it being an emerging area where value is still being developed in the marketplace, such as the use of storage for reducing peak electricity pricing.

Interactive System Retrofit EEM Analysis

As previously discussed, the performance of an end use system (e.g., HVAC or lighting) may be impacted by virtue of an EEM occurring in a different end use system category (e.g., plug load energy use/heat gain reduction) or envelope retrofit (e.g., envelope load reduction, or daylight availability). In this analysis we identified when both different building systems had been retrofit interactively as part of one project, in order to identify opportunities for additional savings (e.g., capital cost via capacity reduction, energy savings). These Interactive System retrofits include:

- Those that reduce loads, affecting HVAC: e.g., lighting and HVAC; envelope and HVAC; plug loads and HVAC; lighting, envelope and HVAC
- Those that provide daylight affecting lighting: e.g., select envelope EEMs and lighting

Overall 6% of the projects with energy savings reported had an Interactive System retrofit. Figure 24 identifies the kinds of Interactive System retrofit types occurring in the low and high energy saving projects.

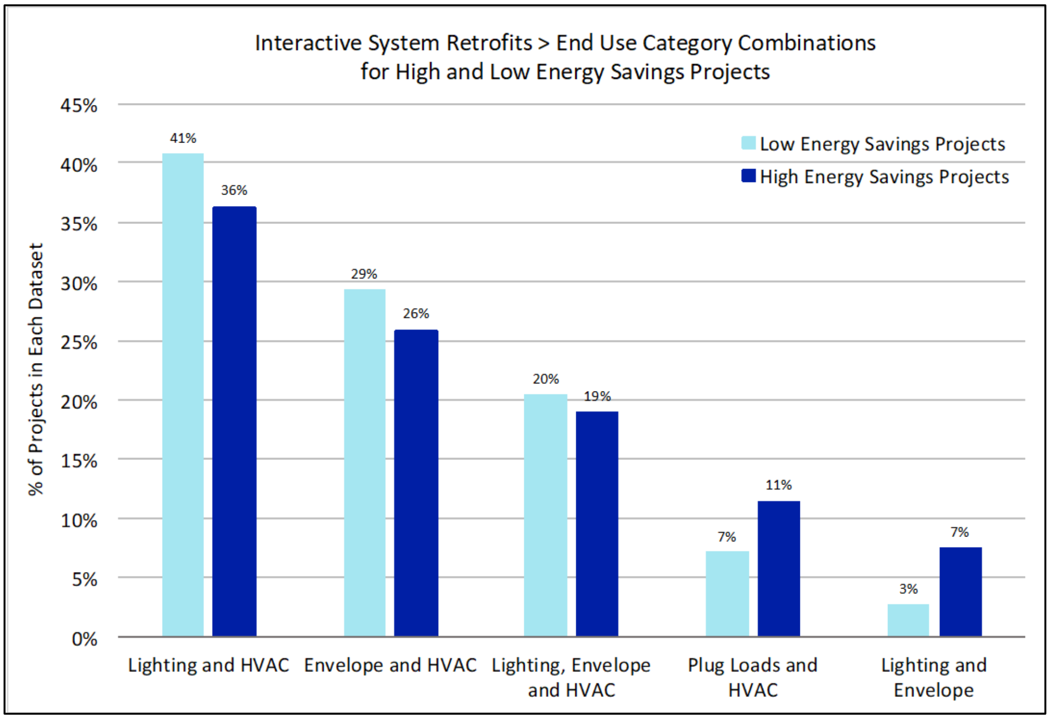

Figure 24. Interactive System Retrofits > End Use Category Combinations for High and Low Energy Savings Projects

Figure 24 indicates that Interactive System retrofits tend to involve similar frequencies of both low and high energy saving projects, although as stated previously they are only occurring at the rate of 3 percent of all low energy projects, as opposed to 18 percent of the high energy saving projects (see again Figure 9). The combination of lighting and HVAC is most prevalent, which may be seen as consistent with the high penetration of lighting measures throughout both datasets. Of interest, however, is that envelope measures combined with HVAC are the second most common combination in about 25 percent of the cases.

Data were not available consistently across all sources to determine whether projects were able to leverage these interactive effects to downsize to smaller or more efficient equipment. However, although they were a small number overall, several projects described downsizing equipment as a result, in some cases enabling a change to a more efficient system type (e.g., radiant heating and cooling). The lack of identification of smaller equipment or different system type may also be another indication of the industry's trend to focus on single measure implementations — such as equipment or controls — and not on system level strategies.

Integrated System Retrofit EEM Analysis

Quantifying the number of Integrated System retrofits in the retrofit projects required sufficiently detailed EEM descriptions to identify whether active controls integration between end use systems categories (e.g., lighting, HVAC) were present. The review of available data, including case study narratives where available, did not provide sufficient detail to identify any instances of Integrated System retrofits in the retrofit projects. This does not rule out that they were present in some cases; only that the descriptions were not sufficient to make a determination. However, based on the responses from industry stakeholders to interview questions, presented in the following sections, it could reasonably be stated for the utility custom program, FEMP, GSA, NAESCO, and the DOE High Performance Database retrofit cases that in general no Integrated System retrofits were present, but that in some cases they were present for the NBI Getting to Zero database projects, as described below. If so, they are very rarely applied throughout the datasets in this study.

While a direct review of the case studies and EEM descriptions available did not reveal any instances of Integrated System retrofits, some literature suggests that such approaches are taking place in some high energy saving retrofits. One relevant study, *Zero Net Energy Building Controls,* was published by the Continental Automated Buildings Association (CABA) and NBI in 2015 (Higgins et al. 2015). This study conducted surveys of the design teams for 21 ZNE projects, including 6 retrofit projects, all sourced from the NBI Getting to Zero Database (NBI 2018). Review of this study reveals that these buildings employed devices with increasing connectivity and monitoring capabilities, and expanded the use of building data to provide individual control and data access. The controls systems included integration across end use systems in 14 (67 percent) of the buildings. Several examples of controls integration were cited, including window or facade automation for natural ventilation or night air flush strategies coupled with the building's HVAC controls, and task lighting combined with plug load controls. Many additional Interactive Systems strategies were also employed, resulting in downsized equipment, or in one case, the complete elimination of a cooling system due to improved exterior shading. The controls systems in these buildings also trended toward expansion beyond the typical building scale to integrate with distributed generation, storage and demand response. One of the most important findings of this study, in short, was that truly integrated systems retrofits are simply not happening, except on the cutting edge of energy efficiency innovations.

5. Stakeholder Perspectives

As a supplement to the quantitative data analysis reported above, LBNL also sought input from several stakeholders — utility program administrators, implementers, and advocacy organizations — to understand work to date, future interests, and barriers to wider deployment of systems-based approaches for existing commercial buildings. Input was obtained via one-on-one discussions as well as email. We obtained input from a total of 18 stakeholder organizations. Below is a summary of the responses we received for each of the questions discussed. We asked each stakeholder to respond based on their actual experience with the programs with which they were engaged, rather than their general impressions of the market as a whole.

Q1. In your experience, what are the most widely implemented types of system retrofits in buildings?

The vast majority of respondents indicated that lighting upgrades combined with controls were the most widely implemented system retrofit, followed by HVAC upgrades with controls. Only two respondents indicated that that HVAC upgrades with controls were the most common, and in one case that was because of the nature of the program they were offering.

Q2. What do you think are the reasons for these being the most widely implemented?

Cost-effectiveness and ease of implementation ("easy to understand") were cited as the most significant reasons for lighting systems retrofits being the most widely implemented. Additionally, the savings and controls settings tend to have greater persistence than is the case with other end use systems, and they do not require intensive infrastructure changes. One respondent noted that lighting is visible to tenants and that HVAC retrofits are often "as a response to either equipment failure or tenant displeasure with comfort." A lot of owners do not want to replace core equipment until end of life. Other market factors include applicability across many building types, scale of the market, and high accessibility to "off-the-shelf" equipment.

Q3. Are certain systems retrofits more widely implemented in certain sectors (building types/sizes/locations)? If so, why?

Several respondents indicated that larger buildings were more likely to implement systems retrofits. Types mentioned include office, retail and warehouse, as well as healthcare and higher education. One respondent noted that public sector institutions are more likely to adopt systems approaches than private sector institutions, because of the longer investment horizon.

Q4. In the programs and projects you're familiar with, approximately what percent have employed system retrofits approaches (these will exclude Non-System retrofits, such as an equipment replacement only, or a controls upgrade only)?

There was a very wide range of responses to this question, depending on the projects within their purview. For broad based utility programs, respondents indicated percentages ranging from "virtually none" to 10 percent, with most saying less than 10 percent. For respondents such as consulting firms that support custom programs, the numbers were much higher, often greater than 50 percent.

Q5. What percentage of building retrofits in your market conduct whole building simulation to guide design, or make use of any other means to understand interactive system effects and design retrofits to take advantage of them? (e.g., equipment right sizing or lower capacity system type).

Almost all respondents who answered this question indicated numbers between 0 and 10 percent. Only a few respondents representing consulting firms specializing in high performance buildings indicated that they routinely use whole building energy simulation.

Q6. Which market sectors (building types/sizes/locations) hold the most potential for systems retrofits?

Not surprisingly, office, retail and schools were commonly identified as having the most potential because of the size of the sectors. In addition, high energy intensity sectors such as healthcare, data centers and bio-tech were also identified as good targets. Other respondents mentioned large buildings in general, the industrial sector, any building that goes beyond low rise with rooftop units (including central plant systems), and other strategies for both low and high rise buildings. One respondent noted that multi-tenanted commercial space was an underserved market.

