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FINAL PROJECT REPORT

Integrated Retrofit Solutions for the Multitenant Light Commercial Market

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Integrated Retrofit Solutions for the Multitenant Light Commercial Market is the final report for the Integrated Retrofit Solutions for Untapped Markets project (Contract Number 500-10-028) conducted by the University of California, Davis Energy Efficiency Center. The information from this project contributes to the Energy Research and Development Division's building end-use energy efficiency efforts.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

Multitenant light commercial buildings are a challenging subset of California's commercial building stock and have long been underserved with respect to energy efficiency programs, incentives, and upgrades. In this project, these buildings were defined as having 2 to 38 tenants, less than 160,000 square feet of floor space, and peak electric demand of less than 500 kilowatts. California has about 90,000 of these buildings that together consume about 26 percent of all electricity used in commercial buildings.

This project analyzed these buildings, identified specific building groups for cost-effective energy retrofit packages, and examined lighting, building envelope, mechanical, and control systems to discover energy-saving potential. The project used computer-based simulation to identify cost-effective retrofit solutions, then conducted on-site demonstrations to measure the actual costs and energy savings of the retrofits. The results provide insight into the energy investments in this sector that can most help California meet its ambitious energy goals and greenhouse gas emissions targets.

Keywords: Multitenant light commercial buildings, energy efficiency, energy retrofit solutions, technology evaluation, simulation modeling, demonstration projects, building and market characterization, stakeholder analysis, energy audits

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EXECUTIVE SUMMARY

Introduction

California has ambitious goals to reduce greenhouse gas emissions, using energy efficiency in buildings as a primary strategy. There are about 600,000 commercial buildings in California that account for 54 percent of electric energy used by buildings in the state, excluding industrial and agricultural buildings. About half of nonresidential buildings were built before state building energy efficiency standards first went into effect in 1978. To meet California's energy goals for buildings, it is essential that existing commercial buildings become more energy efficient since most buildings have outdated and malfunctioning systems that waste energy.

Multitenant light commercial (MTLC) buildings are a key subset of the commercial building sector. They include single and multistory buildings that are typically mixed-use, low-rise developments with offices, retail shops, and other spaces on various floors. A large portion of these buildings are neighborhood or community open-air shopping centers or "strip malls."

Previous research indicates that MTLC buildings range between 100 and 500 kilowatts in electric demand. When electric demand is below 500 kilowatts, utilities generally do not assign account managers to help customers select upgrades to lower their utility expenses. Also, while tenants pay energy bills, owners control and pay for major equipment upgrades, so owners have no incentive to invest in energy efficiency, and tenants have no agency to do so.

The MTLC building sector is challenging because of the diverse building types and tenant spaces. The structure of the typical lease agreements between tenants and owners also makes the sector difficult to engage. As a result, traditional approaches to achieving energy efficiency have been unsuccessful.

Purpose and Process

The research team's goal was to advance wide-scale, energy efficiency retrofits in California by understanding and developing retrofit solutions tailored specifically to MTLC buildings.

The team focused on MTLC shopping centers (small and medium-sized retail/service buildings) with four primary objectives:

- Gather relevant market and technology data to define, segment, and characterize the MTLC market.
- Identify and evaluate various retrofit technologies for individual tenant spaces, as well as within whole-building configurations.
- Develop integrated technology packages and a retrofit modeling tool to provide the user with integrated retrofit technology options.

- Demonstrate and communicate the performance and viability of retrofit packages for the MTLC market.

Results

For purposes of this project, the researchers defined MTLC buildings as those with a commercial end-use, between 2 and 38 tenants, an area less than 160,000 square feet, and a peak demand less than 500 kW. The team identified about 90,000 of MTLC buildings in California that represent 22 percent of the state's commercial buildings and account for 26 percent of commercial building electric consumption. The team defined six MTLC building sub-sets, or "archetypes:"

- Main street buildings
- Office park buildings
- Municipal, university, school, and hospital buildings
- Convenience shopping center buildings
- Neighborhood shopping center buildings
- Community shopping center buildings.

After producing a more detailed definition of these buildings, researchers created the first comprehensive database of information describing the MTLC market, in terms of existing technologies and performance, market stakeholders and decision-making processes. The team identified key barriers to implementing energy retrofits in MTLC buildings, including:

- Stakeholder engagement
- Split incentives
- Leasing structures
- Financing
- Information gaps
- Time constraints

To concentrate on the most neglected buildings, the team focused on convenience shopping centers and neighborhood shopping centers. These buildings are also the most widespread, comprising 65 percent of all shopping center buildings. The largest contributors to electric load were lighting and heating, ventilation, and air conditioning (HVAC). HVAC is the largest single contributor to peak loads, and the equipment is often old and inefficient. Lighting represents about one-third of electric use in commercial buildings.

The team also developed an energy retrofit simulation tool called the MTLC Toolbox that was tailored specifically to the California market. This toolbox allowed the researchers to analyze the energy efficiency of MTLC buildings and identify retrofit solutions to reduce overall energy consumption. Using the MTLC Toolbox, the team conducted numerous retrofit simulations to identify top-performing retrofit packages.

To help promote energy retrofits in the MTLC market, researchers identified three beneficial programmatic strategies:

- Use the California Conservation Corps to conduct on-site audits.
- Use software such as the MTLC Toolbox to conduct energy efficiency analyses.
- Install packages of retrofit measures at the whole-building level.

Researchers demonstrated significant energy and cost savings from lighting or HVAC retrofits at three demonstration sites in the cities of Davis, Upland, and Sacramento.

In Davis, a 20,000 square foot building, including a dry cleaners and a bicycle shop, was retrofitted with skylights, light-emitting diode (LED) interior and exterior lighting, and occupancy controls. An HVAC unit replacement, cool coating ductwork, and a controls upgrade for another HVAC unit completed the retrofit. Electricity savings from lighting improvements were about 10,000 kWh per year or 53 percent. Electricity savings from HVAC were about 1,900 kWh per year or 33 percent.

In Upland, a 12,000 square foot retail retail store was retrofitted with high efficiency HVAC equipment and 48 LED parking lot lighting fixtures with occupancy controls. Lighting savings were calculated to be 52,000 kWh per year, more than 52 percent.

In Sacramento, eight tenants in a 26,000 square foot building received lighting and HVAC upgrades. New LED lighting with occupancy sensors produced 63,000 kWh of savings, about 28 percent, and 16 new high-efficiency HVAC units contributed to about 63,000 kWh, around 40 percent savings.

Benefits

California requires wide-scale energy efficiency retrofits in every building sector, including MTLC buildings, to help achieve its greenhouse gas reduction and energy efficiency goals. The research team's in-depth study of the MTLC market and its technical and business needs provides new insight into a market that has been largely unaddressed. In addition, the results from the demonstration sites provide information on what will be needed to help achieve compelling, cost-effective energy conservation in the MTLC market. Data from the field demonstration sites, while limited, validated many of the researchers' findings. Overall, the team found significant energy savings from implemented retrofits. Cost savings and payback for retrofits varied depending on the specific retrofit and tenant characteristics. The project's findings have the potential to help this sector contribute to California's ambitious energy goals and greenhouse gas emission reduction targets.

CHAPTER 1: Background

California has set a goal to reduce the state's greenhouse gas emissions (GHG) to 1990 levels by 2020 and to 80 percent below 1990 levels by 2050 (Executive Order # S-03-05, 2005). A major aspect of achieving these targets involves reducing the consumption of fossil fuels used in energy production and consumption. The California Global Warming Solutions Act of 2006 establishes a plan to reach these GHG goals (Assembly Bill 32, Nuñez, Chapter 488, Statutes of 2006). Former Governor Edmund G. Brown, Jr. further emphasized a commitment to GHG reduction measures with an April 2015 executive order to reduce California's 2030 GHG to 40 percent below 1990 levels (Executive Order B-30-15, 2015). In his 2015 inaugural address, then-Governor Brown also proposed an ambitious set of objectives for California to achieve by 2030 and beyond: 1) to increase the proportion of the state's electricity derived from renewable resources from 33 percent to 50 percent; 2) to reduce petroleum use in cars and trucks by up to 50 percent; 3) to double the savings from efficiency improvements in existing buildings; and 4) to make carbon based fuels cleaner (Brown, 2015).

Energy Efficiency in Buildings

Energy efficiency is a primary strategy for California to meet its goals for deep carbon emissions reductions. Two primary state energy policies drive building energy efficiency actions: 1) the electricity loading order established in California's 2005 Energy Action Plan (State of California, 2005) and 2) the 2008 California Public Utilities Commission's (CPUC) Long Term Strategic Energy Efficiency Plan (CPUC, 2008).

The state's loading order requires energy demand first be met with cost-effective and environmentally preferable energy efficiency and demand response, followed by renewable energy sources, and lastly by generation of cleaner fuels. Energy efficiency includes programs that (1) require buildings to be built and operated in ways that use less energy; (2) provide incentives for purchasing energy efficient equipment; and (3) provide information to consumers to encourage energy savings. Demand response includes programs by energy planners and operators to balance supply and demand, such as incentive payments to encourage customers to reduce energy use during times of peak demand.

The *2008 CPUC Long Term Strategic Energy Efficiency Plan*, an adjunct to AB32, outlines the state's goals to achieve Zero Net Energy (ZNE) for newly constructed low-rise residential buildings by 2020 and 2030 for all new commercial buildings, and to achieve ZNE for 50 percent of existing commercial buildings by 2030. "ZNE" involves cases where the net amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building.

California has approximately 600,000 commercial buildings, 9 million single-family homes, and 3 million multifamily units (CEC, 2015). Residential and commercial buildings account for almost 70 percent of California's electricity use and 55 percent of natural gas consumption (CEC, 2015). In addition, residential and commercial buildings account for about 20 percent of California's GHG emissions (CEC, 2015). Approximately 50 percent of California's residential and nonresidential buildings were built before California's Building Energy Efficiency Standards went into effect in 1978 (CEC, 2015). Doubling energy savings from building energy efficiency would substantially reduce energy use in 2030 to pre-2014 levels in spite of population increases and economic growth (CEC, 2015).

California Building Energy Efficiency Standards

In 1978, California adopted building energy efficiency standards to help reduce building energy consumption (CEC, 1978). These standards ensure cost-effective energy efficiency measures are incorporated into new buildings during design and construction, and into existing residential and nonresidential buildings when additions and alterations are made. Standards are tailored to California's 16 climate zones and cover four categories of building design: building envelope, lighting, mechanical, and domestic hot water. The Energy Commission updates the building standards every three years, making them more stringent with each iteration. Building agencies and local building officials enforce these building standards through checks and planned inspections.

There are several key challenges to improving energy efficiency in California's existing building stock. Alterations of existing buildings, especially homes, often take place without building permits, and compliance with building codes and energy standards is uncertain. In addition, it can take years to recoup initial energy investment costs from utility bill cost savings. Finally, the stringency of California's building energy standards widens the performance gap between existing buildings and current code, making projects more challenging and expensive.

Multitenant Light Commercial Buildings

To meet California's energy goals for buildings, it is essential for existing commercial buildings to be more energy efficient because half of existing buildings have outdated technologies that waste energy. The commercial building sector is complex, however, so it defies packaged approaches to achieving energy efficiency. Commercial buildings vary in size, use, location, occupancy, and ownership structure. Multitenant light commercial (MTLC) buildings are a key subset of the commercial building sector, and are the focus of this study.

MTLC buildings include single- and multi-story buildings that are typically mixed-use, low-rise developments with offices, retail shops, and other spaces on various floors. A large portion of these buildings are neighborhood or community open-air shopping centers, commonly referred to as "strip malls." These centers are typically less than 350,000 square feet, house different tenant businesses, and have only one to two larger anchor stores, such as a supermarket. The research team estimated that the MTLC market includes a significant portion of the 13,000 shopping centers that exist in California that total more than 900 million square feet of building space. This sector, however, also includes thousands of other buildings of different types, such as small office parks and mixed-use developments.

As directed by the CPUC, current energy efficiency programs from the state's investor-owned utilities (IOU) must meet rigid cost-effectiveness criteria and are designed to engage specific market subsets. Energy efficiency programs generally target large customers (corporately managed building chains, class-A commercial facilities, and energy intensive industries) or are mass marketed to individual residential consumers whose cumulative energy use behavior represents an enormous demand. Buildings and customers not in either of these categories, such as MTLC buildings, comprise a large aggregate efficiency opportunity, are more difficult to reach, and have been mostly untapped.

The MTLC strip mall is a common architectural genre in the United States. The wide range of building and tenant spaces in these numerous facilities are difficult to characterize and their energy use is difficult to influence. MTLC retrofits are also challenging because of the complexities of the owner/manager/tenant relationship. Tenants may not pay directly for energy consumption and short lease terms may not motivate energy efficiency improvements with long payback periods to recoup initial costs. Additionally, the team's research indicates that most retrofit projects address air conditioning, building envelope, lighting, and controls as individual components instead of as integrated solutions.

Retrofits of existing buildings are necessary for California to achieve greenhouse gas reduction and energy efficiency goals. California requires wide-scale energy efficiency retrofits in every sector of the economy, including MTLC buildings. Success for energy efficiency in the MTLC market requires sophisticated research about the market and its technical and business needs, followed by integrated energy efficiency technology and delivery mechanisms to meet identified needs.

Project Goals

The purpose of the "Integrated Retrofit Solutions for Untapped Markets" project was to develop technological and market-based approaches to increase installation of energy-efficient technologies and reduce peak energy demand for existing MTLC buildings in California. The research team's primary project goal was to achieve significant energy savings by developing retrofit programs tailored specifically to MTLC buildings. The team focused on MTLC shopping centers with four major goals:

- Gather relevant market and technology data to define, segment, and characterize the MTLC market.

- Identify and evaluate various retrofit technologies for individual tenant spaces, as well as within whole-building configurations.
- Develop integrated technology packages and a retrofit modeling tool to provide the user with integrated retrofit technology options.
- Demonstrate and communicate the performance and viability of retrofit packages for the MTLC market.

Project Methods

To achieve success in the MTLC market, technology innovation must be appropriate, cost effective, and accessible. The research team combined sophisticated market research with technology innovation to advance wide-scale energy efficiency retrofits in California. The team focused on integrating lighting; building envelope; heating, ventilation, and air conditioning (HVAC); and control technologies into retrofit solutions, and addressing the delivery mechanisms necessary to successfully implement these solutions in the market. This multi-year programmatic research consisted of an interdisciplinary team to implement four primary activities.

Define, Segment, and Characterize the Market

Unfortunately, there is no single source of information to meaningfully characterize the business and technology needs related to energy efficiency in the MTLC market. The team aggregated available knowledge and collected primary data for MTLC buildings, using aerial surveys and interviews with stakeholders, to develop a database of information that describes the MTLC market in terms of existing technologies and performance, as well as assessing the potential for cost-effective performance improvements. The team also developed a structured understanding of market actors and decision-making processes.

Analyze Appropriate Technologies and Implementation Strategies

Numerous energy efficient technologies are available. The research team used its MTLC market research to identify technologies most appropriate to MTLC buildings. The team identified solutions for property-wide application, as well as individual tenant spaces, including efficient building envelope solutions (for example, window replacement, awnings, and internal shading devices), intelligent interior and exterior lighting, and advanced HVAC technologies. Researchers summarized measures and technologies most appropriate for MTLC buildings and identified potential energy savings and peak energy demand reduction. In addition, team researchers conducted a survey of utility representatives who serve the MTLC market and stakeholders who own, manage, or lease MTLC properties to understand their perceptions of specific energy-efficient solutions and their motivations for selecting and installing certain measures over others.

Develop Tools for Integrated Retrofit Packages

Implementing energy efficiency retrofit projects at MTLC buildings is challenging because of the high cost of the retrofit process, ineffective packaging of multiple technologies, and incomplete understanding of savings from retrofit projects. To achieve significant energy savings for MTLC buildings, the research team identified current market shortcomings and potential solutions for improving data collection, analysis, and technology recommendations for the MTLC market. The team developed a MTLC Toolbox, tailored specifically to the California market, to allow stakeholders, primarily owners and tenants of MLTC buildings, to analyze their current energy efficiency and identify steps they can take to reduce their overall energy consumption through technology and construction retrofits. The team conducted numerous simulations with the MTLC Toolbox to evaluate energy performance of technologies for a variety of tenant space configurations (for example, buildings with or without drop ceilings). In addition, the team conducted research with HVAC contractors to understand potential cost savings associated with programs that implement retrofits at the building level for a bundle of HVAC retrofit services instead of the current focus on individual retrofits at the tenant level.

Establish Field Demonstrations

Retrofit demonstrations provide real-world performance data and information on consumer perceptions and experiences of specific energy efficiency measures. The team's utility partners applied lighting and HVAC retrofits to three MTLC demonstration sites in Southern and Northern California (Davis, Upland, and Sacramento). Researchers validated the expected energy savings, peak demand savings, and cost savings from the retrofit packages. The team also validated the business and market approaches.