Q7. What do you see as the key barriers to improving access to and implementing systems retrofits? Please describe for each of the following categories as applicable: (a) Technical, (b) Economic, (c) Market, (d) Policy/regulatory, (e) Other

Most of the responses to this question fell under three broad themes: Complexity of systems retrofits, cost-effectiveness, and utility program structures.

Systems are too complex:

- Installation, commissioning and operations procedures are more complex than those for component upgrades, and there is a technical gap in contractor training, understanding and trust.
- Complexity affects the process speed, i.e., getting the customer the answers they need to make a decision in a timely manner. “Projects feel large, so many people stop it before it starts.”
- Multi-system controls are often too complex for building operators. “It may be better in practice to teach them how to use multiple, simpler controls for individual systems.”
- These systems are often “finicky” and assume everything is installed right and operating right. “You can make them work if you have a Ph.D.”

Systems seen as having poor cost-effectiveness:

- Poor cost effectiveness is especially true in areas with low utility costs. But even in areas with high utility costs, putting down capital for energy efficiency remains a major barrier. The metric for most customers is a payback of fewer than two years.
- In the case of lighting, power densities are already low with LED lighting. The addition of controls is seen as a limited incremental benefit.
- Cost-effectiveness information is not available in a timely manner for the relevant people in the decision-making process.
- Owners and property management companies are still not convinced that energy efficiency increases building value.

Utility programs for the most part are still highly "widget" oriented:

- Generally, only custom programs allow for systems retrofits. There are very few systems retrofits that are available with deemed savings[1] alone.
- Incentive payments are based on measure-based savings without considering the potential additional benefits of interactive effects (e.g., like-for-like replacement with no credit for right sizing).
- In some regulatory environments there is a requirement for packages of measures to have each measure individually be cost-effective, a strategy that does not recognize the potential for system retrofit program design, which includes multiple individual measures.
- The annual energy savings targets and cost-effectiveness requirements set by regulators for utility programs clearly incent short-term savings. As a result, simpler retrofits with very quick paybacks are emphasized, such as lighting and behavioral programs. In some jurisdictions these alone represent more than 50 percent of claimed portfolio savings.
- The use of a code baseline for existing buildings can disqualify savings from some controls upgrades.
- For HVAC, there are cases where the equipment upgrade is a midstream incentive (i.e., applied to the equipment vendor or distributor) while the controls upgrade is for the end user (e.g., owner), making the transaction more burdensome.

Other barriers mentioned included the following:

- Lack of adequate training of vendors and service providers — both to deliver services and to sell the value proposition of systems retrofits.
- The terminology of system retrofits is not standard and can be hard for certain customers to understand.

It is notable that there was almost no mention of the lack of systems technology options as a barrier, although as stated earlier the complexity of system design, controls and commissioning are seen as deterrents. One respondent spoke to the need for better standards and open protocols for controls. It may also be possible that industry understanding of the issues and opportunities has not yet advanced to the point where they can comment effectively on barriers. Beyond that, technology was not identified as a barrier for systems-based retrofits.

Q8. What interventions would allow systems retrofits to be more widely deployed? Please describe for each of the following categories as applicable: (a) Technical, (b) Economic, (c) Market, (d) Policy/regulatory, (e) Other

Paralleling the barriers, the interventions proposed by the respondents include the following, organized by major theme.

[1] Deemed savings are pre-determined, validated estimates of the energy savings attributed to specific energy efficiency measure(s). Deemed savings are commonly applied to 'widget' based technologies such as LED lighting and HVAC equipment.

Reduce complexity and make systems retrofits easier to understand and achieve:

- Increase the pool of technically competent contractors who can deliver the full systems package and reduce the level of customer effort.
- Ensure that the system works seamlessly and that it "works well right out of the box." "It would be great if systems self-heal and self-calibrate."
- Reduce the barriers to energy simulation. Technical innovations in energy modeling should be focused on practical things such as reducing modeling time, and automating interaction with other aspects of the retrofit process workflow such as creating work orders or controls sequences, rather than adding the next "cool" feature to tools.
- Develop product standards to help improve interoperability and drive down costs.
- Provide easy to understand performance data with verified product quality (equivalent to a good housekeeping seal of approval).
- Develop system specifications. "If you ask a typical building operator to put in an integrated system they wouldn't know where to begin."

Reduce the cost barrier:

- Develop simplified financing mechanisms for system retrofits (e.g., on-bill-financing)
- Change market behavior through financing or taxation to help move industry toward retrofits.
- Increase the incentive if more than three measures are done at the same time.

Develop utility programs that effectively support systems retrofits:

- Several respondents recommended midstream programs (i.e., that target product vendors or distributors) that could help market adoption immensely, as incentivized products will be readily available for customers to use.
- Pay for energy modeling and/or energy audits at no cost to the customer in order to get greater program participation.
- Incorporate and value demand response and other benefits beyond energy efficiency.
- Make it easy to claim savings.

Other interventions that respondents mentioned include:

- Unbiased third party information that is "defensible and compelling."
- Case studies about energy savings and customer insights.
- Outcome-based performance codes could drive more system retrofits.
- Deliberate efforts by professional and trade organizations to increase education and awareness among service providers.

Finally, this feedback from one respondent captures an important point about how to approach and engage customers effectively: "What I have found is that it is best to start by understanding the customer and their business needs and problems, and then work backward to the best solution for them. Once it has been demonstrated successful and cost-effective, then it can be replicated with other similar customers, and then perhaps you can scale the program and its positive impacts. Starting with the technology and trying to find a customer it works for is very difficult, and often leads to disappointment and push back."

6. Industry Needs and Recommendations

There is strong evidence that **systems-based retrofits are more prevalent in, and thus correlated with greater whole building energy saving projects,** reaching beyond simple equipment replacements to leverage further energy savings from EEMs involving distribution, supporting devices, termination, sensors and controls, and even leveraging interactions across end use systems. This study provided significant evidence that **the most common practice in building retrofits is to focus on non-systems-based single EEM approaches,** even in programs designed to accommodate (and may or may not achieve) deeper levels of energy savings such as utility custom incentive programs. Notably some programmatic approaches such as those used by **FEMP, GSA and ESCOs more regularly identify and succeed in systems retrofits** across both low and high energy saving projects.

It is of interest to note that higher energy savings (> 20 percent) can be achieved in some cases through the use of sets of discrete Non-System measures, although it is likely these cases are highly dependent on the existing building conditions. For example, where the utility data did show high energy savings through Non-System approaches it was predominantly from lighting measures, suggesting that these buildings likely had some legacy (e.g., T12) lamp conditions previously. It is probable that these higher energy-saving Non-System retrofits will become less prevalent as this legacy equipment is retrofit. Industry needs identified in this section therefore will not focus on barriers to unlocking deeper savings through Non-System approaches.

As systems retrofits become increasingly important in delivering deeper levels of energy savings, a number of strategies involving technology identification and application, retrofit program design, and policy and education may be needed to overcome the barriers identified here.

6.1 Technology

As evidenced through stakeholder discussions, systems-based energy saving technology solutions may already exist but are not well recognized by practitioners, and are perceived as being overly complex to implement. To support growth in this area, it would be prudent to devise additional methods to **streamline systems identification and application**. This effort could include simplified design and assessment methods, as well streamlined installation practices.

Building simulation tools are one avenue that could support systems identification; however, as stakeholders suggested, they may be too burdensome as currently applied for some retrofit applications. Other simplified tools or interfaces might aid in early design and decision making. Research may be needed to identify ways to deliver meaningful energy savings potential assessments, while maintaining simplified inputs, however. These tools also could identify technology options to further reduce energy, relying less on practitioners to identify potential solutions, as there appears to be a significant barrier to system retrofit awareness and their potential to save energy.

Technology cost and payback remain strong motivators for decision makers, in the absence of other non-energy drivers for a building retrofit. **System retrofits may have improved cost effectiveness when bundled with key cost effective measures**, such as LED lighting. **Interactive System retrofits may hold the key to unlocking deeper energy reduction strategies in buildings by unlocking capital savings** from smaller equipment sizes or enabling the change or elimination of a system type. However, the relationship between capital cost and energy savings reduction is only provided at a couple of key moments in the design and construction process currently — during a cost estimation exercise, if done, and during contractor bids. Developing methods to inform stakeholders of potentially cost-effective systems retrofits could lower access barriers further by delivering this information in the simplified design and decision-making tools.

Methods to reduce the complexity of applying systems solutions may also be beneficial. Efforts can be made to help simplify the adoption of End Use System retrofits by creating standardized packages of retrofit technologies and their controls. These efforts should be tailored to the existing building market, which lags behind new construction in gaining access to these approaches. Product manufacturers can aid this process by identifying opportunities to combine product offerings and developing them into cohesive system retrofit solution packages. Contractors also could be encouraged to deliver systems packages spanning multiple end use systems.

New systems technologies also may be developed to deliver lower energy use, particularly with a focus on lowering their cost of design and installation. Equipment replacements may have been a large part of the market focus in part because they achieve significant energy savings while having a lower impact in terms of disruption to the building. Systems approaches that can build from and leverage existing infrastructure, such as piping and ductwork distribution, will inherently be less disruptive and have a greater chance of cost-effectiveness.

Other areas of technical development may include reducing controls complexity in applications, lowering barriers to “plug and play” technologies and controls integration across end use systems. Development of industry standard controls applications — both controls sequences and protocols for deployment — can help improve outcomes and lower risk in general. Development of “self” commissioning controls systems would also lower the costs and complexity of implementing system retrofits, especially where they integrate across multiple end uses.

6.2 Program Design

The analysis illustrated that some significant programmatic differences may contribute to both the success of gaining deeper energy savings and their ability to leverage system based approaches. Utility programs historically have gained much of their energy savings with lighting retrofits, especially over the last decade with the advent of LED lighting, and have developed customer acquisition methods and programs structured to focus on this cost-effective retrofit opportunity. ESCOs, on the other hand, have developed a business practice that requires a strong focus on reducing risks to cost-effective energy reduction, which includes both **identifying energy retrofit approaches with good returns and reducing transaction and other costs** to ensure overall returns on investment are met. In this case, ESCOs may be recognizing that there is a base transactional cost when a trade or service provider conducts work on a site, and that it is most efficient to have that particular trade be leveraged to implement additional retrofit measures at the same time.

Retrofit programs should be designed to **recognize each of the technology, design, assessment and application barriers, and address these issues where possible** — whether through process approaches, tools or use of incentives when applicable.

Cost also remains a significant barrier to systems adoption. This can be addressed both by expanding financing options, providing further incentives such as tax programs and utility rebates, and developing the tools and methods to identify cost-saving opportunities in component or equipment-based upgrades to expand into systems upgrades, leveraging the cost advantage of the equipment's payback. Other means to identify and make transparent the "lost opportunity" cost of not taking a systems based upgrade over a component based retrofit also should be considered.

Utility incentive program design may present specific additional barriers to better leveraging system based retrofit approaches, some of which may need to be addressed by policy changes (see next section). At the program design level however, systems retrofits, if done, will occur in custom programs that inherently have higher program administration costs. In contrast, utility "deemed" incentive programs offer a streamlined application where the savings of a given technology (e.g., LED lamps) are estimated or "deemed" based on prior analysis of potential for savings. This approach works well for component based technologies but does not lend itself to systems based approaches, which inherently have many more variables influencing performance.

Program design should **consider how system packages of technologies can be administered in a similar, lower touch method as "deemed" programs**. This could include development of "deemed" savings for system packages, the use of streamlined tools for customer assessment, and identification of additional system elements that can be retrofit for a given customer, leveraging the use of a single trade contractor (e.g., HVAC) to keep transaction costs low. Utility programs could also consider developing systems retrofits incentives that leverage midstream deployment channels, such as those through product distributors, to further reduce transactional effort and costs.

All retrofit programs would benefit from an **industry standardized EEM description format**, to enable deeper assessments of retrofit trends beyond the equipment level. This would enable deeper program analysis to identify ongoing retrofit trends and identify areas where system retrofits could be leveraged further. Retrofit programs also should track whole building energy use reduction metrics, at least as a percent reduction from pre-retrofit condition, to correlate retrofit strategies to energy use reduction. The inclusion of system retrofit cost metrics would also be recommended to help programs identify and promote cost-effective strategies.

6.3 Policy

To accelerate deployment through utility programs, a means to “deem” system savings could be an important step so that systems retrofits can be administered in a streamlined fashion. A number of methods could be considered to achieve this, such as by allowing program designs to accept accuracy ranges on savings results that could cover the range of performance possible for a given system application.

Other policy barriers may also exist however, including incentive program cost-effectiveness tests that require individual EEMs to pass, rather than evaluating a package of EEMs, such as through a systems retrofit. In general, **utility regulatory landscapes should be reviewed** to ensure that system level strategies that combine multiple measures, and strategies that combine EEMs across end uses (and even with DER technologies), can be assessed and implemented as a cohort. Further, **programs should be encouraged to incentivize retrofits based on lifetime savings**, which inherently will support system retrofits strategies that have longer lifetimes and payback periods. Without this, industry will continue to favor the single, most cost-effective measures such as equipment replacement over accessing deeper levels of systems energy savings. The **use of energy code as a baseline for comparison in these programs may also result in owners not selecting some EEMs for application**. In some cases controls measures could demonstrate significant energy savings over an owner’s existing building condition, but much reduced savings compared to current energy code conditions, which would be the comparison case for some utility programs. An existing building baseline is recommended in these cases, such as through the use of whole building metering.

Other policy efforts can encourage a deeper focus on systems based applications by setting metrics for systems performance, rather than emphasizing equipment performance ratings. Outcome-based codes can also support industry awareness and engagement in systems based design and operations, particularly where system performance metrics are emphasized.

6.4 Education

Further education and awareness about the potential for End Use System, Interactive System, and Integrated System retrofits savings and their non-energy benefits are also needed to help industry value and adopt these approaches. **Even among industry experts and retrofit program managers there appears to be a lack of knowledge about system based retrofit energy savings**, and they generally have concerns over the complexity of analyzing, designing and applying systems retrofits. Lighting systems, which generally have higher rates of adoption, in part due to their relative application simplicity, are the rare exception. **Additional case studies highlighting the value of systems retrofits, in particular in comparison with equipment upgrade only approaches, can help to further illustrate this value**.

Similarly, contractors require training to better understand system implementation and operations, in order to both identify system retrofit opportunities and install and commission systems to operate as intended.

While the results of this study are of interest to owners and managers of existing buildings, much can be learned about identifying energy saving strategies from systems implemented in new construction efforts. Overall, though, given the size of the existing building market, system retrofit approaches that work with the inherent existing building systems and their conditions will be key to reaching sector-wide energy reduction goals.

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Appendix A: Energy Efficiency Measure Data Collection and Processing

A.1 Summary Description of Data Sources, Processing, Formatting and Analysis

Lawrence Berkeley National Laboratory (LBNL) requested data from a number of private and public sector sources to assess systems retrofits from a range of deployment approaches. The information and data collected included information in the public domain (e.g., some public buildings, GSA facilities, and retrofits for which case studies have been published, such as the New Buildings Institute Getting to Zero database cohort) and private information, for which non-disclosure agreements (NDA) were required in all cases before receiving the data.

The requests for data included outreach to a number of U.S. utilities that were active in the custom customer incentive program space as identified through ESource's internal utility incentive program database (ESource 2017) and a related LBNL database of such programs (Hoffman et al. 2018). The utilities that were contacted reflected geographical and climate diversity, focusing on the largest custom program providers by energy savings reported. A number of utilities responded with interest, however a significant number were not able to share their program data due to confidentiality policies. Those utilities that did provide data each required an NDA, and consequently all utility data was anonymized in accordance with these terms. As a result, analyses were tailored such that utilities would not be individually identifiable (e.g., analysis by U.S. state has been omitted).

Most contributors provided information in a format that reflected their internal reporting requirements, with information deemed to be commercially sensitive removed. Other contributors either provided a queryable database access that required authorization for access (CTS-FEMP and GSA) or one that had already published the data via case studies on website portals (DOE High Performance Buildings and the NBI Getting to Zero database).

One data source was not directly accessible at the individual project level; LBNL currently manages a database with data from 5,000+ energy service company (ESCO) projects spanning 20 years, to which access is tightly restricted. Data analysis was accessed through defined queries provided to the database administrator in this case.

A.2 Data Analysis Inputs

IECC Climate Zones

Each retrofit project was mapped to an International Energy Conservation Code (IECC) climate zone. For data in the public domain (NBI, DOE High Performance Buildings) it was possible to determine city and state for several buildings based on building name where other project location information was not provided.

In the case of one utility, data were reported as occurring in one of two separate climate zones defined locally, the boundaries of which did not match the IECC climate zones. In this case, the zones were mapped to each of the IECC climate zones with assignments such that the larger urban centers matched where the larger number of retrofit projects occurred.

All remaining datasets provided sufficient project location information to map them to the IECC climate zones.

Definition of a Project

Projects were defined as the set of EEMs retrofit in one location/building over the retrofit time period identified in the project record. Using this approach, single projects were able to be identified, even where more than one project occurred in the same building in a common year. There were relatively few examples of this condition, but in some cases pre-retrofit and post-retrofit time periods were reported, so that multiple project periods were identified within a single year. More commonly, however, single projects were reported over a given time period.

A.3 Individual Dataset Characteristics

Where available, further characteristics of each dataset are provided as follows.

1. Utility custom customer incentive programs

Building sizes ranged from 64 sq. ft. to 6 million sq. ft., averaging about 87,000 sq. ft. Building types in these datasets were 17 percent offices, 16 percent retail, 8 percent transportation, 8 percent warehouse, 7 percent gas station, and 3–5 percent medical, auto, religious, lodging and education, with several other building types represented as well. Projects were located in the climate zones shown in Table A-1:

Table A-1. Utility Custom Program Percent of Projects by Climate Zone

Climate Zone	% of Total Projects
3. Warm	< 1
4. Mixed	88
5. Cool	12

As far as the types of EEMs implemented, lighting measures were included in about 86 percent of projects, heating and cooling measures were included in only about 8 percent of the projects, and ventilation measures were included in about 4 percent.

2. FEMP Database of Federal Agency Facility Retrofits (Compliance Tracking System [CTS])

While building type was not listed for more than half of the projects, the most common known building type listed was hospital (20 percent of projects), followed by office (10 percent) and post office (8 percent). This dataset included projects spread across all U.S. climate zones and all 50 states. Lighting EEMs occurred in about 43 percent of projects, ventilation in about 41 percent, heating and cooling in about 28–29 percent, envelope in about 16 percent and plug loads in 4 percent.

3. ESCO Database

Due to confidentiality and data access issues, climate zone distribution and building types were unknown for this dataset. Of the projects identified, lighting EEMs were implemented in about 40 percent of projects, with waterside heating and cooling measures in about 35 percent, and airside heating and cooling in about 10 percent. Nine percent of projects included a combination of HVAC, lighting and envelope measures.