Research Team

A multi-disciplinary team of technical experts, utility representatives, and industry partners conducted this project. The Energy Efficiency Center (EEC) at the University of California, Davis (UC Davis) and its affiliated technology centers—the California Lighting Technology Center (CLTC) and Western Cooling Efficiency Center (WCEC)—led the project in collaboration with the UC Davis Graduate School of Management (GSM). EEC Team Members provided expertise on building envelope, lighting, HVAC, and control technologies. GSM Team Members provided expertise in finance, market analysis, needs assessment, and achieving market acceptance. Utility and industry partners included representatives from energy efficiency programs of Pacific Gas and Electric (PG&E), Southern California Edison (SCE), Sempra Energy (the parent company of San Diego Gas & Electric Company [SDG&E]), and Southern California Gas Company (SCGC), and numerous manufacturers, distributors, installers, and end-users. Partnerships with energy efficiency programs of California's major IOUs provided a unique and valuable connection to market intelligence and end use customers, as well as deployment programs, while partnerships with industry (manufacturers and distributors) provided collaboration on development, production, and marketing of energy-efficient products.

Challenges

The research team encountered several real-world challenges in working with MTLC businesses. First, the team experienced a low response rate to surveys of the MTLC market and HVAC contractors. In addition, the team found not all tenants within each of the demonstration site buildings wanted to participate in the project. As a result, the team's retrofit package demonstrations only provide findings for a portion of tenants at each site. Despite these shortcomings, the research team has interesting and beneficial results that can be expanded upon in future studies.

Benefits

Addressing the retrofit market is key to successfully meeting California's aggressive energy efficiency and greenhouse gas emissions targets. The team's research provides insight into a market that has largely been ignored and unaddressed. When coupled with the team's MTLC modeling tool and the results of the demonstration sites, this project's findings offer guidance on the most relevant barriers and potential solutions available for achieving compelling, cost-effective energy conservation in the MTLC market. By developing a portfolio of solutions that fit the requirements of major segments of the MTLC market, and targeting multiple price points to address a broad cross-section of light commercial facilities, the team expects to motivate market adoption, utility rebate programs, and eventual changes in energy codes and standards.

Report Structure

This report presents the project team's findings and recommendations from investigating MTLC building retrofit programs. The remainder of this report is structured as follows:

- Chapter 2, defining, segmenting, and characterizing the MTLC building stock, describes key technical and market characteristics of the MTLC building stock to understand their potential for energy efficient retrofits. The team also describes market barriers to achieving energy efficiency. Finally, the team provides opportunities and recommendations for engaging the MTLC market.
- Chapter 3, energy technology assessment, reviews a subset of retrofit technologies that are most appropriate for the MTLC market in the areas of lighting, building envelope, and HVAC. The team discusses each technology and outlines potential energy savings and performance improvements. The team also describes end-user perceptions of specific energy-efficient lighting and envelope solutions recommended for use in MTLC building retrofits.
- Chapter 4, programmatic tools for achieving deep energy savings in MTLC buildings, proposes a new program for the MTLC market that includes a unique

approach to conducting energy audits, a modeling tool to effectively recommend technology packages, and an approach to cost-effective deployment of HVAC retrofit services.

- Chapter 5, retrofit demonstrations, describes how the researchers collected field measurements and analyzed data from three demonstration sites across California to understand the effectiveness of chosen retrofits and the implementation process.
- Chapter 6 presents the team's overarching conclusions and outlines future research needs.

CHAPTER 2:
Defining, Segmenting, and Characterizing the Building Stock

Introduction

There are three major building sectors: residential, commercial, and industrial. Nationally, the commercial building sector consists of approximately 6 million buildings and 70 billion square feet (sq-ft) in gross leasing area, accounting for about 13 percent of all primary energy used by buildings in the United States (EIA, 2003; EIA, 2012). In California, the commercial sector consists of about 600,000 buildings and accounts for 37 percent of all electric energy used by buildings in the state (EIA, 2003; EIA, 2012). Multitenant light commercial (MTLC) buildings are a key subset of the commercial building sector and the focus of this study.

MTLC buildings include single and multi-story buildings that are typically mixed-use, low-rise developments with offices, retail shops, and other spaces, often on various floors (Figure 1). A large portion of these buildings are neighborhood or community open-air shopping centers, commonly referred to as "strip malls." These centers are typically less than 350,000 sq-ft, house several different tenant businesses, and have only one to two larger anchor stores, such as a supermarket. The MTLC market includes a significant portion of the 13,000 shopping centers that exist in California, which totals more than 900 million sq-ft. This sector, however, also includes thousands of additional buildings, such as small office parks and mixed-use developments.

Figure 1: Example of Multitenant Light Commercial Building

Source: UC Davis

The research team gathered relevant market and technology data to define, segment, and characterize the MTLC market, including key market barriers to achieving deep energy savings. With this information, the team identified deep energy retrofit (DER) opportunities for MTLC shopping centers. The team's research activities addressed in this chapter with key primary and secondary data sources are summarized in Table 1.

Table 1: Topics and Data Sources for Multitenant Light Commercial Building Research

Research Activities	Key Primary Data Sources	Key Secondary Data Sources
1. Define the MTLC building sector.		• Commercial Buildings Energy Consumption Survey (CBECS) microdata (EIA, 2003)
2. Establish subsets or key archetypes of the MTLC building sector.		• CBECS microdata • International Council of Shopping Centers (ICSC) data (ICSC, 2011)
3. Characterize buildings in target MTLC market.	• Aerial survey data • Audit data of 53 buildings	• ProspectNow parcel data [(a)] • California Commercial End-Use Survey (CEUS) data (Itron, 2006) • Itron California Commercial Saturation Survey data (Itron, 2014)
4. Characterize energy efficiency programs in target MTLC market	• Industry expert interviews • Program advisory committee members • Published programmatic information from IOUS, 3P providers, and so on.	• Published reports and content from California Public Utilities Commission • 3Ps Needs Assessment Report by TRC •
4. Perform a stakeholder analysis.	• Interviews with industry experts representing key stakeholder groups • Statewide questionnaire responses from business owners	

(a) ProspectNow (http://www.prospectnow.com/).

Source: UC Davis EEC

Defining the Multitenant Light Commercial Building Sector

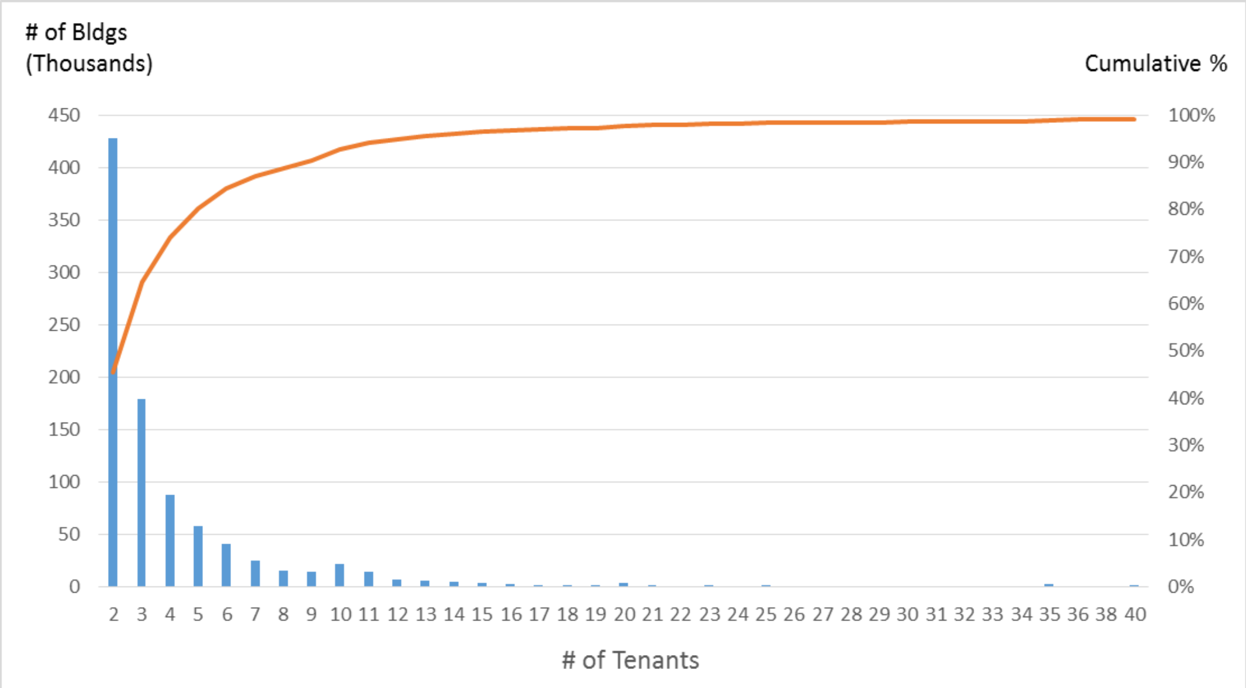
Data and Methods

The team used the federal Commercial Buildings Energy Consumption Survey (CBECS) microdata to define and understand the MTLC market. CBECS microdata had 5,215 records. Each record represented a building in the United States and contained details about its characteristics, including vintage, square footage, climate zone, tenant end-use characteristics, number of floors, types of HVAC units, and so on. Researchers removed inaccurate data (132 records) and analyzed the remaining 5,083 records. The team used this data to define the MTLC building sector based on two key terms: "multitenant" and "light commercial."

Multitenant Buildings

Multi-tenant buildings house more than one tenant, therefore the multi-tenant market includes all buildings that have two or more tenants. Figure 2 shows the distribution of all national MTLC buildings by number of tenants.

Figure 2: Multitenant Light Commercial Distribution by Number of Tenants



Source: UC Davis EEC

The team found that 99 percent of all multitenant commercial buildings in the United States have 38 or fewer tenants. In defining MTLC buildings, the team considered the criteria to be included as buildings between two and 38 tenants.

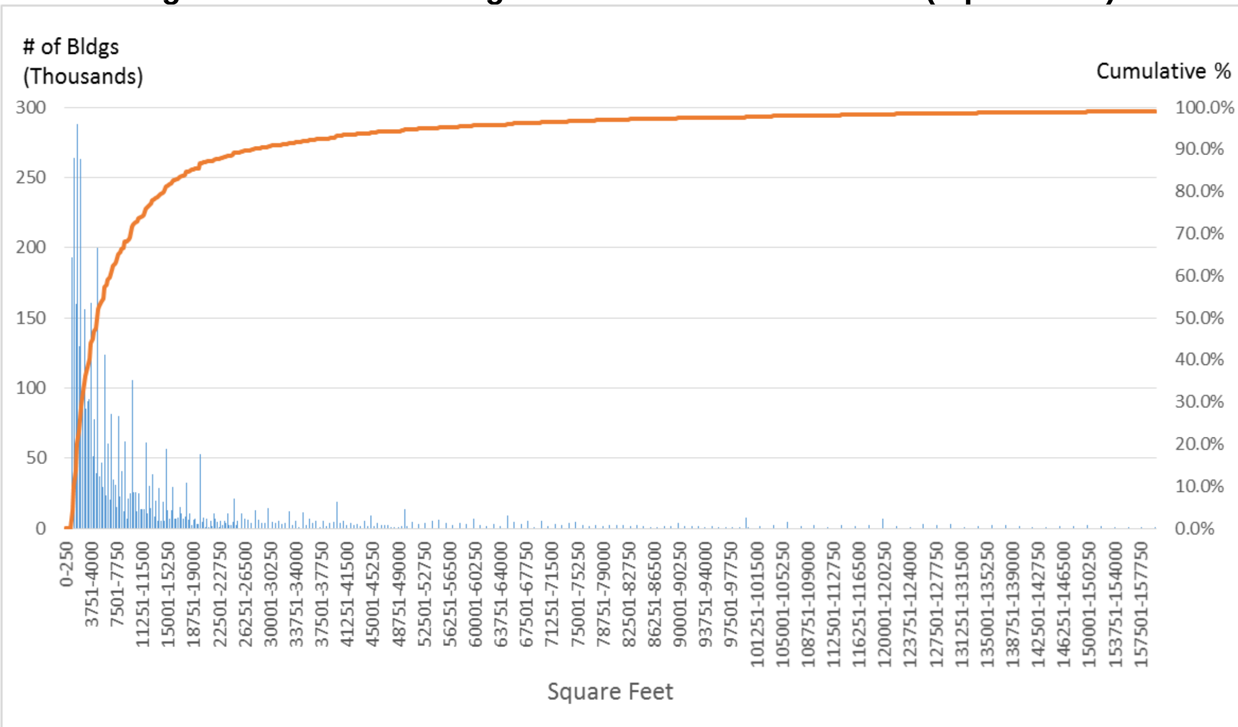
Light Commercial Buildings

The team found that light commercial buildings, also referred to as small commercial, are often defined according to one of two variables: square footage (sq-ft) or peak electric demand (kW) during a given year.

- Based on sq-ft, light commercial buildings are broadly defined as buildings less than 50,000 sq-ft. One rationale often cited, is that 95 percent of all commercial building stock in the United States is less than 50,000 sq-ft. Some definitions limit the maximum sq-ft of small commercial to 30,000 sq-ft (Huppert et al., 2013; ICSC, 2011).
- Based on peak electric demand, utility providers generally define light commercial buildings as small and medium-sized businesses with a peak demand under 200 kW, however, some utilities use a peak demand under 499 kW (Stadler et al., 2010).
- Peak demand also relates to sq-ft. The peak demand for light commercial buildings can be converted to a crude estimate of sq-ft using the value for non-coincidental peak load per sq-ft (3.06 watts per sq-ft) averaged across all commercial buildings in California (Itron, 2006). Using this value, researchers found a 200 kW peak load corresponds to 65,000 sq-ft and a 499 kW corresponds to 163,000 sq-ft.

Figure 3 shows the distribution of all commercial buildings nationally by number of sq-ft. The team found that 99 percent of all commercial buildings in the United States have a gross leasing area of less than 160,000 sq-ft. This value is consistent with the team's calculation of 163,000 sq-ft, which is based on the 499 kW peak load condition. In defining MTLC buildings, the team used 160,000 sq-ft or less leasing area as the inclusion criteria.

Figure 3: Multitenant Light Commercial Distribution (square feet)



Source: UC Davis EEC

Size and Characteristics of the Multitenant Light Commercial Market

Based on the research described above, the team defined MTLC buildings as having four key characteristics:

- A commercial end-use. Specific tenant end-uses include, but are not limited to, retail stores, grocery stores, offices, restaurants, and so on.
- Between two and 38 tenants.
- Less than 160,000 square feet.
- Peak demand less than 499 kW.

The research team worked with the program advisory committee (PAC) consisting of industry experts to review this definition and ensure its appropriateness (Appendix B). The team applied its definition to available data sets for commercial buildings to isolate MTLC building data. In their analysis, researchers found approximately 910,000 MTLC buildings in the U.S (Table 2). These buildings account for 20 percent of all commercial buildings and use roughly 25 percent of all energy used by commercial buildings. In addition, the team found a total of approximately 90,000 MTLC buildings in California, accounting for roughly 10 percent of United States MTLC buildings, 10 percent of United States MTLC sq-ft (1.5 billion sq-ft), and 8 percent of all MTLC electricity consumption (20 billion kWh). Furthermore, researchers found the MTLC market in

California accounts for 22 percent of California commercial buildings, 26 percent of California commercial sq-ft, and 26 percent of California commercial building electricity consumption. These statistics highlight the importance of MTLC buildings nationwide and in California.

Table 2: Multitenant Light Commercial Market in the United States and California

	Number of CBECS Records	Total number of Buildings	Total Area (Millions of SQ FT)	Annual Electricity Usage (GWh)	Total number of Buildings (% of total U.S.)	Total Area (% of total U.S.)	Annual Electricity Usage (% of total U.S.)
Nationwide Commercial Buildings	5100	4,600,000	70,000	1,000,000	100%	100%	100%
Nationwide All MTLC Buildings	1200	910,000	15,000	250,000	20%	21%	25%
California Commercial Buildings	N/A - Approximated	410,000	5700	76,000	9%	8%	8%
California MTLC Buildings	N/A - Approximated	90,000	1,500	20,000	2% (10% of US MTLC; 22% of California commercial)	2% (10% of US MTLC; 26% of California commercial)	2% (8% of US MTLC; 26% of California commercial)

Source: EIA, 2003

Establishing Archetypes of the Multitenant Light Commercial Building Sector

After defining MTLC buildings, the research team created building sub-sets or "archetypes:" buildings that are similar in interests, needs, barriers, or drivers. These archetypes helped the team investigate opportunities for cost-effective energy retrofit solutions. Researchers created archetypes through a process of segmentation.