4. DOE High Performance Buildings Database

Buildings ranged in size from 2,330 sq. ft. to more than 1 million sq. ft., and were mostly office buildings, with a few restaurant, education buildings and public assembly facilities. This dataset included 27 projects and buildings, across 16 states (5 in California, and 3 in Washington and Colorado most strongly represented). As far as the types of EEMs implemented, heating measures occurred in ~59 percent of projects, cooling measures in ~67 percent of projects, ventilation EEMs in ~52 percent, lighting in ~78 percent, envelope in ~56 percent, domestic hot water in 7 percent, and plug loads in 33 percent of projects.

Some of the most common EEMs implemented in these projects were natural ventilation, heat recovery ventilation, ground source heat pumps, HVAC system downsizing, variable frequency drives (VFDs), demand control ventilation, daylighting and occupancy sensing, LED lighting, low-E windows, shading, roof and wall insulation, and ENERGY STAR plug loads.

5. GSA Deep Retrofit Program

Building sizes ranged from 40,000 sq. ft. to 1.9 million sq. ft., averaging 624,000 sq. ft. in 25 states. The buildings were mostly offices, with some courthouses.

Typical EEMs implemented in these projects included new boilers, air handler modifications, new chillers, chiller downsizing, magnetic bearing compressors, new cooling towers, dedicated outside air systems (DOAS), demand controlled ventilation (DCV), VFDs, underfloor air distribution, HVAC downsizing, ground source heat pumps (GSHP), lighting controls interfaces, lighting scheduling, bi-level switching, occupancy sensing and daylight dimming, LEDs, fluorescent retrofits, workstation specific lighting, low-E windows, operable windows, roof insulation, facade and vestibule retrofits, and clerestory windows. In terms of end use systems affected by retrofits, lighting measures were included in all projects (100 percent), envelope measures in about 88 percent, ventilation measures in

83 percent, cooling measures in about 83 percent, heating in about 78 percent, and domestic hot water in 15 percent.

6. NBI Getting to Zero Database

These projects were conducted across nine U.S. states. Buildings ranged in size from 1,636 sq. ft. to 52,000 sq. ft., averaging 18,000 sq. ft. The buildings were mostly offices, with some retail, a community center, and education facilities. Projects were distributed across the climate zones shown in Table A-2:

Table A-2. NBI Getting to Zero Database Percentage of Total Projects by Climate Zone

Climate Zone	% of Total Projects
2. Hot	15
3. Warm	40
4. Mixed	35
5. Cool	10

In terms of end use systems affected by retrofits, projects included heating measures about 95 percent of the time, with cooling measures in about 90 percent of projects, ventilation in about 55 percent, lighting in about 55 percent, envelope in about 80 percent, domestic hot water in 25 percent and plug load measures in 35 percent.

Common EEMs for these projects included variable refrigerant flow (VRF), radiant heating, natural ventilation and DOAS, demand control ventilation, heat recovery ventilation, ceiling fans, HVAC downsizing, GSHP, night flush, thermostat setbacks, LED lighting, workstation specific lighting, occupancy sensing and daylight dimming, low-E windows, operable windows, shading, roof and wall insulation, cool roofs, daylight augmentation and skylights, solar tubes, plug load controls, programmable switches, and solar hot water.

A.4 Total Dataset Characteristics

For projects that had energy savings reported, Table A-3 shows the distribution of projects by building type.

Table A-3. Projects per Building Type (Top 40)

Building Type	Total No. of Projects	No. Projects with % Energy Savings
Office	1,935	992
Other/Blank/Unknown	1,669	424
Retail	1,522	279

Building Type	Total No. of Projects	No. Projects with % Energy Savings
Trans. Infrastructure	782	0
Warehouse	738	152
Gas Station / Conv. Store	654	244
Hospital	593	540
Restaurant	542	178
Education	514	354
Lodging/Hotel/Motel	439	240
Religious/Spiritual	399	128
Medical Office	279	122
Auto Service	276	66
Grocery	198	141
Amusement/Recreational	180	98
Mailing Center/Post Office	178	178
Bank/Financial Institution	172	30
Car Dealership/Showroom	150	47
Gym/Athletic Club	142	72
Meeting/Conv. or Comm. Center	137	83
Unspec. Govt/Public Sector	84	48
Fire Protection	75	38
Courthouse	70	62
Parking Structure/Garage	53	0
Library	49	31
Data Center	46	37
Manufacturing/Industrial Plant	46	16
Museum	46	27
Car Wash	44	9
Jail/Reformatory/Penitentiary	33	26
Laundry/Dry Cleaner	31	16
Residential/Multifam/ Assisted Living	29	14
Veterinarian's Office	28	11
Enclosed Mall	24	17

Building Type	Total No. of Projects	No. Projects with % Energy Savings
Military (Armory, etc.)	18	2
Laboratory	12	10
Transportation Terminal/Station	10	10
Police	10	8
Repair and Maintenance	8	2
Small Data Center	7	1
Total	**12,222**	**4,753**

A.5 Data Formatting for Analysis

During the data collection process, the project team built up a list of EEM descriptors compiled from those present in all projects. This list was translated into an EEM Database format, with the EEM descriptors parsed out to map to the reflected system EEM categories (equipment, supporting devices, distribution, termination, and controls). In some cases the EEM descriptors mapped one-to-one to their end use system element and measure counterparts (e.g., LED lamp replacement mapped to lighting equipment; new chiller mapped to HVAC cooling waterside equipment). However, in some cases the EEM descriptors encompassed a range of measures across elements and needed to be broken out into separate measures. For example the EEM descriptor "Light Fixture replacement and occupancy controls" became two measures: "Light fixture replacement" in the Lighting-Equipment element, and "Lighting Occupancy Controls" in the Lighting-Controls element. Appendix B provides a complete listing of the full EEM nomenclature used, broken out by end use system category and element.

Information from certain sources (e.g., FEMP, GSA) could be readily translated into the EEM database template via mapping allocation of source EEM descriptors designation to the appropriate database EEM categories and measures designation. In cases where EEM descriptors had insufficient or lacking specificity, such EEMs were logged under an end use system in a defined "Unknown/Other" element, of which there was one for each end use system category. In all cases, at least one end use system category was identifiable.

Other sources provided data and information that required further manual review at the project level to identify and map EEMs implemented for each project. These data and information were provided in a variety of formats, such as those described briefly below:

- Example Utility A: Database with predominantly qualitative EEM descriptors, supplemented by select quantitative content
- Example Utility B: Application submissions to a rebate incentive program with descriptions of installed EEMs, in PDF format

- DOE High Performance Buildings, and NBI Getting to Zero Database: Case studies published online in a webpage format

In each of these cases, it was necessary to translate the reviewed information into the database template.

The project team had limited access to the NAESCO database, so an exception to the method above was necessary. In that case, the project team mapped the list of measures in the NAESCO database to the end use system categories. The NAESCO data were then queried to derive metrics around End Use System, Interactive, and Integrated System retrofits according to specific combinations of EEMs between system types and categories.

EEM Descriptor Technical Assumptions

In the course of reviewing EEM descriptions from case studies and program documentation, several interpretations were necessary to map these descriptions to the end use system categories and specific measures. In general, when an EEM descriptor was insufficiently descriptive to identify what system elements were included, the EEM was biased toward being inclusive of system related elements, as indicated below. Similarly, if an EEM was not specific to an end use system application (e.g., heating or cooling), the approach assumed it was applied in all such applicable circumstances (i.e., it was counted once both in heating and in cooling). The assumptions described below reflect this approach. In general, where ambiguity was present a conservative approach was used, assuming a measure description was inclusive of a system retrofit. Overall, the occurrences of these areas of ambiguity were low, and not expected to significantly affect the outcomes of the analysis. Other examples of assumptions made include the following:

- For the vast majority of cases, it was assumed that an equipment retrofit consisted of a like-for-like equipment replacement, and any time a piece of equipment was replaced, the replacement was of higher efficiency.
- For equipment that could be utilized to provide heating or cooling, such as motors, pumps, fans, ducting, and pipe insulation, unless explicitly stated as being for use in heating or cooling, it was counted as applied to both heating and cooling.
- For equipment that could be utilized on waterside or airside systems, such as motors or temperature controls, unless explicitly stated otherwise, it was assumed to apply to both.
- Any kind of equipment downsizing assumed replacement with new equipment.
- Maintenance, cleaning, retrocommissioning or equipment tuning were not included as retrofit measures.
- Installation of radiant heating, radiant cooling, air source heat pump, or ground source heat pump was assumed to be a change of HVAC system type given their relatively low incidence rates in existing commercial buildings.
- Air handling unit retrofits were allocated to both airside and waterside HVAC systems.
- The Ventilation, Distribution and Termination categories include specific airside EEMs, some of which are also applicable to heating and cooling applications.

- Lighting controls EEMs were categorized as load reduction, daylighting augmentation, or both for the purposes of assessing whether an Interactive System retrofit occurred.
- Lighting fixture retrofits were separated into LED and non-LED categories. The non-LED retrofit included all retrofits of fluorescent and other technologies, regardless of lamp type. The same approach was adopted for lamp retrofits.
- In the NAESCO database, the “Lighting Retrofit” EEM descriptor was assumed to include both light fixture replacement and lighting controls.
- Envelope EEMs were categorized as load reduction, daylighting augmentation, or both, determined individually by measure, for the purpose of identifying whether an Interactive System retrofit had occurred.

A.6 Systems Data Analysis Assumptions

End Use System Retrofits

End Use System retrofits are defined here as a project constituting two or more EEMs for a particular end use system category. HVAC end uses (heating, cooling or ventilation) require two or more waterside EEMs or two or more airside EEMs; for example, a heating systems project with one waterside measure and one airside measure was not counted as a End Use System retrofit.

Interactive System Retrofits

Interactive System retrofits were defined as consisting of two or more EEMs from at least two specific end use systems in question.

Integrated System Retrofits

The level of detail in the data analyzed does not support identification of Integrated System retrofits at any level of confidence. It was assumed that the number of these types of projects was zero.

Appendix B: Energy Efficiency Measure Nomenclature by End Use System Category

Table B-1. Energy Efficiency Measure Nomenclature – Heating and Cooling

End Use System Element	HVAC - Heating, Waterside EEM Description	HVAC - Heating, Airside EEM Description
Equipment	Air Handler Modifications	Air Source Heat Pump
	Boiler - Burner Retrofit	Custom Motors
	Boiler - Downsize	Furnace/Heater
	Boiler - New	Replace with higher efficiency
	Boiler - Upgrade/Modification	New/Upgraded Fans
	Convert system from steam to hot water	New/Upgraded Exhaust Fans
	Custom Motors	Rooftop Units
	New system type due to downsizing	Split/DX System
	Other - Unknown	Variable Refrigerant Flow
	Radiant Heating	
	Recirculating Pumps	
	Replace with higher efficiency	
	Smaller capacity due to interactive effects	
Supporting Devices	Heat Recovery/Storage	Add Energy Recovery
	Server Room Heat Recovery	Heat Recovery Ventilation
		Other - Unknown
Distribution	Pipe Insulation	Dampers and Blowers
	Pumping and Piping	Underfloor Air Distribution
	Primary Only Loop	Duct Insulation
		Other - Unknown
		Repair/Seal Ducts
		Task Ambient Conditioning Systems
Termination	Hot Water Zone Reheat	
	New Fan Coil Units	
	New Terminal Units	
Controls	HVAC Scheduling	Energy Management Controls
	Pumps and Fans	HVAC Scheduling
	Smart Valves	Pumps and Fans
	Variable Frequency Drives	Supply Air Temperature Reset
		Thermal Comfort Controls
		Thermostat Setback Controls
		Variable Frequency Drives

End Use System Element	HVAC - Cooling, Waterside	HVAC - Cooling, Airside
	EEM Description	**EEM Description**
Equipment	Air Handler Modifications	Air Source Heat Pump
	Air Cooled Condenser	Custom Motors
	Chiller - Downsize	New/Upgraded Fans
	Chiller - Magnetic Bearing Compressor	New/Upgraded Exhaust Fans
	Chiller - New	Rooftop Units
	Chiller - Upgrade/Modification	Replace with higher efficiency
	Cooling Tower Upgrade	Split/DX System
	Custom Motors	Variable Refrigerant Flow
	Custom Refrigeration	
	Evaporative Cooler	
	New Cooling Tower	
	New system type due to downsizing	
	Other - Unknown	
	Radiant Cooling	
	Recirculating Pumps	
	Replace with higher efficiency	
	Shower Tower	
	Smaller capacity due to interactive effects	
	Water Cooled Condenser	
Supporting Devices	Heat Recovery	Heat Recovery
		Dedicated Outdoor Air System
		Other - Unknown
Distribution	Pipe Insulation	Cold Aisle Air Containment
	Pumping and Piping	Dampers and Blowers
		Duct Insulation
		Natural Ventilation
		Other - Unknown
		Repair/Seal Ducts
		Underfloor Air Distribution
Termination	New Terminal Units	CRAH EC Plug Fan
	New Fan Coil Units	Other - Unknown
	Server Room Air Conditioning	
Controls	Smart Valves	Airside Economizer
	Variable Frequency Drives	Cold Aisle Temperature Sensors
	HVAC Scheduling	Computer Room Air Handler VFDs
	Waterside Economizer	CRAH Supply Air Temperature Sensors
	Hartman Loop	Energy Management Controls
	Condenser Water Reset	HVAC Scheduling
	Pumps and Fans	Improved Controls and Sensors
	Upgrade Chiller Water Pump Controls to Operate a Single Pump	Night Flush

End Use System Element	HVAC - Cooling, Waterside	HVAC - Cooling, Airside
	EEM Description	**EEM Description**
		Other - Unknown
		Pumps and Fans
		Supply Air Temperature Reset
		Thermal Comfort Controls
		Thermostat Setback Controls
		Variable Frequency Drives

End Use System Category: HVAC - Ventilation

Table B-2. Energy Efficiency Measure Nomenclature – Ventilation

Element	EEM Description
Equipment	Custom Motors
	New/Upgraded Fans
	New/Upgraded Exhaust Fans
Supporting Devices	Ventilation Heat Recovery
	Dedicated Outdoor Air System
	Other - Unknown
Distribution	Air Flow Optimization
	Dampers and Blowers
	Distribution Other - Unknown
	Natural Ventilation
	Repair/Seal Ducts
	Underfloor Air Distribution
Termination	Ceiling Fans
	CRAH EC Plug Fan
	Fume Hoods
	New/Upgraded Exhaust Fans
	Other - Unknown
Controls	Computer Room Air Handler VFDs
	Demand Controlled Ventilation
	Duct Static Pressure Reset
	HVAC Occupancy Sensors
	HVAC Scheduling
	Improved Controls and Sensors
	Other - Unknown
	Variable Air Volume
	Variable Frequency Drives

End Use System Category: Lighting

Table B-3. Energy Efficiency Measure Nomenclature – Lighting

Element	EEM Description
Equipment	Ballasts
	Fiberoptic Lighting
	Fixtures - LED
	Fixtures - Non-LED
	Lamps - LED
	Lamps - Non-LED
	Other/Unknown
	Task Lights
Distribution	Workstation-Specific
Controls	Bi-Level Switching
	Daylight Dimming
	Lighting Occupancy Sensors/Control
	Lighting Scheduling
	Spectrally Enhanced Lighting
	Lighting Tuning

End Use System Category: Domestic Hot Water

Table B-4. Energy Efficiency Measure Nomenclature – Domestic Hot Water

Element	EEM Description
Equipment	Domestic Hot Water Heat Pump
	Domestic Hot Water Water Heater - Insulation
	Domestic Hot Water Instantaneous Hot Water Heater
	Domestic Hot Water Solar Domestic Hot Water
	Domestic Hot Water Water Heater - New
Supporting Devices	Domestic Hot Water Heat Recovery
Controls	Domestic Hot Water Scheduling

Appendix C: Supplementary Results

This appendix provides additional charts that were not included in the main report for brevity.