Data and Methods

The team used CBECS microdata to segment the MTLC market based on seven key bases or factors (Table 3). For more detailed information on the team's segmentation process, please see Appendix A.

Table 3: Segmentation Bases and Process

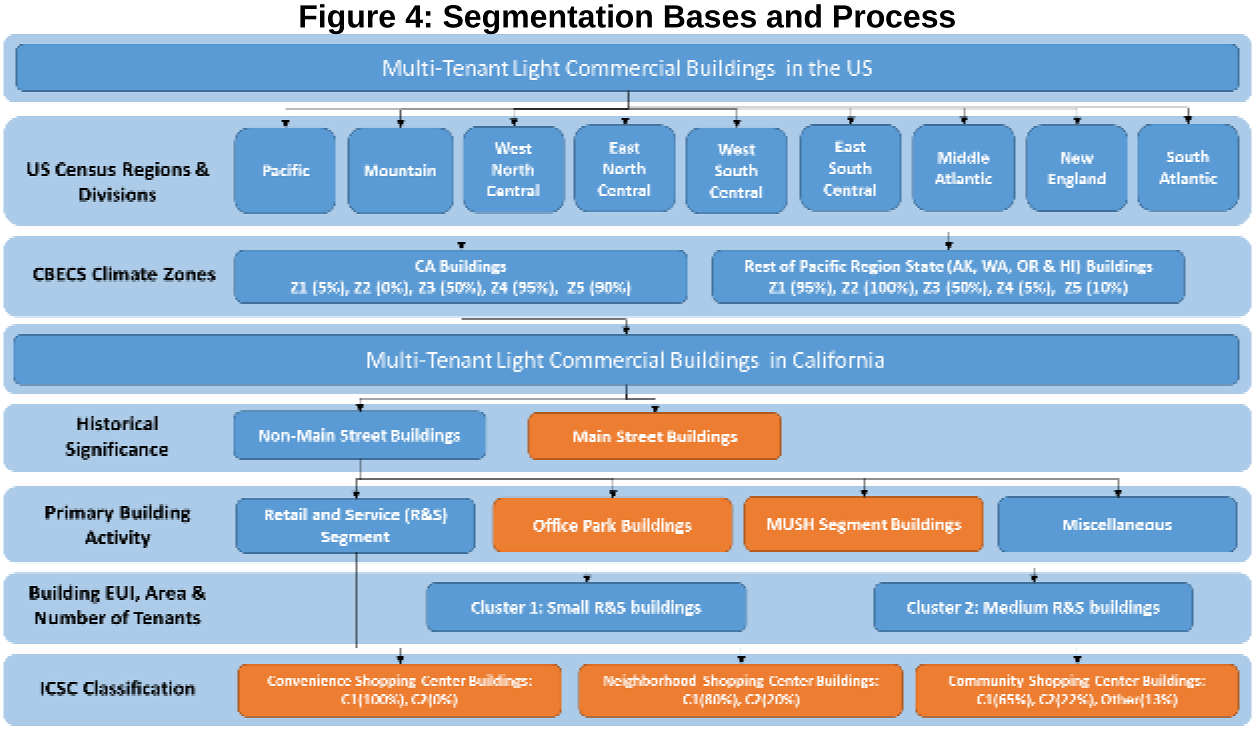
Goal	Segmentation Bases (Factors)	Process for Segmentation
Isolate California specific MTLC buildings	1. Region and Division 2. Climate Zones	Each CBECS record included information regarding the U.S. Census region and division. Climate zone information was also included for each record. The team used "region and division" and "climate zones" to filter the California specific records from the overall national MTLC building records.
Identify buildings with historical significance	3. Historical Significance (Main Street Buildings)	Influenced largely by Preservation Green Lab's (PGL) research, the team paid special attention to buildings that have historical significance because PGL observed that buildings located in historical downtown districts were typically constructed before WWII and built next to each other (Huppert et al., 2013). To segment MTLC buildings, the team adopted a broad version of PGL's definition for "Main Street buildings."
Divide buildings into recognized market segments	4. Primary building activity	Based on input from industry experts (see Appendix B), the team divided all non-Main Street MTLC buildings into four key sub-segments: Offices; Municipalities, Universities, Schools, and Hospitals (MUSH) sector; Retail and Services; and Miscellaneous (a catch-all segment).

Goal	Segmentation Bases (Factors)	Process for Segmentation
Investigate if natural grouping of buildings exist based on key building attributes	5. Building Energy Use Intensity (EUI) 6. Building Sq-Ft 7. Number of tenants	Due to the broad variety and heterogeneous nature of MTLC buildings, the team used k-means cluster analysis to identify similar groups or clusters of buildings using three variables (EUI, sq-ft, and number of tenants). The team found that when they divided buildings into 2 clusters, the individual clusters aligned very closely with the ICSC definition of two of its key markets: convenience shopping center buildings and neighborhood shopping center buildings (ICSC, 2011).

Source: UC Davis EEC

Figure 4 shows the segmentation bases and the team's process to identify key archetypes.

Figure 4: Segmentation Bases and Process



Source: UC Davis EEC

Archetypes

Based on the results of the segmentation, the team identified 6 key archetypes for MTLC buildings, highlighted in orange in Figure 4:

- Main street buildings

- Office park buildings
- Municipalities, universities, schools, and hospitals (MUSH) buildings
- Convenience shopping center buildings
- Neighborhood shopping center buildings
- Community shopping center buildings

Figure 5 lists the six key MTLC archetypes and their broad definitions.

Figure 5: Multitenant Light Commercial Archetypes

Source: UC Davis EEC

Building Characterization of Target Market

Of the six key archetypes, the team focused on two archetypes for this project: convenience shopping centers and neighborhood shopping centers (also referred to as MTLC shopping centers). The team selected these two archetypes because they have been underserved, and numerous potentially cost-effective energy savings opportunities. Researchers did not focus on Main Street buildings because they are too complex to address energy efficiency without costly solutions because of their diversity of primary building activities. Researchers also did not focus on Office Parks and MUSH buildings because they already receive attention from industry and utilities. Finally, among shopping centers, the team did not focus on Community shopping centers because they are frequently anchored by big-box stores such as Walmart, Target, Home Depot, and so on and have their own corporate sustainability and energy efficiency initiatives, as well as the attention of utilities.

Data and Methods

To assess energy saving potential for MTLC shopping centers, the team created a database of building attributes. Unfortunately, there was no one source of building attribute data and the data available was not specific to convenience and neighborhood shopping centers. Therefore, the team created a database using multiple sources of data, which focused on all commercial parcels/buildings in California. The procedure consisted of five steps:

Step 1: Developed a stratified sample framework to select a representative group of buildings.

Using commercial parcel data, the team set out to select a representative group of 1000 MTLC buildings in California through stratified sampling. Researchers assumed that the number of buildings in a given area was proportional to the population in that area. The team stratified the buildings by climate zone to ensure that the amount of buildings from each climate zone in the sample was representative of the total MTLC buildings from that climate zone in the state (that is if climate zone #3 has 30 percent of California's population, then 300 buildings in the 1000 building sample would be from Climate zone #3). Once researchers determined the number of buildings required from each climate zone, they applied a similar population-based stratification to select the cities from which those buildings would be selected. The team produced a final list of 244 cities with a corresponding proportion of buildings representative of California climate zones and population distribution.

Step 2: Randomly selected buildings according to sample framework.

With the final list of cities, the team used the real estate database, ProspectNow, to randomly select commercial parcels from each city, creating a total of 1000 buildings/parcels (parcels can contain one or more buildings). ProspectNow lists property data associated with assessor parcel information from each California county assessor. Each parcel has an assessor parcel number that is the legal identifier for both the parcel owner and the county in which it is located.

Parcel information from county assessors includes property owner information. Researchers integrated the ProspectNow information with other databases to provide phone numbers, property characteristics, and building owner and tenant information. The team preformed several iterations to achieve the target of 1000 parcels/buildings; in the building sample about 70 percent of the parcels had only one building a piece. Researchers then extracted and analyzed a sample of 1000 parcels to ensure compliance with the MTLC definition. The team manually verified parcel data using aerial maps (primarily Google and Bing Maps), and other online resources. In addition, researchers eliminated almost 20 percent of the parcels from the database for data quality issues (for example, incorrect addresses, no building on the parcel, not matching the MTLC definition) and replaced them with new parcels. After quality control processes, the team produced a final list that included 766 parcels and 945 buildings.

Step 3: Collected physical attribute data using aerial surveys.

The team collected individual physical attributes of the final 945 MTLC buildings by manually inspecting the aerial and street view functions of Google Maps. Researchers used an online area calculation tool to assess total square footage of buildings and parking lots.

Step 4: Collected physical attribute data using audits.

The California Conservation Corps (CCC), a state agency that places young men and women in positions where they work outdoors for a year to improve California's natural resources, conducted audits on 83 tenants in 53 buildings in northern California to gather physical attribute data that could not be collected remotely, such as via Google Maps. The UC Davis project team trained CCC auditors. The scope of these audits was comparable to an American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) level one audit (Appendix C for more information). Auditors collected extensive data on energy-related technologies, including existing interior and exterior lighting, building envelope, and thermostats.

Step 5: Collected physical attribute data using industry reports.

The team gathered further technical characteristics on MTLC buildings from Itron's California Commercial Saturation Survey (CSS) (Itron Inc., 2014). This survey collected and analyzed information on electric consuming measures, building characteristics, and business demographics. The team entered all identified MTLC building and tenant data into a Microsoft Excel-Access database. Data was standardized according to current industry practices whenever possible. Researchers eliminated Main Street buildings, MUSH buildings, and Office Parks to analyze only MTLC shopping centers. The resulting list included 428 buildings and 2,885 tenants. These buildings were further divided into small (0-30,000 sq-ft) and medium (30,000-160,000 sq-ft) buildings. Researchers then used this database to understand the current MTLC shopping center market. This analysis included average number of tenants in a particular sized building, number of HVAC rooftop units (RTU's) per building, shape and orientation of building, roof color, and so on.

Database Findings and Implications

Building Size Characteristics

Using a 30-building subset of the data, Table 4 displays an analysis of the overall size distribution of shopping center buildings in the MTLC database. The table indicates that most buildings fall into the categories of "convenience" and "neighborhood" shopping centers, collectively comprising 65 percent of all shopping center buildings. It also confirms that a majority of the buildings are small and medium-sized, cumulatively making up 96 percent of all the shopping center buildings in the database. Small-sized buildings are categorized as those between 0 and 30,000 square feet, medium-sized between 30,001 and 160,000 square feet, and large-sized above 160,001 square feet.

This data highlights the importance of focusing on convenience and neighborhood shopping centers when developing retrofit solutions.

Table 4: Distribution of Buildings by Size and Shopping Center Type

Shopping Center Type	Small	Medium	Large
Convenience	41%	0%	0%
Neighborhood	19%	5%	0%
Community	23%	8%	4%
Total	83%	13%	4%

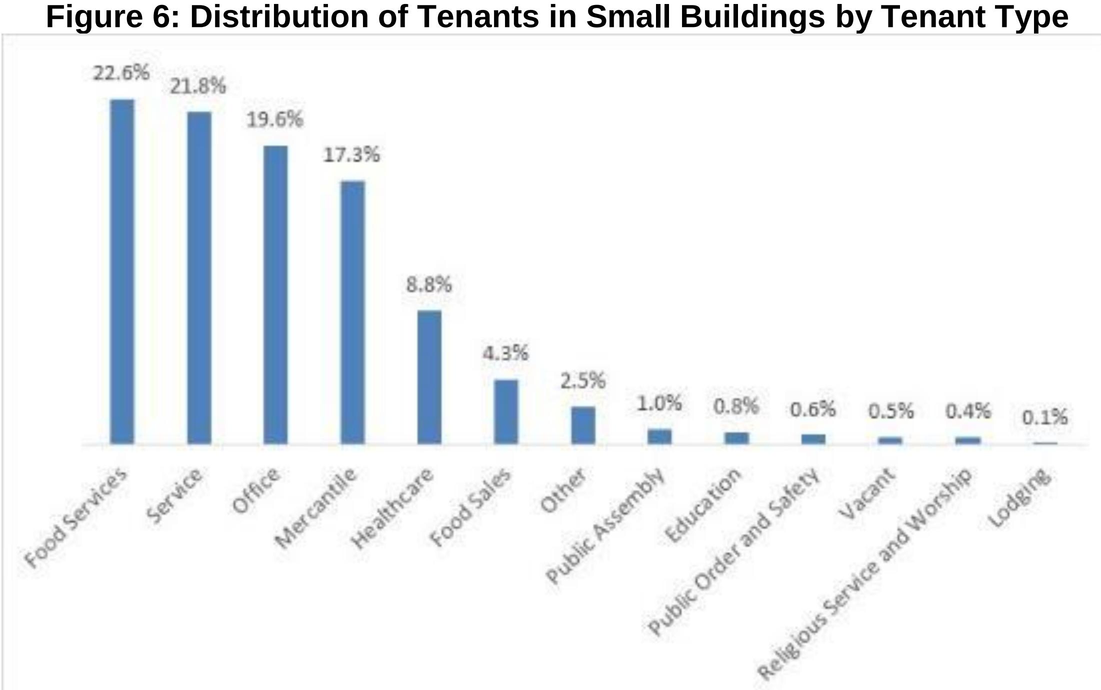
Source: UC Davis EEC

Nonphysical Building Characteristics (Number of Tenants & Tenant Type)

The team evaluated the average number of tenants per building. In small buildings there was an average of 6 tenants and in medium there was an average of 9 tenants. This suggests that, across the board, in small and medium shopping center buildings, there are multiple tenants and thus there is potential for reducing retrofit costs by employing solutions at the building scale instead of targeting individual tenants.

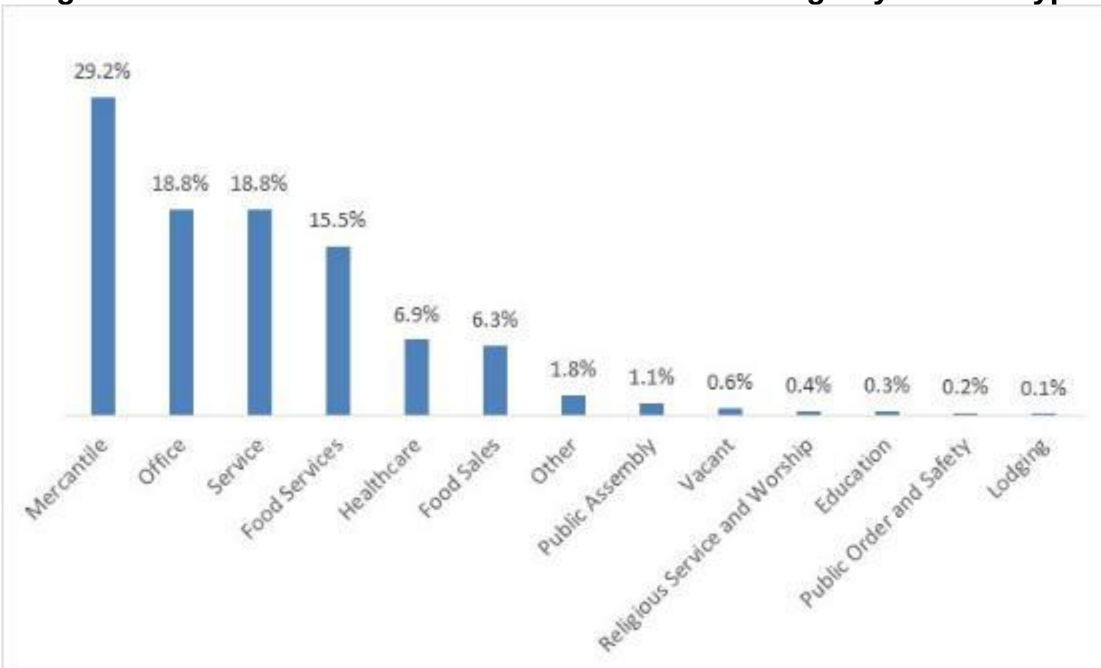
Figure 6 and Figure 7 show tenant type distributions within the small and medium building segments. In both segments, there was a high percentage of food service, service, office, and mercantile buildings, indicating these particular primary building activities should be considered when developing energy conservation measure packages for the MTLC shopping center market.