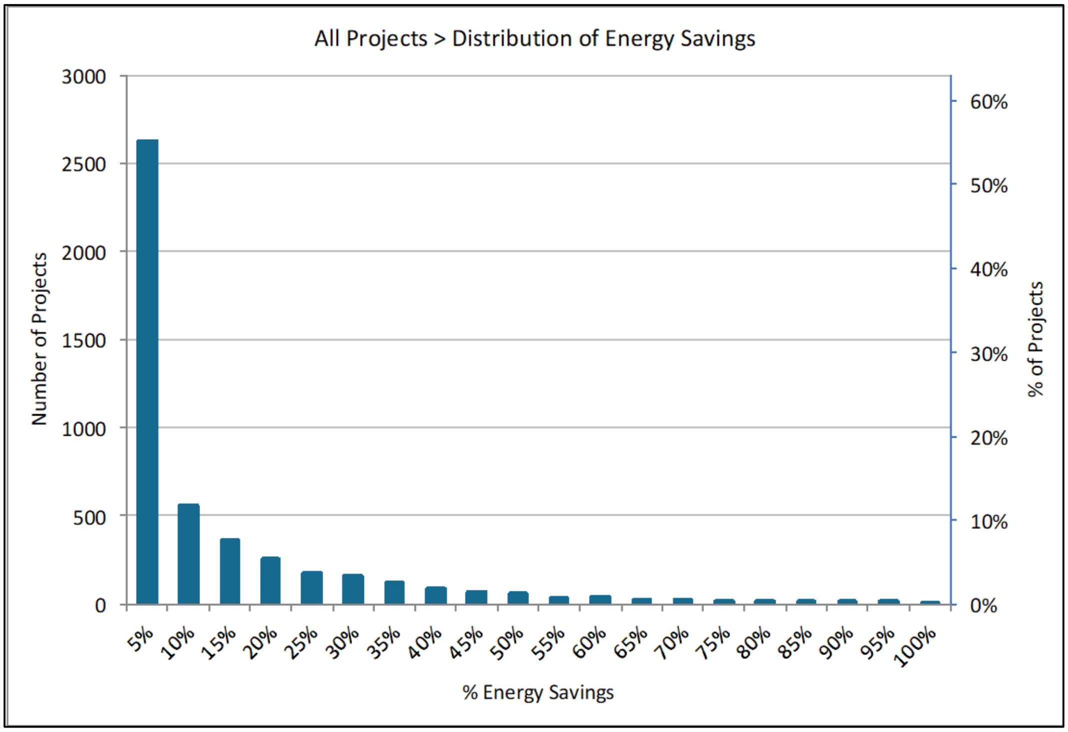

Figure C-1. All Projects > Distribution of Energy Savings

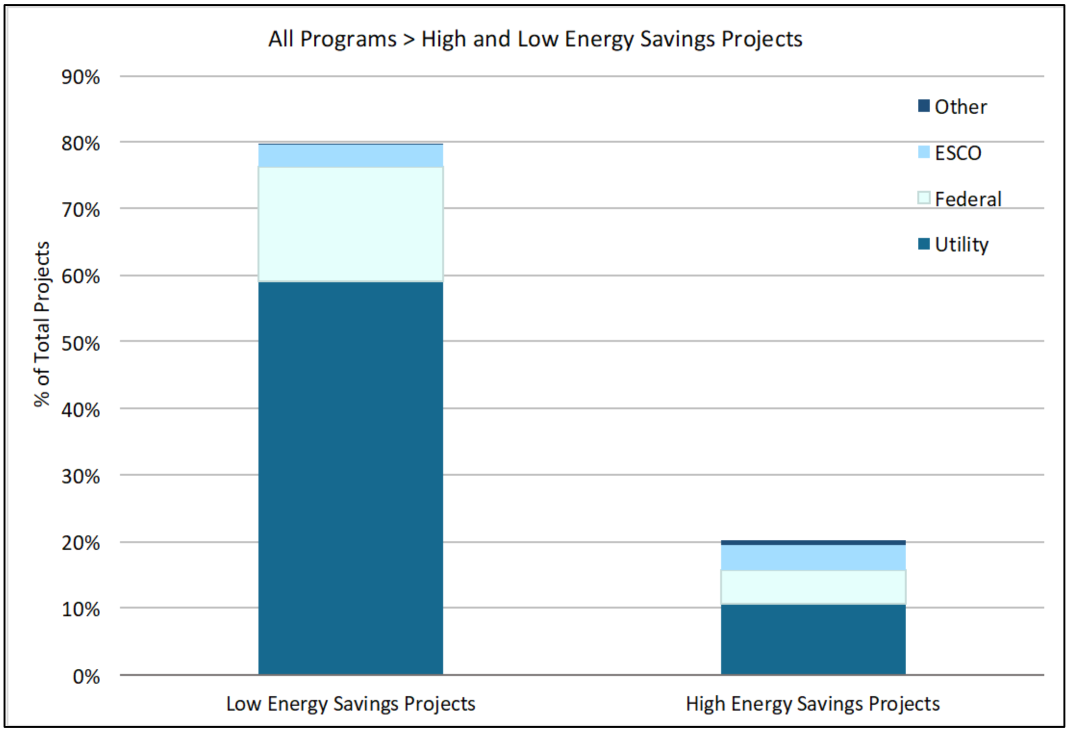

Figure C-2. All Programs > High and Low Energy Savings

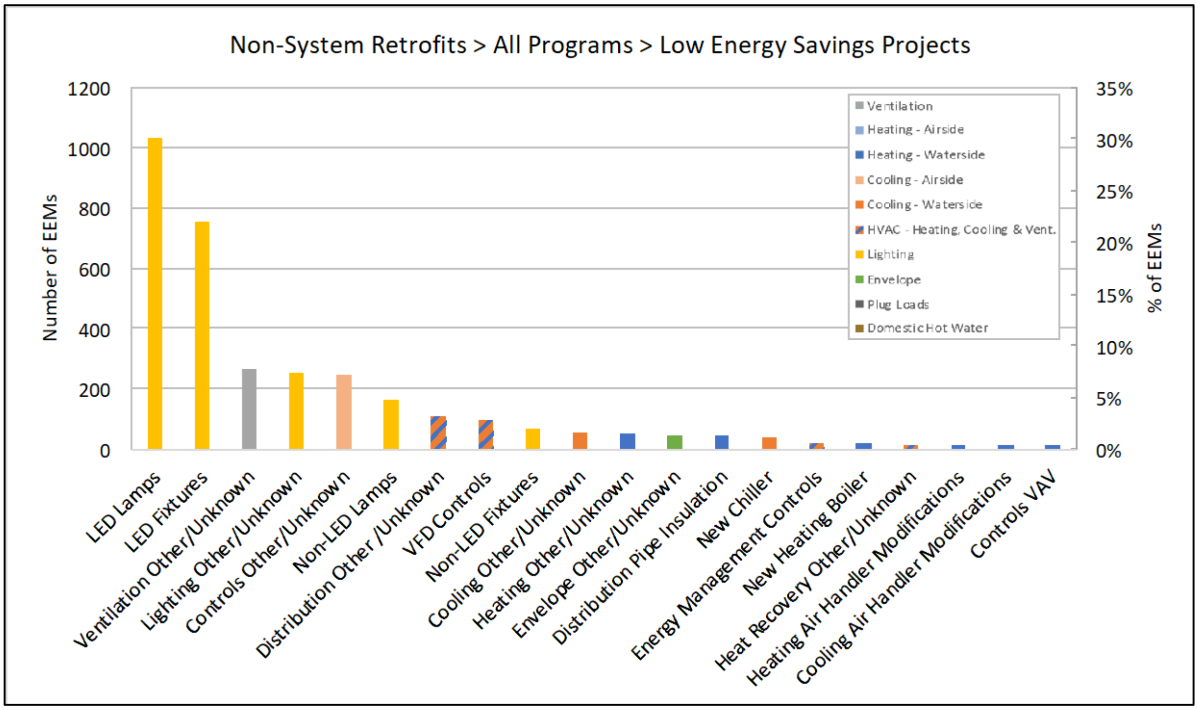

Figure C-3. Non-System Retrofits > All Programs > Low Energy Savings

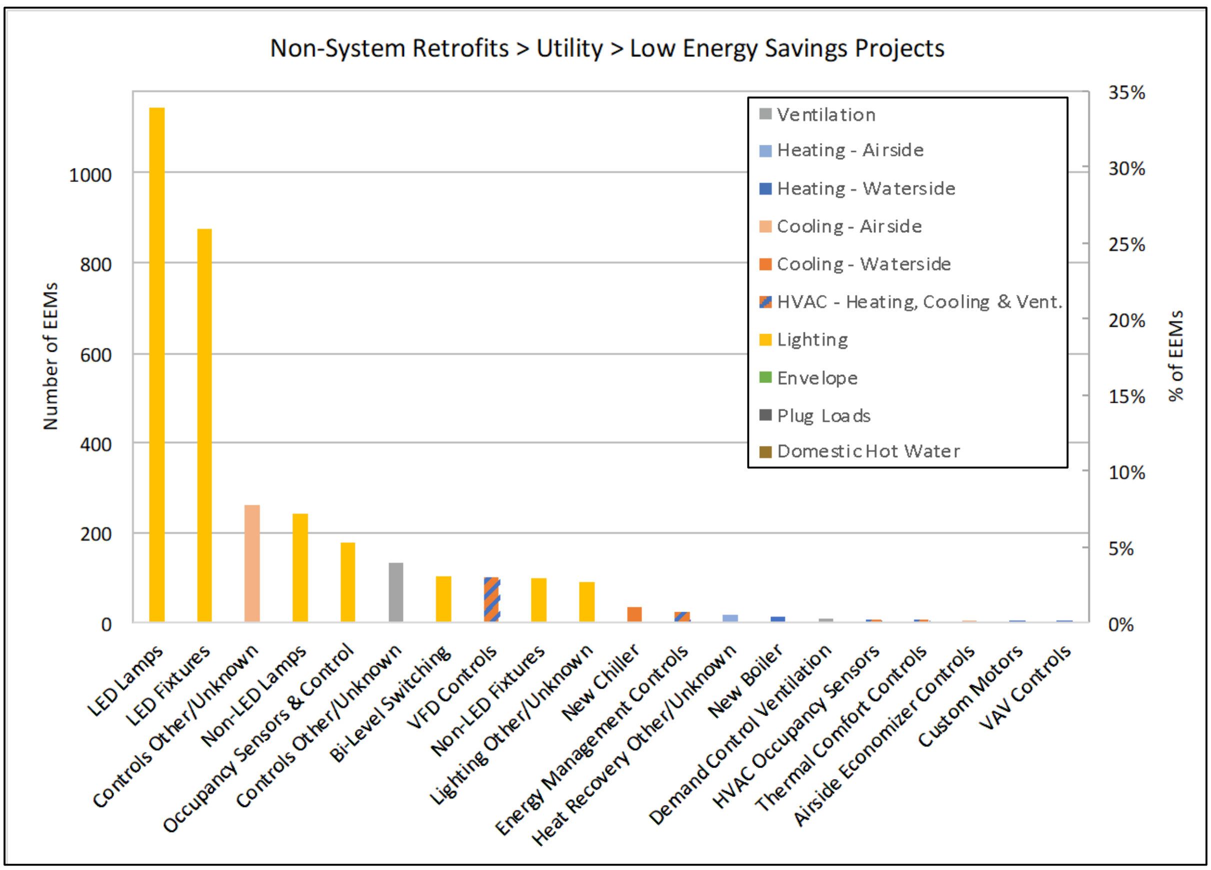

Figure C-4. Non-System Retrofits > Utility > Low Energy Savings Projects