Figure 6: Distribution of Tenants in Small Buildings by Tenant Type



Source: UC Davis EEC

Figure 7: Distribution of Tenants in Medium Buildings by Tenant Type



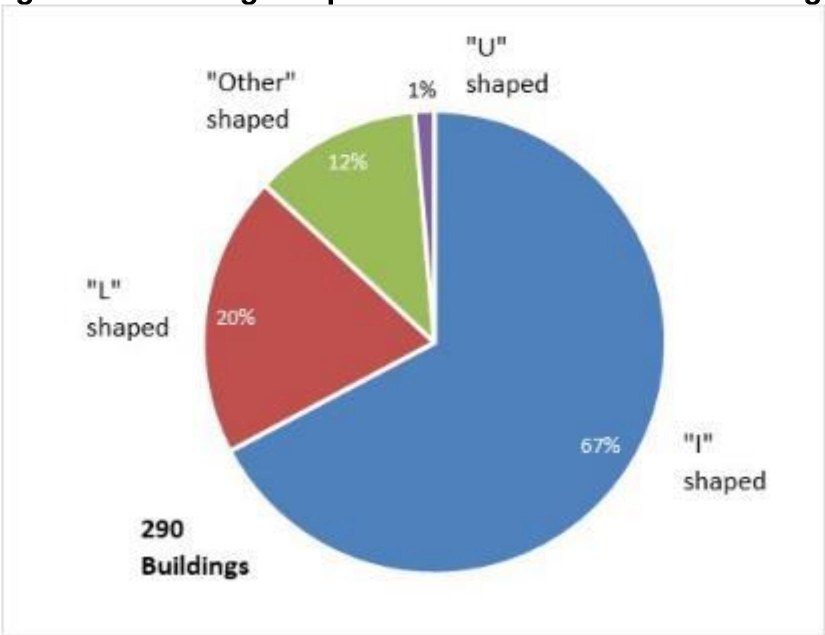
Source: UC Davis EEC

Physical Building Characteristics (Building Shape, Orientation, Roof Color, and Energy-Related Technologies)

Building shape plays an important role in heating and cooling of building rooms. A building with a given volume and building orientation will heat up or cool down differently depending on if that building has a high surface area (such as with "I" shaped buildings with high aspect ratios) or low surface area (such as with a square shaped building, which is not common for shopping center buildings). Figure 8 and Figure 9 detail building shapes in the MTLC building database. Buildings were grouped into four different shapes: "I," "L," "U," and "Other." Most buildings were "I" shaped, overall, as well as within each of the building segments in the collected data (small and medium), which indicates that these buildings may be easier to heat or cool down than other types of buildings.

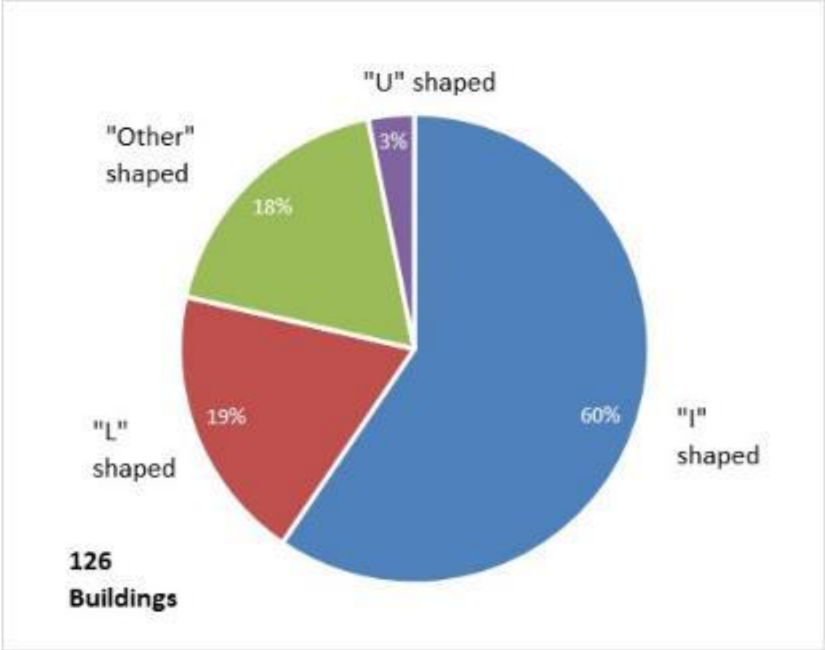
Building orientation and building shape, is crucial for passive solar applications (daylighting, natural heating in winter, and so on), which can be incorporated into virtually any building design, depending on the climate zone. South-facing buildings are ideal for passive solar applications, followed by southwest and west-facing buildings. Figure 10 and Figure 11 show the orientation of database buildings. The team found that roughly 16 percent of all of California's commercial buildings face south, with 16 percent of small and 15 percent of medium buildings facing south. This data highlights the importance of considering building orientation in MTLC building energy conservation measures.

Figure 8: Building Shape Distribution of Small Buildings



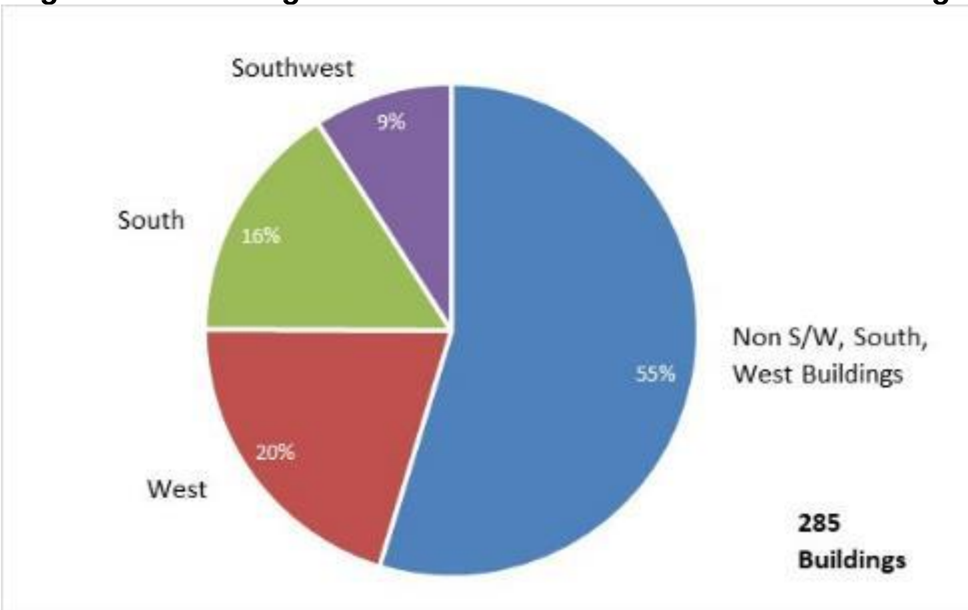
Source: UC Davis EEC

Figure 9: Building Shape Distribution of Medium Buildings



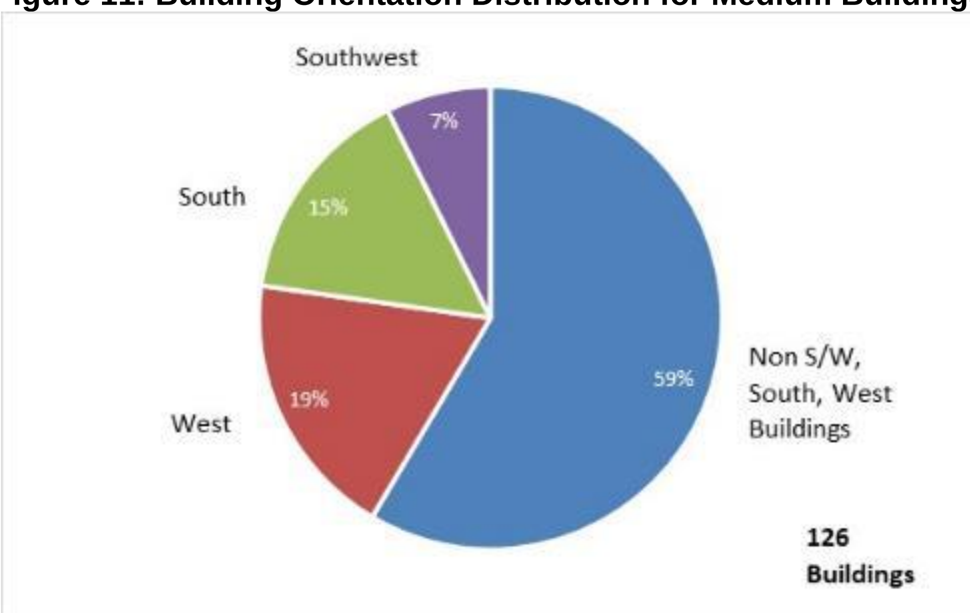
Source: UC Davis EEC

Figure 10: Building Orientation Distribution for Small Buildings



Source: UC Davis EEC

Figure 11: Building Orientation Distribution for Medium Buildings

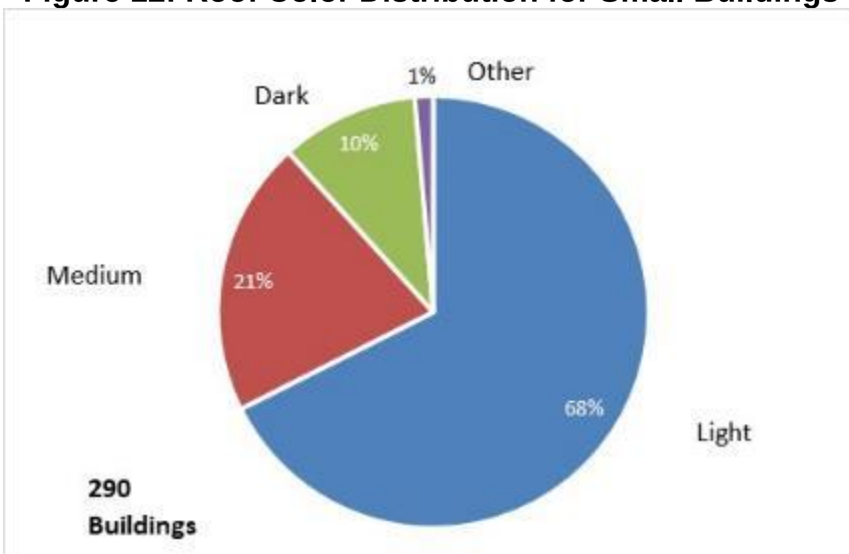


Source: UC Davis EEC

Researchers analyzed roof color data to understand current energy use and potential savings. Roof color has a strong effect on the sun's impact on a building and on the indoor building temperature, particularly in hot regions with high solar intensity. Light colored roofs reflect more heat and generally have lower indoor building temperatures. The team evaluated the data to understand the percentage of buildings that had light, medium, or dark colored roofs. Light colored is considered to be white; medium colored is multiple shades of grey; and dark colored is somewhere between dark grey and black.

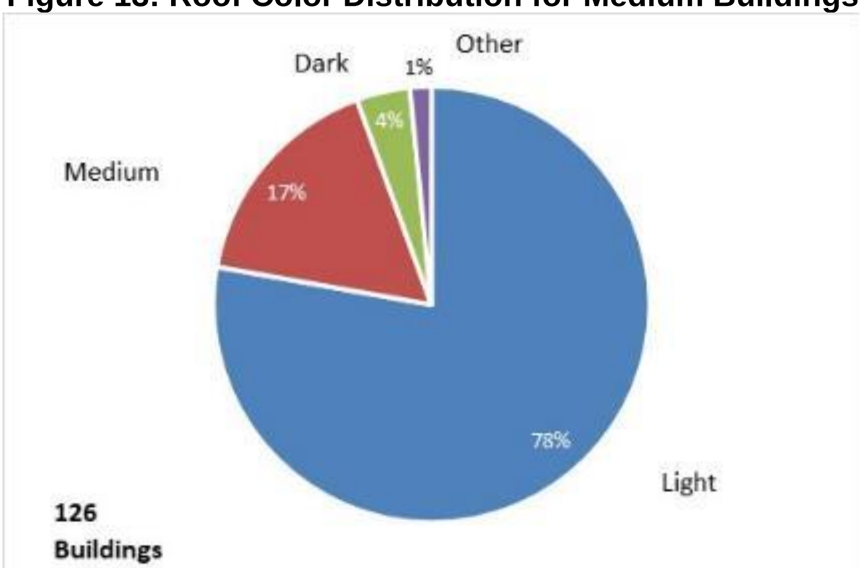
Figure 12 and Figure 13 show the roof color distribution of small and medium buildings, respectively. Across all building sizes, researchers found that light colored buildings make up more than half of the building population, indicating that changing roof color through the installation of highly reflective, white roofs is not a highly valuable energy conservation measure for MTLC shopping centers.

Figure 12: Roof Color Distribution for Small Buildings



Source: UC Davis EEC

Figure 13: Roof Color Distribution for Medium Buildings



Source: UC Davis EEC

Finally, the team characterized the presence of rooftop units (RTUs) in MTLC buildings using data from the CCC audits. While the audit sample size of 53 buildings was small, researchers found an average of nine RTUs in small buildings and 18 RTUs in medium buildings. This suggests the possibility of scale in bundling RTU services across all RTUs in a single MTLC building, as opposed to servicing one RTU at a time. Bundling services could also reduce contractors' time/cost to engage in the sales process.

Technology Characterization in Commercial Buildings

Lighting and HVAC systems are major end uses of energy in commercial buildings. Enormous energy savings are possible using energy efficient equipment, effective controls, and careful design.

Heating, Ventilation, and Air Conditioning

Cooling and ventilation account for more than 25 percent of the annual electricity consumption in California's commercial buildings. When natural gas use is also considered, HVAC typically accounts for more than 35 percent of a commercial building's annual primary energy footprint (EIA, 2012). Air conditioning is also the largest single contributor to peak electrical demand. Rooftop units are usually the single, largest connected load in a commercial building, and can account for more than 50 percent of its on-peak demand. California's electric grid is especially stressed during summer periods when generation requirements can be twice as high as other seasons.

Packaged rooftop air conditioners (RTUs) are predominately responsible for heating and cooling in commercial buildings. Rooftop units use technology that has not evolved at a pace in-line with efficiency improvements of other key end-use systems such as lighting. In addition, the RTU lifetime may be quite long, on the order of 25-30 years, meaning that existing systems, on average, are far less efficient than current technology.

Lighting

Lighting is one of the largest electricity loads in commercial buildings, representing about one third of commercial electricity use (Itron Inc., 2006). Lighting in most MTLC spaces consists of one or two lighting layers: ambient lighting and task lighting. The ambient layer is composed of general, uniform lighting that illuminates a majority of the tenant space. The second layer, task lighting, is typically installed in the form of spotlights, which focus light in a small area. In retail and food service establishments this lighting is typically meant to illuminate displays or highlight product. In the service sector, task lighting may be used in specific areas to supplement the general ambient lighting for specific service activities. Outdoor lighting at most MTLC buildings consists of parking lot lighting, select-area (spot) lighting, sign lighting, and exterior, building-mounted wall packs.

Heating, Ventilation, and Air Conditioning and Lighting Characterization

To characterize lighting and HVAC technology in MTLC buildings, the team used data and results from Itron's CSS (Itron, 2014). Instead, however, of using the building designation sizes of "small" (0-30,000 sq-ft), "medium" (30,000-160,000 sq-ft), and "large" (more than 160,000 sq-ft), as in the team's analysis, Itron classified buildings by electricity consumption as:

- "Very small" – sites with annual usage less than or equal to 40,000 kWh.
- "Small" – sites with annual usage greater than 40,000 kWh and less than or equal to 300,000 kWh.
- "Medium" – sites with annual usage greater than 300,000 kWh and less than or equal to 1,750,000 kWh.
- "Large" – sites with annual usage over 1,750,000 kWh.

The energy consumption for commercial buildings can be converted to a crude estimate of sq-ft using energy intensity values, or kWh consumed per sq-ft (13.63 kWh per sq-ft). Using these calculations, researchers found that "very small" and "small" buildings in Itron's analysis were roughly equivalent to buildings under 22,000 sq-ft, and "medium" buildings were roughly equivalent to buildings under 130,000 sq-ft. Although these revised categories did not match up perfectly with the building labels in the team's analysis, Itron's data was the best tool available for understanding lighting and HVAC technology in California commercial buildings.

It is also important to note that Itron's CCS was a phone survey and the results presented here have been weighted by site weight. In the tables below, "*n*" represents the number of surveyed sites included in the analysis. The on-site sample was stratified and weighted to most accurately represent the population in order to reduce any potential response bias.

Table 5 details the percentage of businesses by size with a given lighting technology.

Table 5: Share of Businesses with a Given Technology for Indoor Lighting, by Business Size

Technology Type	Large	Medium	Small	Very Small
Linears	100%	100%	99%	91%
Incandescents	38%	36%	48%	49%
Halogens	42%	22%	20%	18%
CFLs	82%	74%	67%	59%
LEDs	16%	13%	8%	2.2%
HIDs	32%	19%	9%	4.5%
Other	0.3%	1.0%	1.1%	0%
n	97	463	484	392

Source: Itron, Inc.

Itron found lower use of compact fluorescents (CFLs) and high-intensity discharge lamps (HIDs) in the two smallest categories compared to medium and large businesses. They also found higher use of incandescent lamps in very small and small buildings (49 percent and 48 percent, respectively) compared to medium and large buildings (36 percent and 38 percent, respectively).

Table 6 shows the share of lamps for individual lighting technologies by business size. Very small and small businesses have the lowest share of linear lamps, but the highest share of ICLH (incandescent, compact fluorescent, light emitting diode, or halogen) lamps. Very small, small, and medium businesses also have few HID lamps, while large businesses have a comparatively high percentage (4.4 percent) of its indoor lighting made up of HID technology.

Table 6: Indoor Lighting Technology Distribution by Building Size

Technology Type	Large	Medium	Small	Very Small
Linears	82%	90%	80%	76%
ICLH Pin- and Medium Screw-Based	13%	8%	16%	20%
ICLH Other Base	0.6%	0.8%	2.7%	2.8%
HIDs	4.4%	0.6%	0.5%	0.4%
Other	<0.1%	<0.1%	0.1%	0%
Total	**100%**	**100%**	**100%**	**100%**
n	**97**	**463**	**484**	**392**

Source: Itron, Inc.

Table 7 shows the share of indoor lamps by control type for the various business sizes. Large businesses have the highest distribution of lamps controlled by motion sensors and energy management systems (EMS) compared to the smaller business sizes. Unsurprisingly, as they have few, other lighting control technologies, smaller buildings have a substantial number of manual controls for indoor lighting (86 to 96 percent) whereas large buildings have 39 percent.

Table 7: Indoor Lighting Control Technology Distribution by Building Size

Control Type	Large	Medium	Small	Very Small
Manual	39%	76%	86%	96%
Manual w/Occ. Sensor	0.7%	1.4%	0.5%	0.3%
EMS	29%	9%	3.6%	0%
Photocell and Motion Sensor	2.9%	0.4%	3.7%	0.1%
Motion Sensor	20%	11%	5%	2.7%
Continuous On	1.7%	0.5%	0.4%	0.2%
Photocell and/or Timeclock	4.0%	2.7%	0.9%	0.1%
Daylighting and other	1.8%	0.2%	<0.1%	0.1%
Total	**100%**	**100%**	**100%**	**100%**
n	**97**	**463**	**484**	**392**

Source: Itron, Inc.

The Itron analysis also evaluated outdoor lighting distribution according to business sizes. As seen in Table 8, CFLs are the most common technology for very small businesses and small businesses at 64 percent and 41 percent, respectively. For medium and large businesses, linear lamps compose the largest portion of outdoor lighting at 40 percent and 57 percent, respectively, followed by a sizable portion of HIDs and CFLs.

Table 8: Outdoor Lighting Technology Distribution by Building Size

Technology Type	Large	Medium	Small	Very Small
Linears	57%	40%	25%	5%
CFLs	18%	20%	41%	64%
Incandescents	0.7%	5%	12%	10%
Halogens	0.3%	1.8%	3.5%	9%
LEDs	1.2%	1.4%	0.8%	3%
HIDs	21%	31%	16%	9%
Other	2%	1%	1.0%	0.2%
Total	**100%**	**100%**	**100%**	**100%**
n	**84**	**393**	**339**	**164**

Source: Itron, Inc.

Table 9 displays the distribution of outdoor lamps controlled by particular technology types according to business size. In contrast to indoor lighting controls, Itron found businesses use photocells and/or time clocks as the most common outdoor lighting control technology. It is also interesting that a sizable portion of outdoor lamps for large businesses are controlled by EMS.

Table 9: Outdoor Lighting Control Technology Distribution by Building Size

Control Type	Large	Medium	Small	Very Small
Manual	19%	16%	18%	13%
EMS	16%	8%	0.4%	0%
Photocell and Motion Sensor	0.6%	1.4%	0.8%	3.3%
Motion Sensor	9%	0.5%	2.7%	1.8%
Continuous On	3.8%	9%	0.4%	0.2%
Photocell and/or Timeclock	51%	63%	78%	82%
Daylighting and other	0.4%	1.2%	<0.1%	<0.1%
Total	**100%**	**100%**	**100%**	**100%**
n	**84**	**393**	**339**	**164**

Source: Itron, Inc.

Finally, another major technology that the Itron analysis characterized in commercial businesses was HVAC. In Table 10, Itron characterized HVAC units according to business sizes, both by HVAC unit zoning, as well as a breakdown of those single zone units. "Zoning" refers to the ability to have separate temperature controls in different parts of a building. Results show that very small and small businesses have substantially higher single zone HVAC technology relative to medium and large businesses.

Table 10: HVAC Technology Distribution by Building Size

Efficiency Level	Large	Medium	Small	Very Small
Single Zone	79.5%	82.4%	97.9%	99.9%
Multi Zone	20.5%	17.6%	2.1%	0.1%

Source: Itron, Inc

Table 11: HVAC Technology, Single Zone Unit Distribution by Building Size

	Large	Medium	Small	Very Small
Package Single Zone	62.1%	60.1%	67.5%	47.8%
Unit Ventilator	2.6%	2.3%	5.9%	14.8%
Split Single Zone	5.0%	10.9%	15.2%	11.5%
Package Terminal Unit	2.4%	2.4%	3.7%	13.1%

	Large	Medium	Small	Very Small
Mini Split System	5.6%	4.5%	2.3%	4.1%
Baseboard Radiant Heater	0.2%	1.7%	1.7%	3.9%
Other Single Zone Systems	1.5%	0.6%	1.6%	4.7%
n	2,517	8,341	2,861	583

Source: Itron, Inc.

The data in Tables 10 and 11 suggests that MTLC buildings which are primarily small and very small buildings have largely single zone packaged units serving the spaces and hence the retrofits options should primarily target those systems.

Energy Efficiency Program Characterization of Target Market

To identify opportunities for deep energy savings for MTLC shopping centers, the team characterized utility energy efficiency programs, energy efficiency audit programs, and retrofit technologies included in utility programs.

Data and Methods

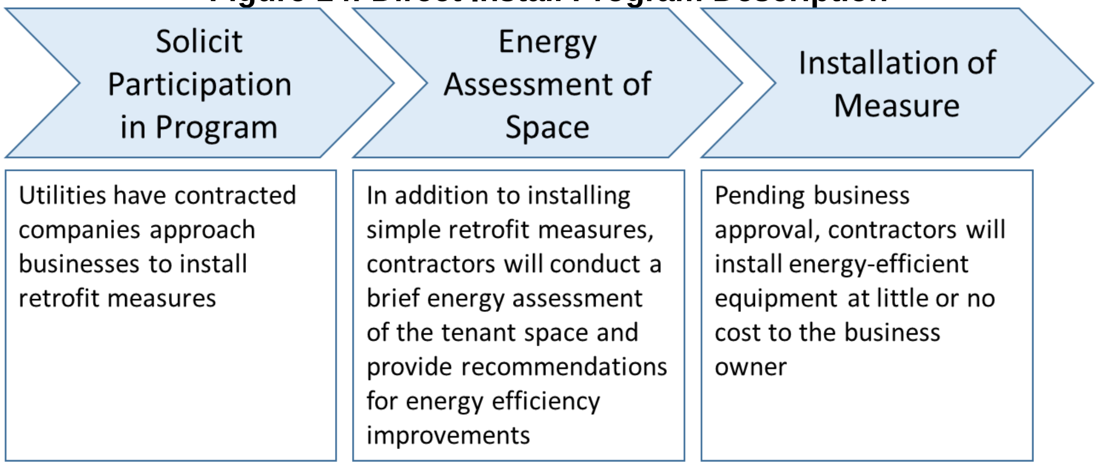
To characterize the existing efficiency programs, the team reviewed published information regarding programs on all three IOU websites as well as reviewed published reports on California Public Utilities Commission's website. The findings are summarized in the reminder of this section.

Findings and Implications

Utility Energy Efficiency Programs

The team characterized how utilities currently work to implement energy saving programs in MTLC shopping centers. There are several types of utility programs working to implement energy efficiency measures in California. However, many contractors work through incentive, rebate, or other third-party programs and do not typically approach MTLC buildings directly (aside from office and MUSH buildings) due to lack of financial incentive. The main tool currently used to address energy efficiency measures for hard-to-reach customers, like MTLC shopping centers, is direct install programs (Jayaweera & Haeri, 2013). Figure 14 briefly describes direct install programs.

Figure 14: Direct Install Program Description



Source: UC Davis EEC

Direct Install Programs

A direct install (DI) program's core mission is to lower peak demand and meet utility energy efficiency goals. DI programs accomplish this mission by pursuing energy savings, for a variety of sectors, through the delivery of low-cost and free energy efficiency upgrades and retrofits via installation contractors, acting on a utility's behalf. The programs emphasize financial savings and ease of implementation.

After a resident or business enrolls in a DI program, contractors, acting on a utility's behalf, perform energy audits and provide recommendations on energy efficiency upgrades for various technology types, including HVAC, lighting, and refrigeration. The contractor then provides low-to-no-cost energy-efficient products and free installation, pending approval from the business. The installation of energy efficiency upgrades is free or offered at a reduced cost due to the incentives and rebates provided by the local utility. Payments are made to the contractor, or third-party vendor, who provides energy efficiency services to offset its bill to the end customer. At some utilities, instead of having the rebate payment sent to the contractor, the business/building owner can choose to pay the trade contractor the entire amount at the time of service and have the rebate sent directly to the business/building owner.

Although this program has the benefits of no-cost retrofit technologies for businesses and a simple implementation process, it has several shortcomings.

- The business model for DI programs is not centered on pursuing DER savings for tenants, but on accruing sufficient savings to meet utility energy efficiency goals. The energy audit conducted by the contractor is limited to understanding how to implement a fixed set of measures with known savings and return on investment.
- DI programs are funded by the utility to provide low-to-no-cost retrofit technologies and limited savings, not more expensive and comprehensive deep energy savings for tenants.

- DI programs do not account for the interactive effects of multiple retrofit measures implemented together, as they estimate savings for each measure individually.
- DI programs are limited by the requirement of meeting the cost effectiveness total resource cost (TRC) test. The TRC test compares the benefits to society as a whole with the cost of installing the identified measure. More expensive energy efficiency measures, such as upgrading HVAC systems, are generally not implemented through this program.
- DI programs depend on the Database for Energy Efficient Resources (DEER) to estimate energy savings, and thus tend to inaccurately measure savings.[1]
- Core technologies of DI programs in California are centered on lighting, refrigeration, and HVAC upgrades (rarely whole system HVAC upgrades). In addition, typical measures for small businesses include linear fluorescents, screw-in LED lamps and ballasts, LED display case lighting and open/close signs, window film, occupancy sensors, and vending misers.
- Small business programs historically have modest participation rates, as many programs are budget constrained (York et al., 2013).

As a result of these limitations, current DI programs provide incomplete energy savings.

Energy Audits

Audits play an important role in the implementation of energy efficiency retrofit projects. As part of the direct install program process, for example, an energy audit takes place. While there is no standardized audit process, the ASHRAE guidelines for energy audits in commercial buildings are designed to be universally applicable. The guidelines define the level of effort required for an energy survey; illustrate best practices to perform an audit; specify tools, methods, and procedures; and provide a series of sample spreadsheets to collect data. The ASHRAE definition of "level of effort," which describes the goals and depth of the investigation, is widely referenced in the literature and used as a standard for audit practices (see Appendix C for more information). There are three levels of effort for an energy audit, as well as a preliminary energy-use analysis.

ASHRAE and the Association of Energy Engineers (AEE) offer courses on conducting energy audits as well as a certification process to become a Building Energy Assessment Professional (BEAP) and Certified Energy Auditor (CEA).[2,3] PG&E also offers audit-

1 California Public Utilities Commission Database for Energy Efficiency Resources (http://www.deeresources.com).

2 http://www.aeecenter.org/i4a/pages/index.cfm?pageid=1.

3 https://www.ashrae.org/education--certification/certification/building-energy-assessment-professional-certification.

related classes through the energy education program at the Pacific Energy Center in San Francisco. These free classes target energy professionals, contractors, building managers, and any other parties interested in understanding the audit process.

Available audit resources do not specifically target MTLC buildings, leaving several unique issues and characteristics of this sector unaddressed.

- Audits do not tackle the split incentives problem that often occurs when the tenant pays the energy cost directly and the owner maintains and upgrades equipment. Although the energy analysis is not influenced by this problem, how the information is communicated can impact the retrofit decision after the audit.
- The ASHRAE procedure is quite general and is meant to apply to any size building however, the time (and cost) of an audit is largely independent of the site size and as a result audits might not make financial sense for small businesses.
- MTLC buildings are difficult to benchmark in terms of energy use because a single building might include several very different tenants, such as restaurants and retailers, making it difficult to define the building's "principal activity."

The ASHRAE manual specifies how to collect data, what tools are necessary, the people that need to be involved, and how to identify potential retrofit opportunities. The three-day PG&E class titled "Energy Auditing Techniques for Small and Medium Commercial Facilities" extensively describes how to measure energy use and estimate savings for each of the main energy systems in a facility.[4] Best practices for the different phases of an energy audit are listed in Appendix C.

Existing Energy Audit Programs

The big three California IOUs (PG&E, SCE, and SDG&E) each have a variety of audit programs and energy analysis tools that are applicable to MTLC building owners and tenants. Information regarding these services is available online and the majority of programs allow customers to participate by logging into their account on the utility's website. Services range from short online surveys, where customers provide basic information about their buildings and monthly bills in exchange for generic energy-saving recommendations to detailed, on-site audits that require benchmarking and advanced measurements. The audit programs are closely aligned with the utilities' other rebate and incentive programs and aim to guide customers to other programs for which they are qualified. While some programs are standardized across the state, there is some variability in the types of audit services offered by the different utilities. In Appendix C, the team describes major California IOU audit programs, as well as those in municipal utilities and third party programs. The traditional energy audit process is represented in Figure 15.

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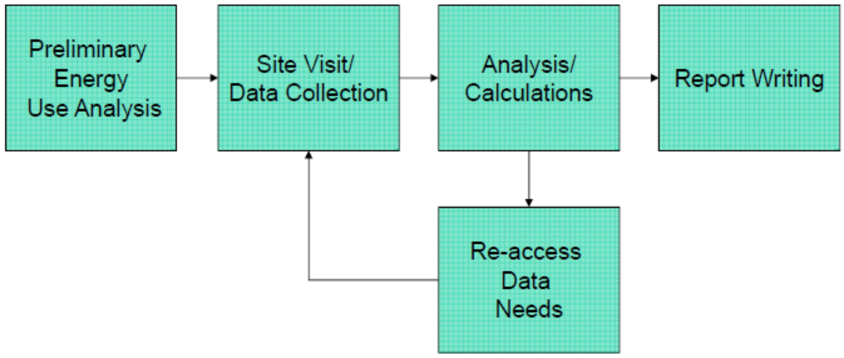
4 http://www.energy.wsu.edu/documents/omchecklists.pdf.

Figure 15: Energy Audit Process Schematic



Source: Pacific Gas & Electric, 2011

Energy Audit Cost

There are few reliable sources about the average cost of an energy audit. The CEC published a report in 2000 describing the process of hiring an energy auditor (CEC, 2000). The cost figures in the report are old and represent 1997 costs and tools available at the time and do not match the ASHRAE classification. However, they are among the few publicly available sources (see Table 12). Using these values, an energy audit including lighting, HVAC, and controls for a 100,000 sq-ft building would cost $12,000 on average, and an audit for a 1,000 sq-ft building would cost $120 (in 1997 dollars). The report explains that costs for small buildings are higher, but it does not provide accurate estimates for very small sites.

A more recent online source addresses the problem of estimating audit costs for small buildings by adding a minimum cost for the audit:[5]

- Level 1: $ 0.025 / per square foot ($600 minimum)
- Level 2: $ 0.05 / per square foot ($1,500 minimum)
- Level 3: $ 0.10 / per square foot ($5,000 minimum)

With these values, a level 2 audit for a 100,000 sq-ft facility would cost $5,000, and one for a 1,000 sq-ft facility would cost $1,500.

Very few private companies publicly disclose the price of their audits, but private conversations with consultants confirmed that energy audits for small buildings are rarely performed because they are very expensive in proportion to the potential savings. This prohibitively high cost, along with split incentives, are one of the reasons that discourages small buildings and businesses from pursuing energy efficiency retrofit projects, especially deep energy retrofits.

5 Michigan GREEN, 2011. The 5-minute Energy Audit Primer. http://www.michigangreen.org/pdf/michigan-green-energy-audit-primer.pdf.