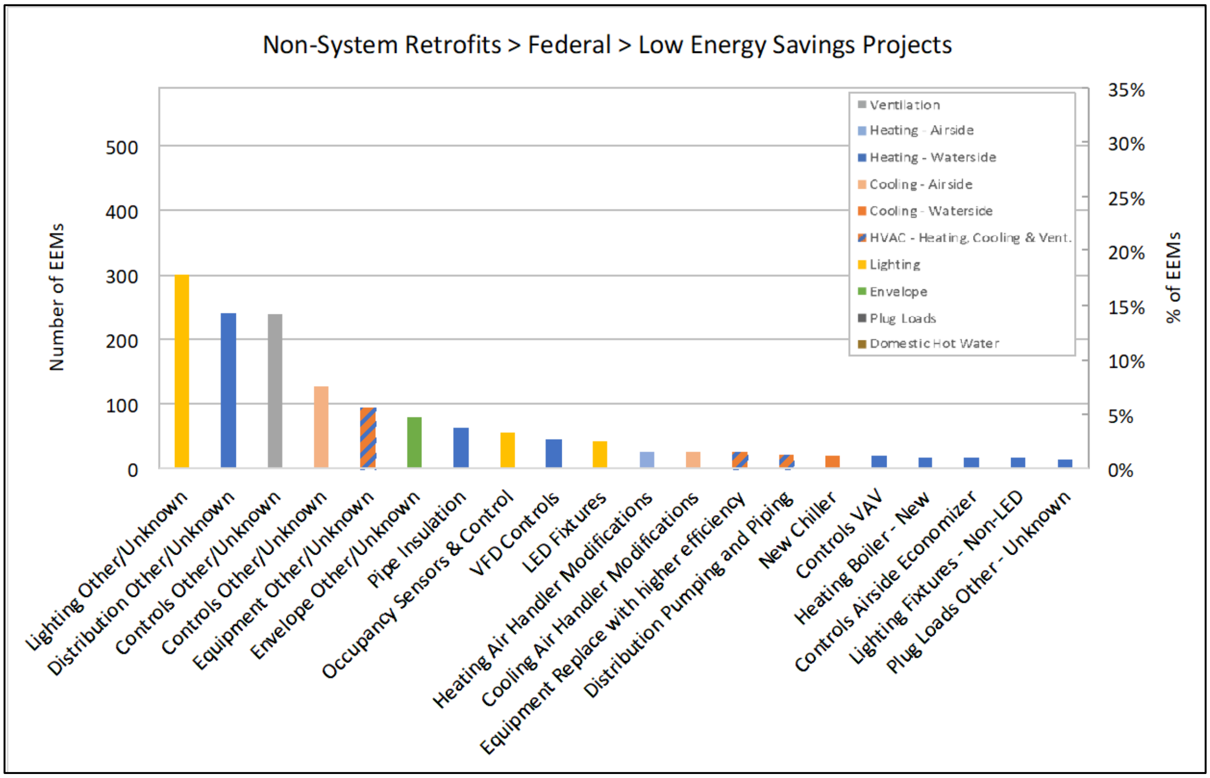

Figure C-5. Non-System Retrofits > Federal > Low Energy Savings Projects

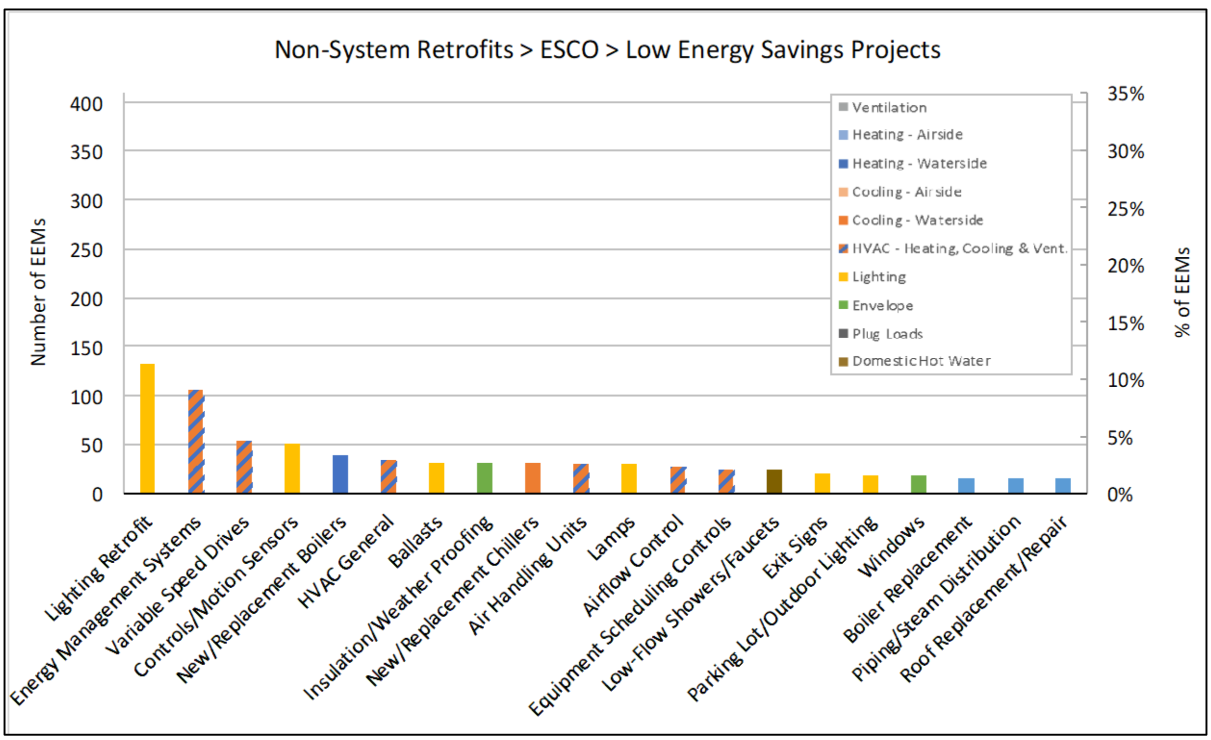

Figure C-6. Non-System Retrofits > ESCO > Low Energy Savings Projects

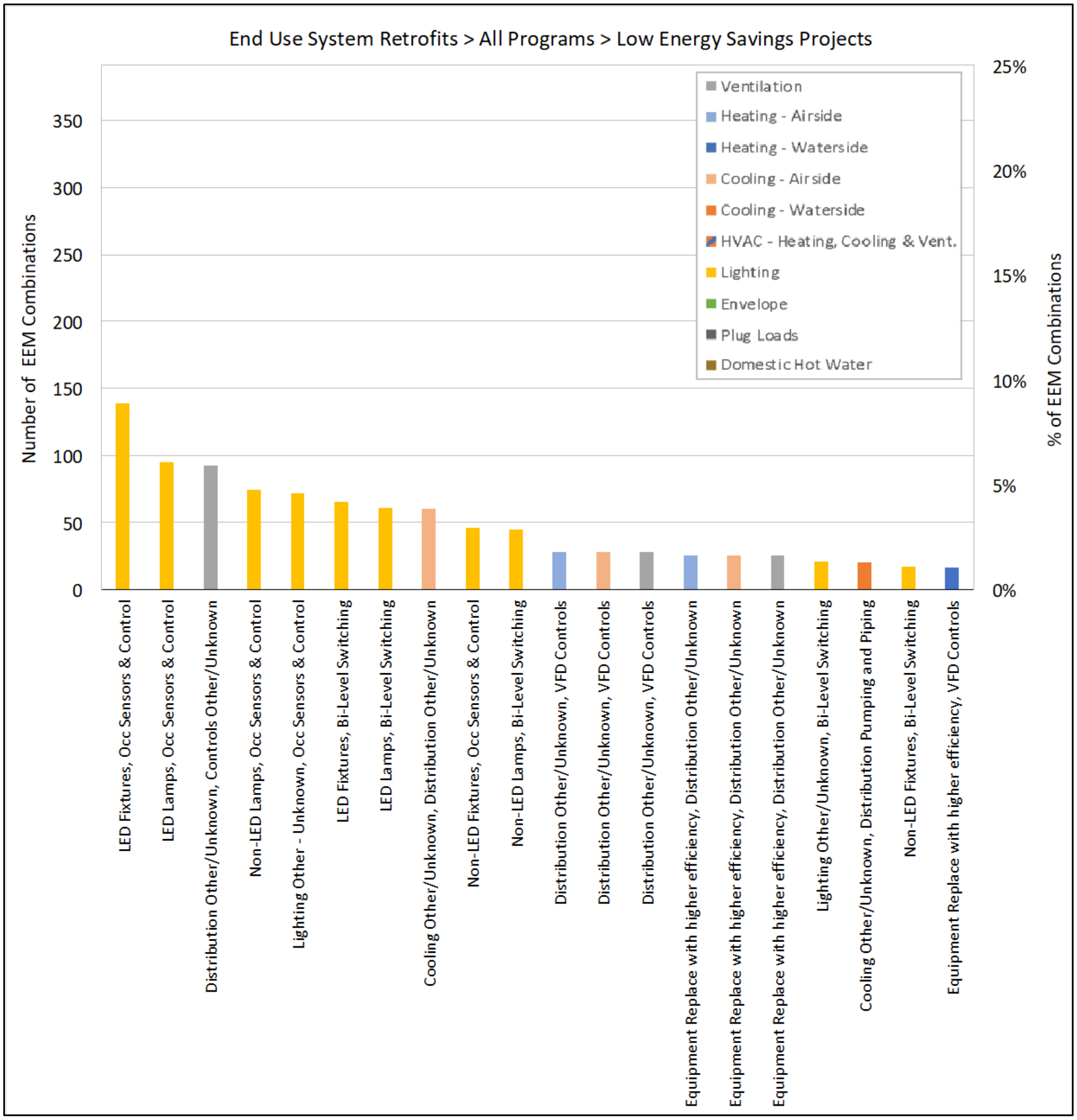

Figure C-7. End Use System Retrofits > All Programs > Low Energy Savings Projects