Table 12: Typical Cost for Energy Audits in 1997 Dollars

Type of Audit	Typical Cost (1997 $/sq.-ft.)
Preliminary audits	$0.013 to $0.03
Single purpose audit	$0.03 to $0.07 (lighting) $0.05 to $0.09 (HVAC and controls)
Comprehensive audit	$0.18 to $0.50 (less than 50,000 sq-ft) less than $0.12 (more than 250,000 sq-ft)

Source: California Energy Commission, 2000

Retrofit Technologies Included in Utility Programs

Retrofit technologies offered in rebate programs are similar across utilities; they include lighting (linear fluorescent, accent and directional, CFLs, induction, HID), lighting controls (occupancy sensors, timers), water heaters, kitchen equipment, HVAC (mostly higher efficiency units), refrigeration equipment, and other appliances. There are no rebates that consider the effect of "integrated packages" and these solutions need to be approved through customized retrofit applications. Table 13 describes the availability of rebates for some of the technologies evaluated in this MTLC project. Technologies are categorized as being included in deemed savings programs, where pre-determined kW, kWh and/or therm savings are attributable to energy efficiency measures in a particular type of application, or as part of a customized program.

Table 13: Technologies Under Evaluation for the Project and Type of Utility

MTLC Project Technology	Type of Program
HVAC replacement	D/C
RTU retrofit kits (economizer, VFD)	C
Evaporative Pre-Coolers	C
Advanced HVAC Controls	C
Duct Sealing	C
Compressor Downsizing	C
Window Films	D/C
Skylights	C
Shading Devices	C
Lighting Controls	D/C
Exterior lighting	D/C
Interior lighting	D/C

Program technologies are currently included in (D=deemed savings, C=customized program)

Source: UC Davis EEC

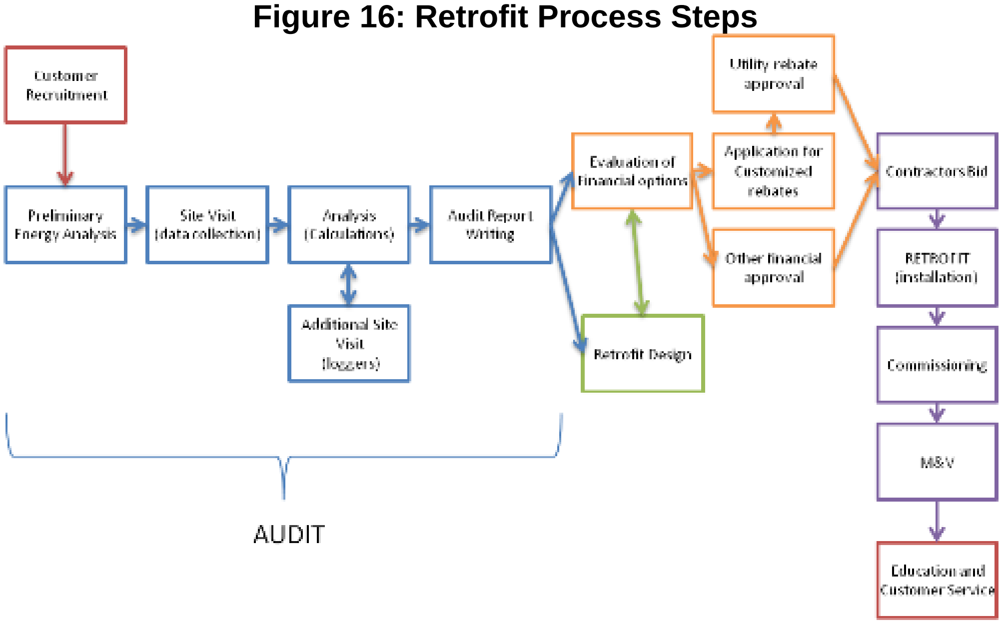
Broader Implications for Multitenant Light Commercial Project

Figure 16 shows the different phases of the retrofit process. In the broader sense, the whole retrofit process, including the cost for the audit, should make economic sense. It is important to note that in the most general case, the actual installation of the retrofit technology is only one of several steps in the retrofit process. For small businesses, this process can become complex and overwhelming, thus becoming an insurmountable barrier. The complexity of the process, coupled with split incentives and a low potential for energy savings, prevents mass deployment of retrofits in small businesses, including those located in MTLC buildings. When developing an integrated solution for MTLC buildings, sufficient attention should be dedicated to streamlining the retrofit process. Key issues for small and medium-sized customers appear to be:

- The cost of customer acquisition of the energy savings measures.
- The cost of energy analysis.
- The design/engineering of customized solutions.
- Required utility approval before installation of customized retrofits and the need for monitoring and evaluation, which increases the cost.

DI programs currently provide a limited set of inexpensive retrofit measures. This project developed a program for MTLC shopping centers that significantly advances energy efficiency retrofit projects. The program would result in implementing more retrofit measures than DI programs, account for interactive effects, and also reduce costs for, and increase access to, more expensive measures such as energy audits and HVAC retrofits.

Figure 16: Retrofit Process Steps



Using California customized retrofit rebates.

Source: UC Davis EEC

Stakeholder Perspective and Analysis

In addition to charcterizing the technical and market characteristics of MTLC shopping centers, it is critical to understand the market barriers to achieving deep energy savings. While there are a number of targeted programs and efforts aimed at building tenants, efficiency gains have remained modest. Existing literature agrees that barriers facing small commercial customers include difficulties in stakeholder engagement, high costs and lack of capital, split incentives, and time constraints (Lee et al., 1999; Wellinghoff et al., 2000). The current process for implementing DER is also very complex. The success of any retrofit solution strategy will rely on how well these barriers are addressed. What may appear as a simple, actionable solution will ultimately fail in effecting market transformation if it does not take into account the multitude of barriers facing stakeholders. For instance, providing free audits to building owners changes little if they are not also provided with assistance in lowering cost barriers and navigating the logistics of retrofit projects (Living Cities & Institute for Sustainable Communities, 2009).

To improve understanding of the MTLC market and barriers to achieving deep energy savings, the team gathered information about stakeholder perspectives and attitudes through a combination of interviews and questionaires. Researchers also collected stakeholders' recommendations for overcoming barriers.

Data and Methods

The team used primary data collected by the UC Davis EEC through a series of targeted interviews and statewide deployment of a questionnaire aimed at business owners.

Interviews

Researchers conducted individual interviews with representatives of key MTLC stakeholder groups: building owners, utilities, financing institutions, third-party implementers, non-profit researchers, industry associations, and regulatory agencies. The interviewees were comprised of members serving on the MTLC program advisory committee (PAC), industry experts recommended by the PAC members, and through the general network of industry contacts associated with the EEC (Appendix B). Some interviewees worked directly within the MTLC market, while others offered perspectives based on their experiences with similar markets. The interviews, which followed a scripted questionnaire and lasted approximately 30 minutes, were recorded, transcribed, and coded to identify themes and key findings. Researchers asked stakeholders to comment and offer their perspective on five areas:

- State of the MTLC market.
- Program implementation serving the MTLC market: what's working and what isn't?
- Financing barriers and options.
- Regulatory/Jurisdictional Issues.

- Future events or technologies that might affect the market.

Interviews are referred to in this report as "EEC interviews."

Questionnaires

Researchers distributed a one-page questionnaire to 5,500 tenants of MTLC buildings throughout California. Business names and addresses of MTLC tenants were collected through property databases and web research as part of developing the MTLC building attribute database. Several questionnaires were administered to tenants in person by CCC team members while they were conducting building audits. Though business owners were targeted, in cases where the business operated on a larger corporate or franchise level, business managers were often the highest-ranking employee available to answer the questionnaire. The team received and analyzed 113 questionnaire responses, though the completeness of the responses varied.

Stakeholder Analysis and Findings

In EEC interviews, stakeholders from utilities, finance industry, third-party implementers, non-profit researchers, industry associations, and regulatory agencies overwhelmingly agreed that there are great difficulties and numerous barriers in implementing deep energy retrofits in MLTC buildings. Table 14 provides a summary of barriers identified by representatives from several industry categories.

Table 14: Summary of Barriers Identified by Stakeholders in Interviews

Stakeholder	Perceived largest barriers
Utilities	Customer Outreach/Determining Decision Makers Program Implementation Codes/Regulatory Issues Education Lack of Communication Training
Building Owners	Underserved/No Small Customer Representative Split-Incentive Financing Leasing Return On Investment (ROI)
Tenants	Underserved/No Small Customer Representative Split-Incentive Financing Leasing ROI EE not Major Driver
Third Party Implementers	Customer Outreach/Determining Decision Makers

Stakeholder	Perceived largest barriers
	Education Financing Training
Industry Associations	Customer Outreach Leasing Financing EE not Major Driver

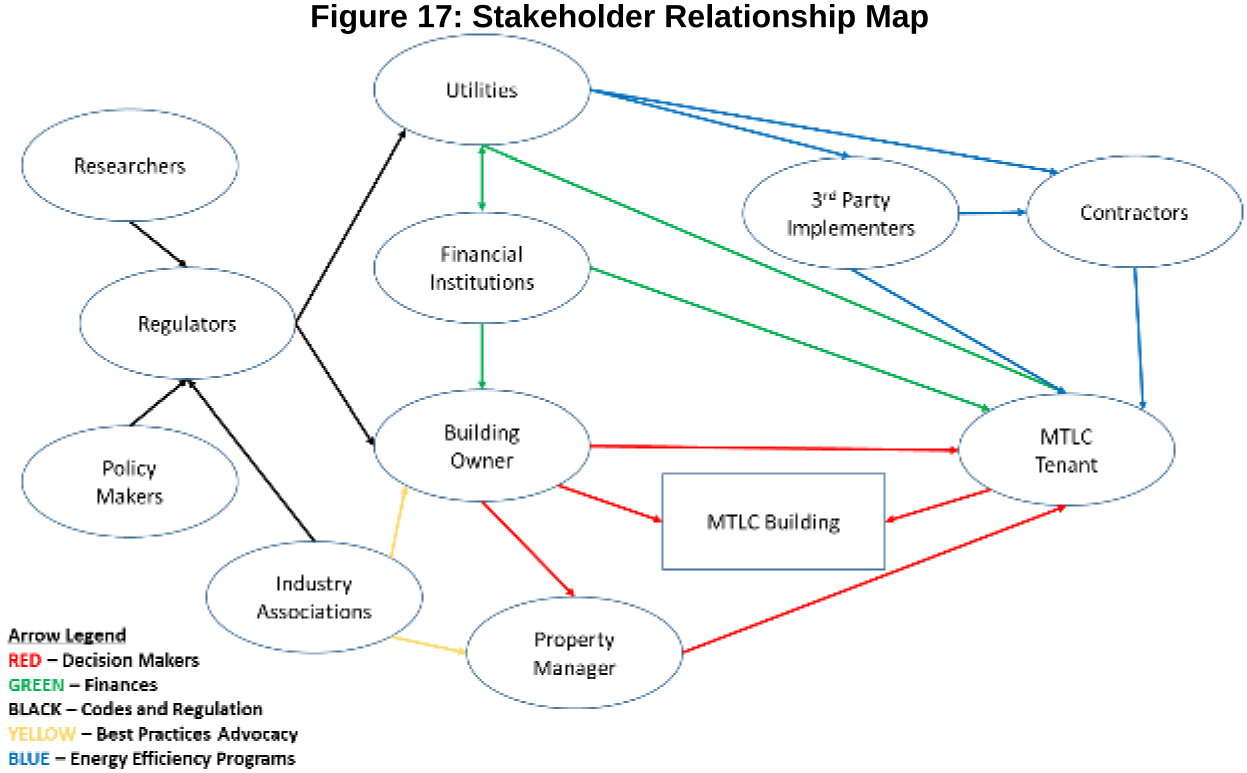
Source: UC Davis EEC

In the following sections, researchers describe, and detail the significance of, major barriers identified in EEC interviews, questionnaires, and existing literature. Key barriers include stakeholder engagement, split incentives, leasing structures, financing, information gaps, and time constraints (USDOE, 2013). These barriers often overlap and therefore must be addressed concurrently as much as possible.

Stakeholder Engagement

Implementing DERs in MTLC buildings is complex and requires engagement of many stakeholders. Figure 17 shows the complex and often convoluted relationship between the various parties who play significant roles in energy efficiency decisions in the MTLC building market.

Figure 17: Stakeholder Relationship Map



Source: UC Davis EEC

The main decision makers for DERs are the MTLC building owner and tenant. Often there is a property manager who acts as the owner's agent and facilitates communication with other stakeholders. Red arrows indicate building owner and MTLC tenant influence on the MTLC building space and the interplay between owners, tenants, and property managers. The green arrows reflect the relationship between the decision makers and the utilities or financial institutions that provide programs and financing options.

Industry associations, such as ICSC, have a multi-faceted role as they may inform and also disseminate knowledge of best practices in energy efficiency in the form of industry sustainability and energy efficiency processes, as well as policy recommendations. As industry associations represent property managers and owners, they strive to affect policy to benefit their members, as indicated by the yellow arrows. Researchers and policy makers (and to some extent industry associations) affect regulators who, in turn, affect the practices of utilities and the building owners, as indicated by the black arrows. Finally, utilities employ a combination of third-party implementers and contractors to implement energy efficiency programs and customer acquisition on the utilities' behalf, indicated by blue arrows.

The DER implementation process requires cooperation and coordination among several parties with conflicting goals. These parties must work together to prioritize and carry out energy efficiency in a cost effective manner that does not require much time commitment from the building owner and/or tenant and addresses the key barriers described in this chapter. Researchers found that more work needs to be done to engage the decision makers--building owners and tenants.

Utility Lack of Resources

With a highly complex network of stakeholders, diverse needs, and limited resources, the MTLC market is a challenging target for energy efficiency programs designed by utilities and carried out by contractors and third-party implementers. For example, as indicated by the CPUC's 2013-2015 Energy Efficiency Program Plan, light commercial buildings represent over 90 percent of SCE's and SDG&E's customer base, yet on average, less than 3 percent are participating in energy efficiency non-residential programs (CPUC, 2013). Current industry practices are lacking in the development and implementation of programs that successfully engage the MTLC customer, produce deep energy savings, and are cost effective enough to motivate all parties involved.

The team found that utilities have limited resources for designing effective programs that target MTLC customers. In EEC interviews, utility representatives agreed that the MTLC market is currently underserved. Respondents explained that the majority of utilities typically have customer representatives for over 400-500 kW usage, but do not communicate much with the smaller customer, like an MTLC tenant, unless the customer calls a customer service center and asks for program information. Only one utility representative said they had a department solely targeting customers who used 200 kW or less. As of fall 2013, that department was less than a year old, and it will be some time before its success can be measured. While some utilities are in the planning stages for programs to specifically support the MTLC customer, other utilities only offer typical direct install or prescriptive programs, which do not produce the transformative energy savings of DERs.

Customer Acquisition

The MTLC market has typically been served through DI programs administered by utility-approved contractors who contact tenants directly and offer free equipment installation. The programs usually include lighting, refrigeration door insulation, or occupancy controls, but the limited scope of these installations means they typically do not offer the extensive energy savings of a DER. Beyond DI programs, third-party implementers deliver a more inclusive service. Most companies offer an initial complimentary audit of the tenant space or building and recommend a retrofit package that will achieve the greatest savings. Some of the implementers will do the retrofits themselves and others use vetted sub-contractors to do the work. Business owners are often required to cover a portion of the cost and most third-party implementers are compensated based on projected energy savings.

Utilities perform customer outreach or acquisition in a variety of ways. Interviewed stakeholders described a range of communication methods, from including fliers in the utility bills to direct contact by contractors or third-party implementers, all directed at individual business owners. When asked about customer acquisition, one representative from a third-party implementer said, "It depends on the leasing structure and the duration of the lease. Sometimes they'll find a landlord or a property manager or owner that is really interested in energy efficiency and recognizes that it can be advantageous to them in terms of maintaining leasing, and attracting new tenants, and so on. They will then introduce us to all of the folks, all of their tenants within a building, and say, 'Hey look, this program is out there, you can get all this great stuff.' And then, on the other end of that, we'll have customers, particularly in the MTLC market, where they're leasing space and they're only willing to do a project that's going to pay back in two years."

Some utilities also have a hybrid program in which approved contractors offer DI programs, but get additional revenue for any additional energy efficient measures they can up-sell to the customer. However, MTLC customers are not as attractive to these energy services contractors and other vendors because they usually entail higher transaction costs and lower profit margins, and due to varied ownership structures, they may also encounter difficulties identifying and engaging decision makers (Rufo et al., 2004; STAMATS, 2013; York et al., 2013). In order for the installations to be profitable for the contractors, they try to convince all the tenants in one building to accept the upgrades to take advantage of economies of scale. This can be difficult, as customers often respond to free programs with skepticism. Additionally, as the installations are free, the business owner may have no vested financial interest in the permanence of the new equipment. For example, some utility program managers reported hearing that installed energy efficient lighting fixtures and lamps had been torn out because the business owner did not like the color, or had changed the purpose of the space where they were installed.

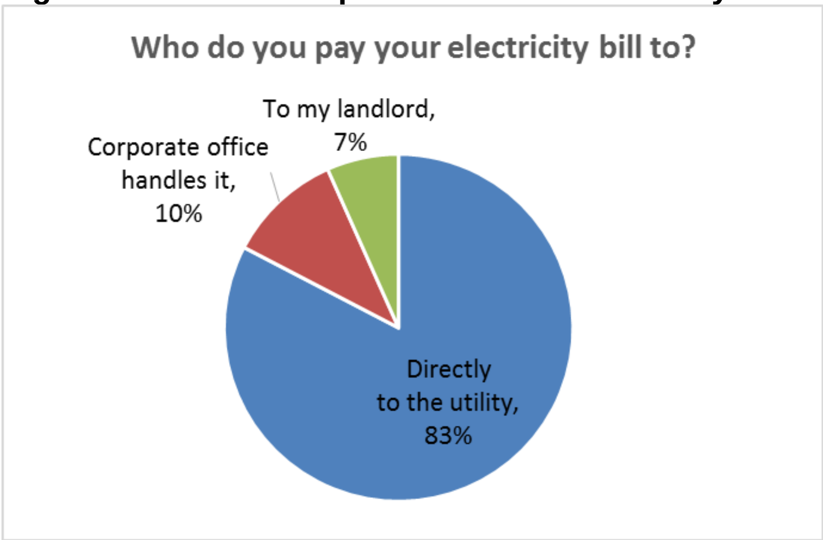
In regard to building owners, energy efficiency customer acquisition may be difficult because of misaligned time frames—that is, the times when higher property values are important do not line up with the times during which implementing DER is achievable. If the owner is selling the building soon, they may not want to invest in a long-term method of increasing property value. In contrast, if the owner is not planning to sell the building for a very long time, they may not be interested in investing in increasing property values now (Jewell, 2002).

Split Incentives

Split incentives, sometimes called "principal-agent" problems, are the result of an agency issue whereby two parties engaged in a contract have incompatible economic incentives driving their behavior (Next Ten, 2010). This incompatibility prevents one party from taking an action that would benefit the other party. In the MTLC market, split incentives arise frequently between landlords and tenants when the individual responsible for making investment decisions is not the customer paying the energy bills (Living Cities & Institute for Sustainable Communities, 2009). One common scenario is that tenants pay their own electricity bills, but the landlord owns most or all building equipment and makes the decisions about any replacements or remodeling. The tenant has the incentive to pursue energy efficiency, but has no agency to do so; conversely, the landlord has the power to change building equipment, but has no immediate financial incentive to take action as improving the equipment lowers the utility costs that the tenant is responsible for. Even in cases where the tenant does have permission and resources to change building equipment, the issue remains that any changes to the building shell, lighting, and HVAC system are permanent, and therefore must be made by the owner.

In EEC tenant questionnaires, out of 75 questioned respondents, 83 percent said they paid their own electric bills directly to their utility. Though some said they paid bills through their landlord (indicating a lack of submetering), none said that the landlord was independently responsible for energy costs (Figure 18).

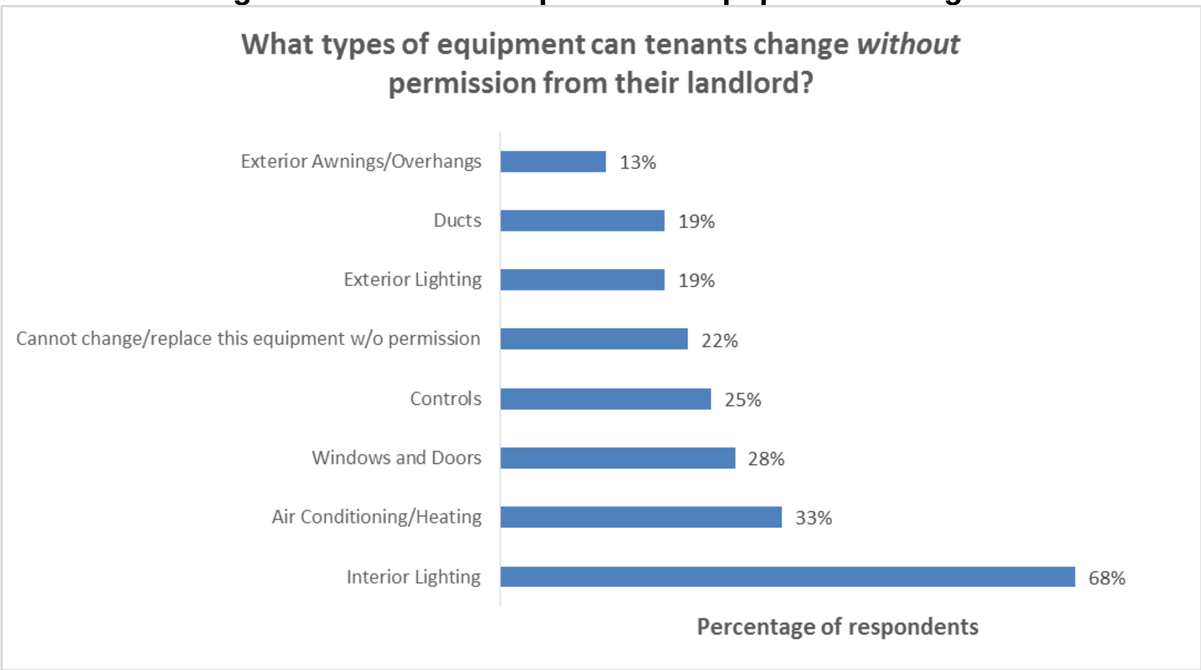
Figure 18: Tenant Response on Electric Bill Payments



Source: UC Davis EEC

As seen in Figure 19, which details what type of equipment respondents could replace or change without permission from their landlord, 68 percent reported being able to change at least the lighting fixtures. However, far fewer were able to change other types of equipment, and 22 percent reported not being able to replace or change any of the listed equipment types. These figures demonstrate the common example of split incentives: the tenants are responsible for the energy bills, but have limited agency to affect building equipment.

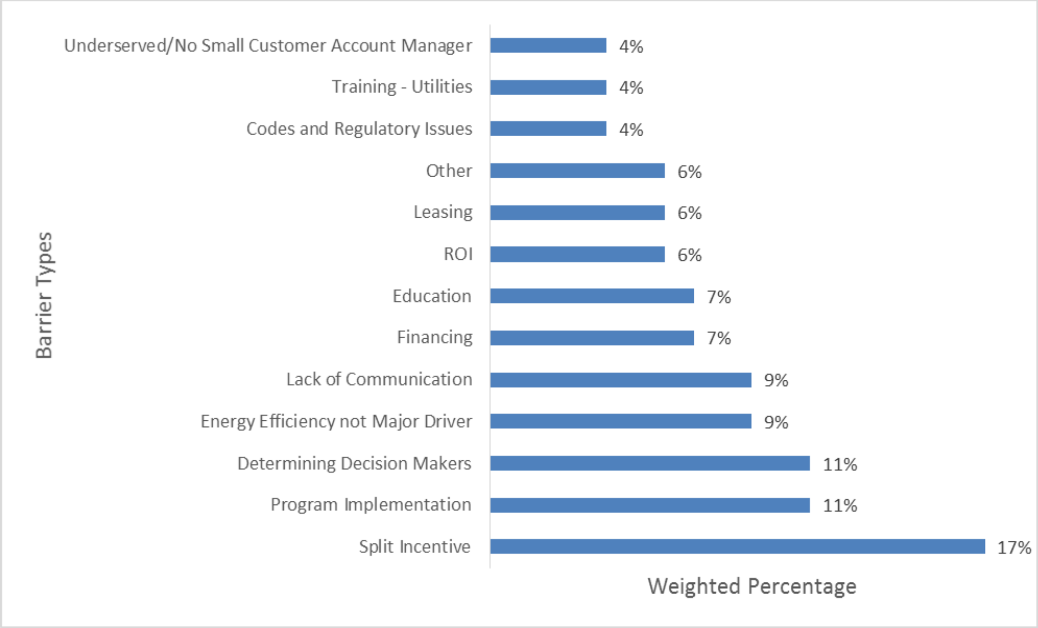
Figure 19: Tenant Response on Equipment Changes



Source: UC Davis EEC

Furthermore, in EEC interviews with representatives from utilities, financial institutions, third-party implementers, non-profit researchers, industry associations and regulatory agencies, the split incentive issue was mentioned most often as a barrier to achieving DER savings in the MTLC market (Figure 20).

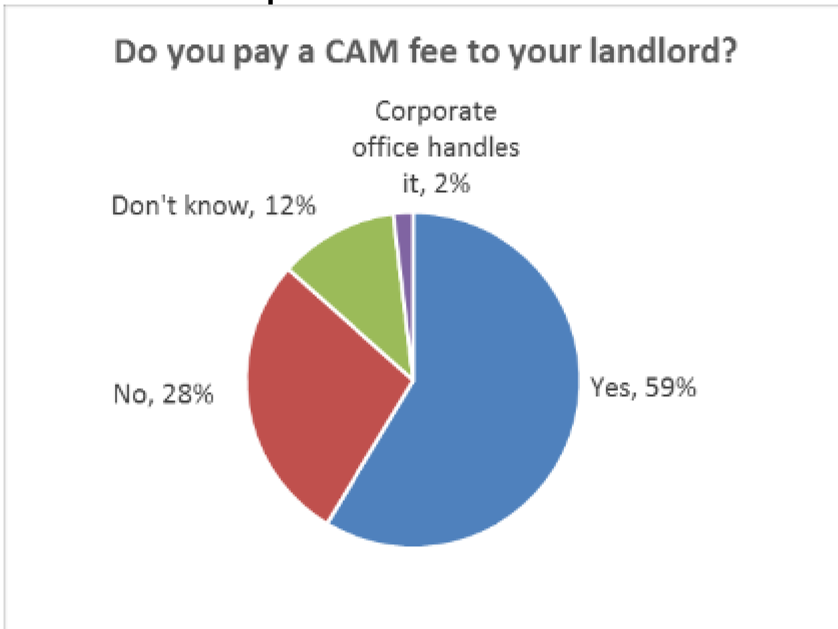
Figure 20: Stakeholder View on Most Significant Barriers to Retrofit Projects



Source: UC Davis EEC

Though landlords may handle the electricity bill for common areas of a property such as parking, shared plazas, and walkways, these costs may still be passed on to tenants through a common area maintenance (CAM) agreement in the lease. On the EEC tenant questionnaire, 59 percent of 104 question respondents reported having to pay a CAM fee (Figure 21).

Figure 21: Tenant Response on Common Area Maintenance Fees



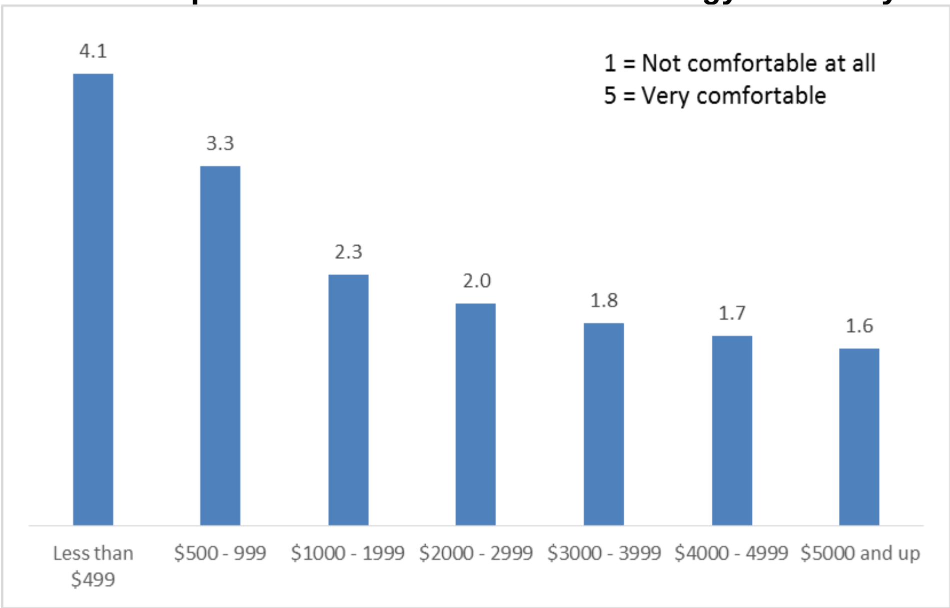
Source: UC Davis EEC

One situation, in which the landlord still has incentive to retrofit common areas, is if the CAM fees are a fixed amount in the lease agreement. If this is the case, the landlord may be able to profit by collecting the same fee amount even though the energy costs are reduced. However, this depends not only on the exact leasing agreement, but on whether the common areas have enough cost and energy savings potential for the landlord's effort to be worthwhile.

Financing

Existing literature indicates that high upfront costs and lack of capital are major barriers to energy efficiency in small commercial buildings (Lee et al., 1999; Wellinghoff et al., 2000). This is supported by evidence that conversion rates of program participants who receive audits compared to those who actually complete projects appears to be strongly linked to incentive levels (Poirier et al., 2010). Tenants of MTLC buildings (and small commercial buildings in general) are often small, independent business owners for whom any cost is a strain on their operating budget. Figure 22 shows the 60 responses from the EEC tenant questionnaire, in which tenants were asked to rate their comfort level on a scale of 1 to 5 with various energy efficiency project cost price ranges, where 1 is "not comfortable at all" and 5 is "very comfortable." Predictably, tenants are less comfortable with higher cost ranges.

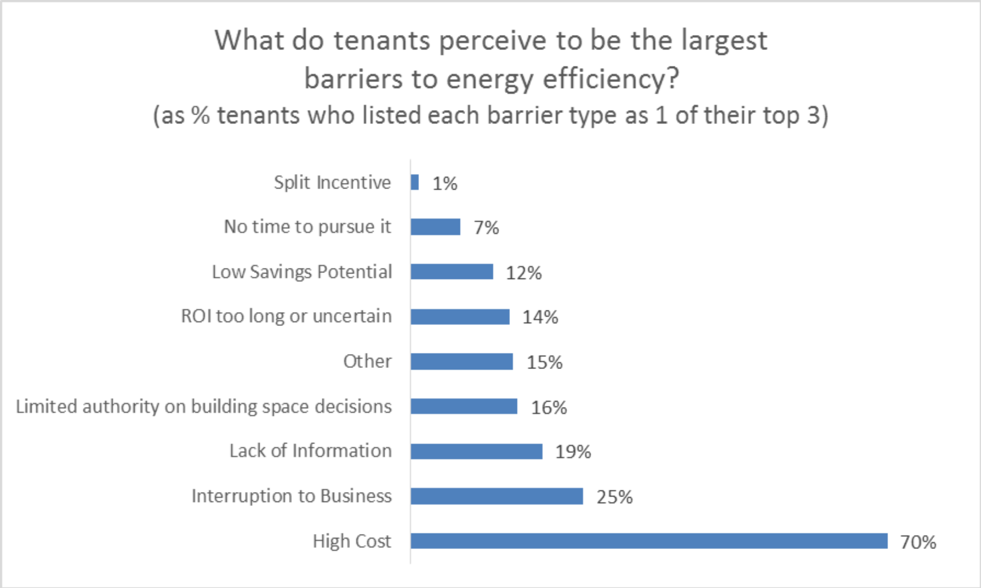
Figure 22: Tenant Response to Comfort Level with Energy Efficiency Project Cost



Source: UC Davis EEC

Tenants often perceive cost as the biggest barrier to energy efficiency. In the EEC tenant questionnaires, out of 82 respondents who listed their barriers to pursuing energy efficiency improvements, 71 percent of tenants listed "high cost" as one of their top three choices (Figure 23). It should be noted that for this question, "Other" responses included: building age, permitting, and not having reliable energy efficiency professional contacts. Also, "limited authority on building space decisions" may play into split incentives.

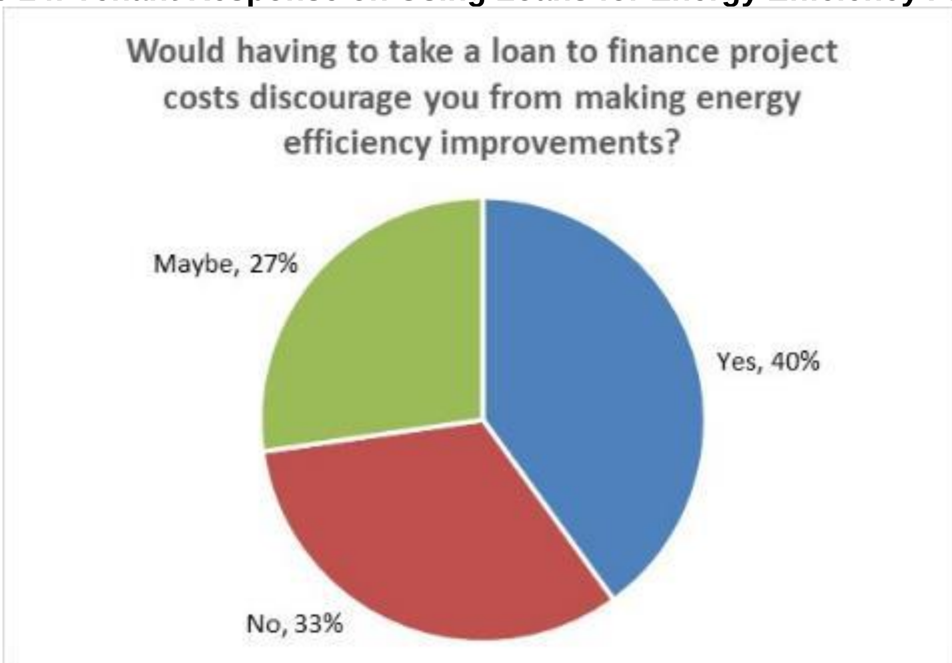
Figure 23: Tenant Response on Most Significant Barriers



Source: UC Davis EEC

The huge role that cost plays in decisions to pursue energy efficiency measures is highlighted by the fact that, for the 55 respondents on the question, "Would having to take a loan to finance project costs discourage you from making energy efficiency improvements," only a third of tenants were willing to take a loan without hesitation (Figure 24).