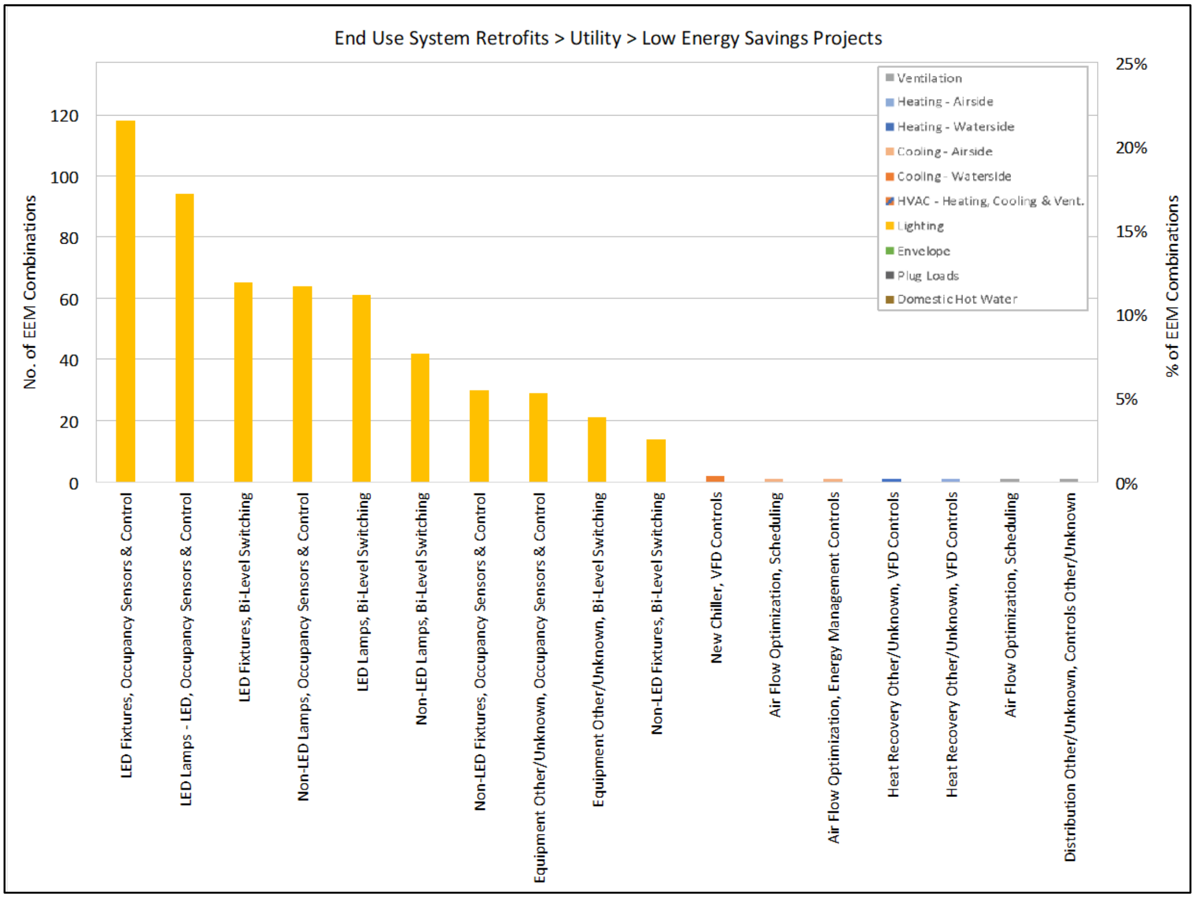

Figure C-8. End Use System Retrofits > Utility > Low Energy Savings Projects

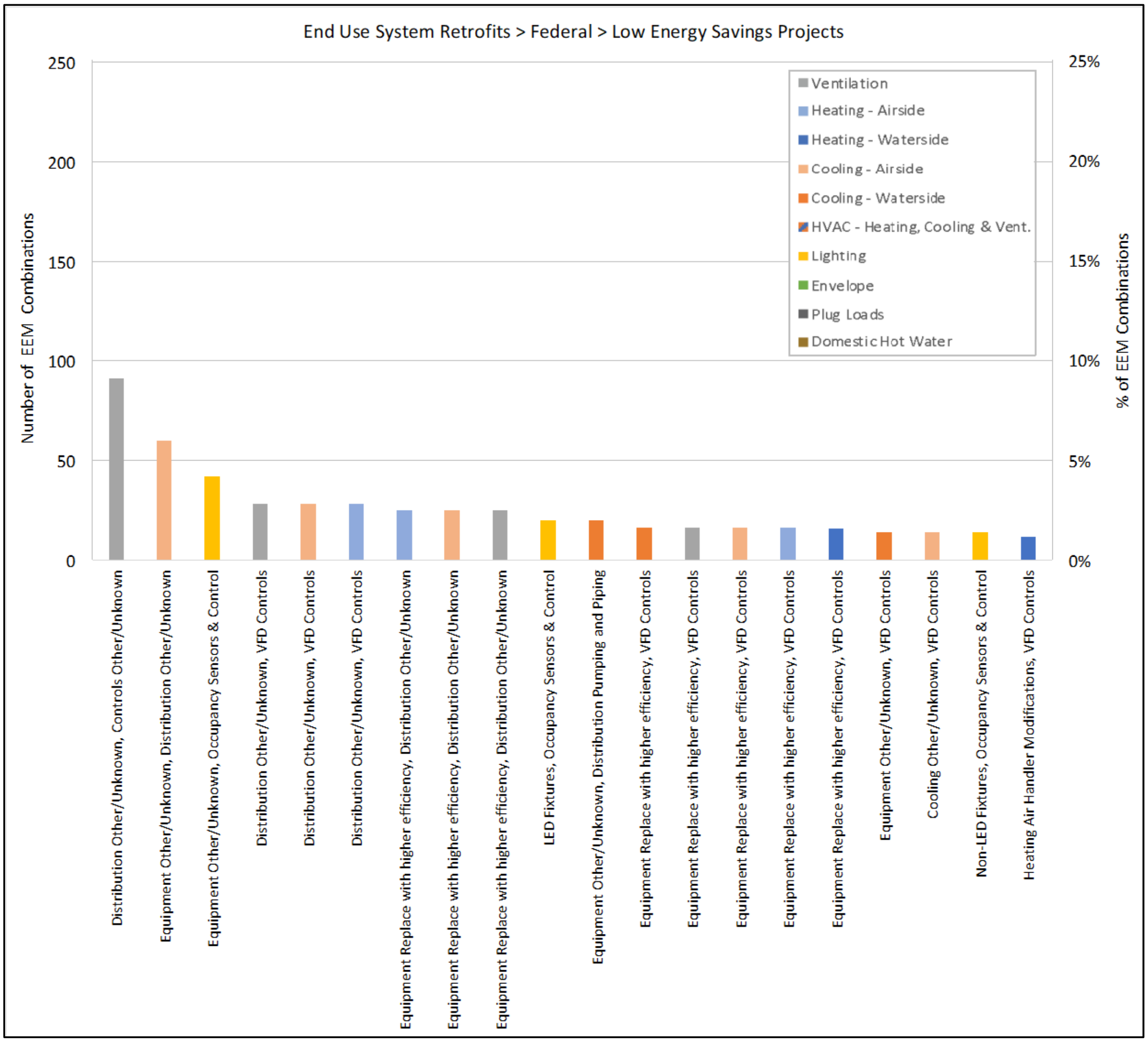

Figure C-9. End Use System Retrofits > Federal > Low Energy Savings Projects

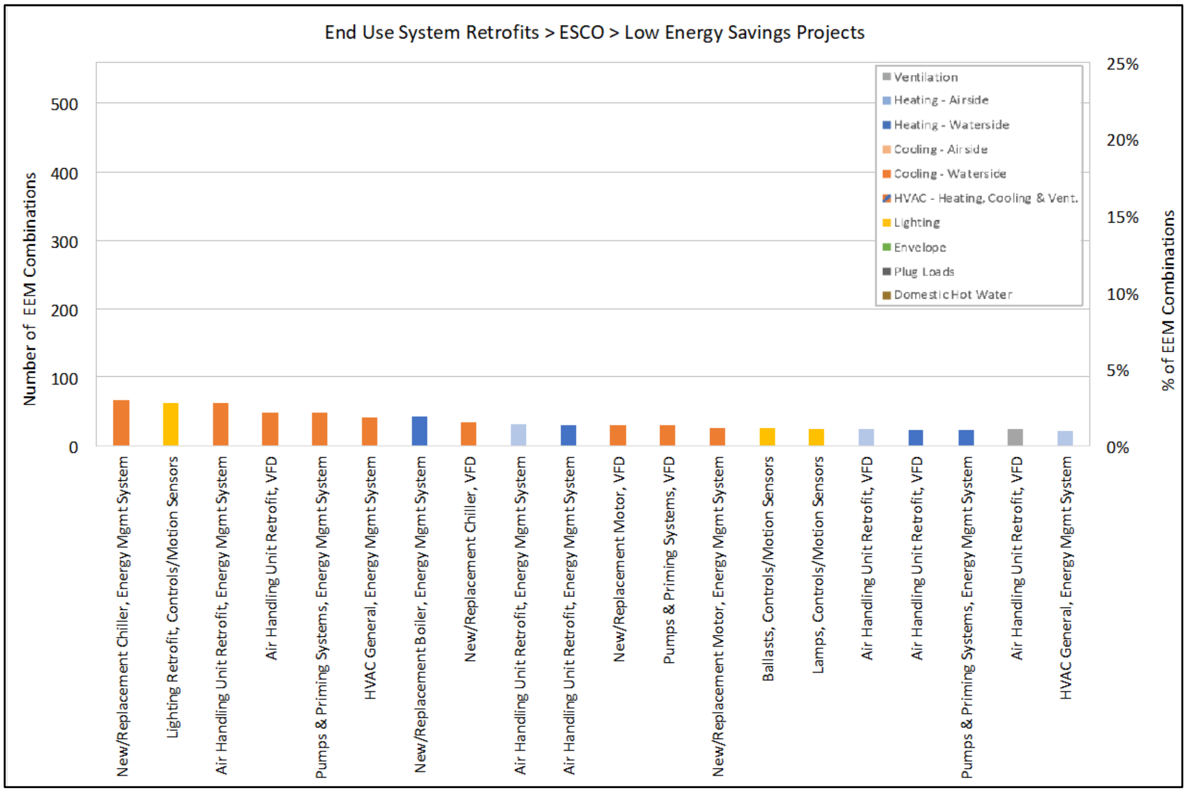

Figure C-10. End Use System Retrofits > ESCO > Low Energy Savings Projects