Figure 24: Tenant Response on Using Loans for Energy Efficiency Projects



Source: UC Davis EEC

Building owners also face this cost barrier. According to Johnson Controls' 2010 North American Energy Efficiency Indicator study, lack of available capital was the number one barrier to funding energy efficiency projects for decision makers in the commercial market. Their survey of 1,435 CEOs, vice presidents, property managers, and building owners found that 38 percent saw lack of capital budget as the number one barrier preventing the approval of energy efficiency projects (Hughes, 2012).

A STAMAT consulting group survey of building owners and facility managers in June 2013 also supported the importance of cost as a barrier. When asked to name the greatest obstacle to an energy retrofit, initial cost was ranked as the number one obstacle by 44 percent of respondents, more than four times larger than the percentage of respondents for any other barrier type (Figure 25) (STAMATS, 2013).

This perception of initial cost as the highest barrier may be related in part to the difficulty in finding financing; financiers tend to be less willing to lend to projects for privately-owned buildings because the risks of default are higher, relative to municipal and public-building risk (Next 10, 2010; STAMATS, 2013). Utilities have rebate and incentive programs to help finance energy efficiency projects, but those offerings vary between utilities and change from year to year. Additional finance tools vary widely depending on the utility and jurisdiction.

Figure 25: STAMAT Research on Barriers to Energy Efficiency Projects

Source: STAMATS

On-Bill Financing

In September 2008, the CPUC adopted the Long Term Energy Efficiency Plan in which four large IOUs offer non-residential businesses zero percent interest loans to implement energy efficient retrofits to their buildings. These loans are then repaid through their monthly utility bills.[6] Municipal utilities do not provide on-bill financing (OBF), but do have loans available for their customers. The interest rates tend to be fairly high at 6 percent and are therefore not attractive to most customers.

Property Assessed Clean Energy Programs

Similar to OBF, property assessed clean energy (PACE) programs allow local governments to create financing districts to allow both residential and non-residential owners to finance energy efficiency retrofits to their buildings and on-site energy generation and repay through a voluntary assessment on their property taxes. Up until the time of writing, only eight cities or counties in California have a PACE program. One drawback to the program is that any supplemental tax takes priority over other financial obligations, including mortgages. In addition, the PACE process can be very lengthy. One California county admitted that in three years they had received 12 applications

6 California Public Utilities Commission. "Fact Sheet: Energy Efficiency On-Bill Financing Program (2010-2012)". http://www.cpuc.ca.gov/NR/rdonlyres/2CC4EAB4-2D17-4074-9D25-ECFD428B9AF3/0/EE11OnBillFinancing0710.pdf. 2010.

and had seen only five projects complete the process. Again, the interest rate is quite high at 6 percent.[7]

Small Business Administration Loans

Business owners can get Small Business Administration (SBA) loans at a very low interest rate, around 3 percent. In EEC interviews, a stakeholder from a major bank explained: "If you're a real estate investment trust (REIT), you can get money from any major bank, any day of the week. If you're the small mom and pop store, you don't have the credit and you go with a SBA loan. It has a good (interest) rate and that's what SBA is for."

Upcoming Program: On-Bill Repayment

OBR is an upcoming CPUC program that would allow IOU customers to access third-party financing for energy efficiency retrofits with repayment occurring back on the customer's utility bills. The financing is expected to have low interest rates and variable terms. In return, the utilities will provide the billing services in exchange for fees from the lenders.[8]

Table 15 from Stanford University Public Policy Practicum (SUPPP) shows a summary of energy efficiency financing options, their availability in California in March 2012, and the advantages and disadvantages of each option (Brown et al, 2012).

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7 http://energycenter.org/policy/property-assessed-clean-energy-pace.

8 https://www.edf.org/news/california-proposes-nation's-first-statewide-bill-repayment-program-using-third-party-financing.

Table 15: Summary of Energy Efficiency Financing Options and Available in California as of March 2012

Option	Description	Availability
Own capital with rebates	Owner pays all initial costs out-of-pocket. State and utility rebates exist to reduce financial burden.	N/A
On-bill financing	Utility company finances loan, and owner pays no upfront cost but repays loan through monthly utility bill	Available for PG&E, SCE, SoCalGas, SDG&E customers. Not available in Palo Alto.
Property Assessed Clean Energy	Local government issues bond secured to property, collects payment from owner through property taxes, and remits loan to project lender.	Available in Sonoma County (self-financed), City of San Francisco (open market), Sacramento (private financing by Ygrene Energy Fund). Los Angeles County (open market), Placer County, WRCOG, Palm Desert.
Bank loan	Owner borrows money from bank and repays with interest.	N/A
Private	Various models, including Shared Savings Agreement, Receivables Purchases Agreement, and Managed Energy Services Agreement.	Currently, small pool of private lenders.

Source: Stanford University Public Policy Practicum

Table 16: Advantages and Disadvantages of Financing Options for Energy Efficiency

Option	Description	Availability
On-bill financing	• Bill neutrality • Tenants pay if submetering • Goes to next owner if sold	• Only for certain projects • Only building owners can apply • Capped at $100,000. 5-year payback (PG&E)
Property Assessed Clean Energy	• Accounting: not debt • Goes to next owner if sold • Flexible loan terms (20 yrs, max and min $ amount)	• Interest rate > market rates • Only building owners can apply • Local govt. run • Lender community education
Bank loan	• Flexible loan terms • May bundle finance and contract work	• Currently small lender pool • May require set technology
Private	• Lower rates	• Strict underwriting criteria • High min $ amount

Source: Stanford University Public Policy Practicum

While financing seems to be a crosscutting theme among barriers to energy efficiency, EEC stakeholder interviews revealed some disagreement about the actual weight of its influence. As one stakeholder in the EEC interviews explained, "If finance is really the problem, then in 2006 when the economy was booming, the energy efficiency projects should have been raining down."

Existing literature supports the idea that addressing financing barriers is not enough to effect wide-scale implementation of DER due to high transaction or opportunity costs that remain.[9] Even if loans are available to compensate for a customer's limited capital, the customer is assuming debt, which is in itself a limited resource.[10] Additionally, the customer may not have the human resources to follow through on the execution of retrofits--this is especially true of small business owners (STAMATS, 2013). Tenants

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9 Energy Center of Wisconsin. "Making the Energy Efficiency Case to Customers: Overcoming the Five Key Barriers to Participation." http://www.ecw.org/publicpowerguidebook/COWSFinancingPaper.pdf. 2009.

10 Energy Center of Wisconsin. "Making the Energy Efficiency Case to Customers: Overcoming the Five Key Barriers to Participation." http://www.ecw.org/publicpowerguidebook/COWSFinancingPaper.pdf. 2009.

may also have higher priorities than energy efficiency on which to spend capital, especially if energy usage accounts for only a small proportion of operating costs.

Energy efficiency may rank low in the priorities of building owners as well, despite the potential for significant financial returns on investment, and evidence showing that energy efficiency can improve building value and occupancy rates (Christmas, 2010; Eichholz, Kok & Quigley, 2009; Fuerst & McAllister, 2011; Pivo & Fisher, 2009; Wiley, Benefield & Johnson, 2010). This could be due to other options with better and more certain return on investment (ROI) estimates, or to a lack of information about energy efficiency improvements and their benefits.

Information Gap

Lack of information is a key barrier facing multiple stakeholders, especially building owners and tenants. Building owners and tenants may not know how efficient their buildings are or have the resources to benchmark them (Next 10, 2010; Brown et al., 2012). They may also be unaware what potential cost and energy savings exist, what retrofit options they have, and whether the ROI would be desirable or even calculable. In the absence of information about the quantified cost and benefits of making changes, the consumer has no price signal to spur decisions (Next 10, 2010).

In EEC tenant questionnaires, 24 percent of respondents listed "lack of information" as one of their top three largest barriers to pursuing energy efficiency. In the absence of information, consumers may make their own (often incorrect) assumptions about the energy use of equipment in their building or tenant space, and especially tend to underestimate energy use of larger appliances (Attari et al., 2010).

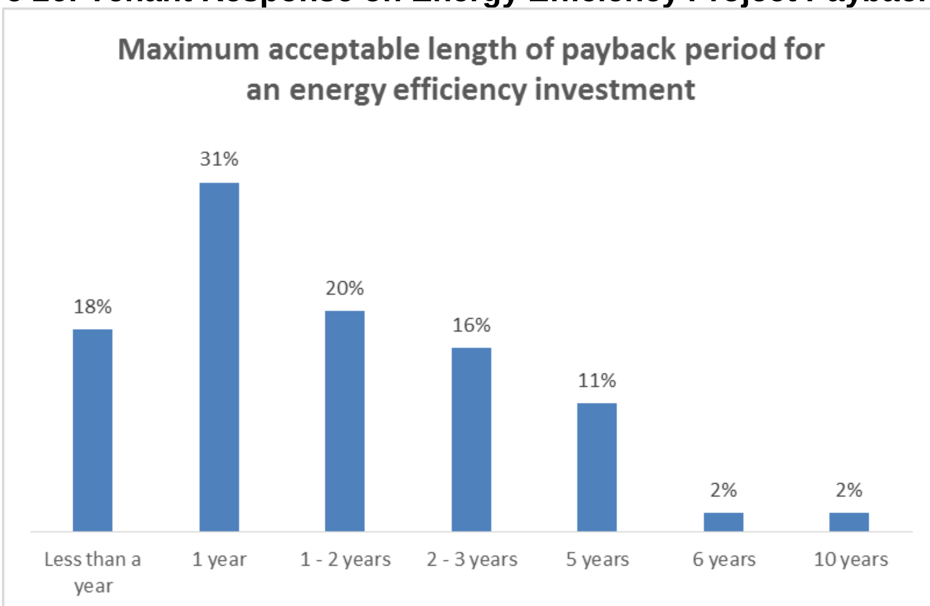
Even if the owner or tenant has knowledge of their potential energy savings, the typical building owner does not necessarily know whom to contact to initiate a retrofit, what the process entails, the timeline for ROI, or what financing options are available (Granade et al, 2009). Without this type of information, it may be difficult for an individual operating in the context of a larger organization to access capital or to obtain the necessary buy-in from other stakeholders, which is especially important for organizing and executing retrofit projects capable of achieving high cost savings (Kapur, Langdon, & Abramson, 2011).

Time Constraints

Time constraints are a barrier in several contexts, including restrictions on length of payback periods as well as the lack of time decision makers have available to actually research and execute retrofit installations. Energy efficiency retrofits require substantial capital upfront, but their expected ROI time frames are relatively long in comparison to other types of investments that generate revenue (Kapur et al., 2011). If the tenant is funding the DER, they must have an ROI at least before the end of their lease, or the investment is not worthwhile. Energy efficiency improvements only benefit customers while they occupy the building where they are installed, and there is a risk that they will need or want to leave before the energy efficiency investment is returned through energy savings.[11] For corporate chains, long payback periods also conflict with corporate focus on short-term profits (Kapur et al., 2011).

In EEC tenant questionnaires, tenants listed their desired ROI time frame for energy efficiency investments. Predictably, shorter lengths of time are preferred over longer ones - and 69 percent of 61 respondents reported wanting an ROI in 2 years or less (Figure 26).

Figure 26: Tenant Response on Energy Efficiency Project Payback Time



Source: UC Davis EEC

Even if an energy efficiency project has an ROI within a tenant's desired time frame, pursuing the project may require an unacceptably long time commitment. Energy efficiency is geneally a low priority compared to other activities, especially in small businesses where energy use is not a significant part of operating costs.

Pursuing energy efficiency also entails committing time to researching available options. Tenants may not be willing or able to spend the time necessary to do these things. As a 2010 One-Stop program evaluation showed, 39 program participants reported the amount of time they spent researching energy efficiency. The average response was ten hours per year and 13 respondents reported that they spent no time researching energy efficiency, which was also the most common answer (Frontier Associates, 2010).

Interruption to business is also a barrier for tenants. In EEC tenant questionnaires, 25 percent of respondents listed "interruption to business" as one of their top three

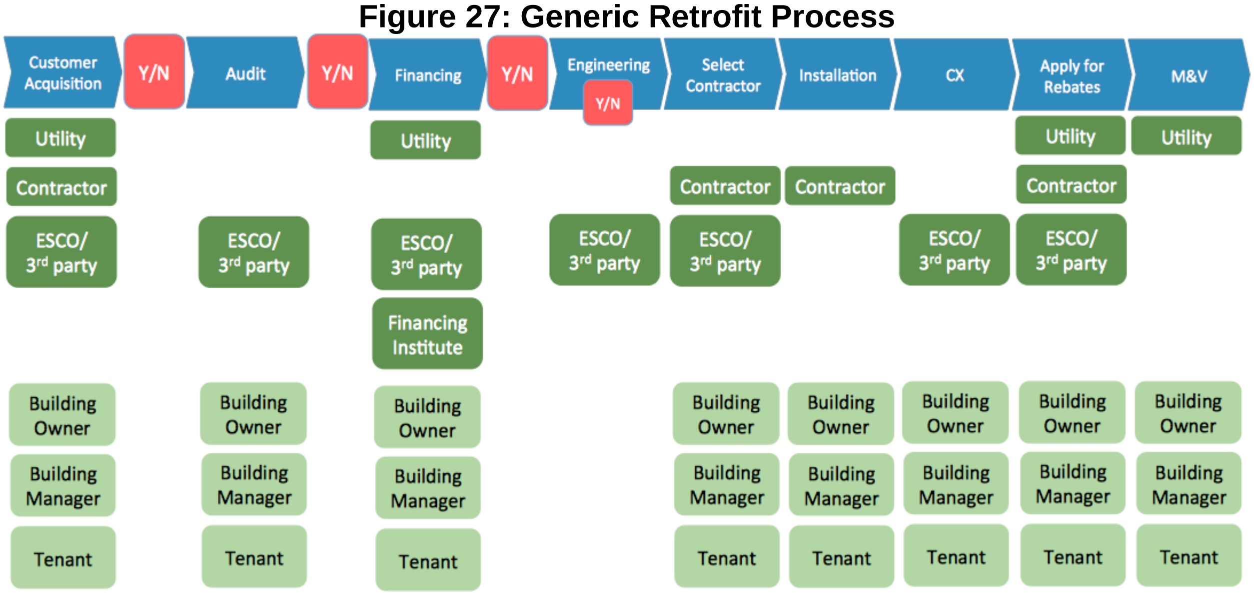
11 Energy Center of Wisconsin. "Making the Energy Efficiency Case to Customers: Overcoming the Five Key Barriers to Participation." http://www.ecw.org/publicpowerguidebook/COWSFinancingPaper.pdf. 2009.

barriers to energy efficiency. Tenants may also need to find and supervise the installer of the energy efficiency measures, which is another barrier to energy efficiency in general, as well as a cause of lower conversion rates in utility programs that provide low or no-cost audits.[12]

Complex Implementation Process

Implementing a DER is a long and complex process involving multiple stakeholders. Figure 27 depicts the typical process for implementing a DER in a multi-tenant commercial building. The top row depicts major phases in the project timeline and the actions involved. Each "Y/N" indicates the transition between major stages, a "yes" meaning the phase is complete and the next one can be started. The rows below name the stakeholders that might need to be involved in each phase, of which there are often many. The higher the number of stakeholders needed to complete a phase, the higher the potential for barriers to arise through information gaps, conflicting priorities, lack of time, and lack of interest on the part of one or more stakeholders. It is unsurprising that customers seeking retrofits often find the process to be too complex and confusing (Brown et al., 2012).

Figure 27: Generic Retrofit Process



Source: UC Davis EEC

Even for one category of stakeholder, there may be further complexities as to who the actual decision maker is, and how easy it is to communicate with them. In the case of tenants, for example, decision-making power may vary according to whether the tenant is corporate or independently owned. The person(s) occupying the tenant space may not be the actual decision maker(s). Table 17 shows several roles within the

12 Energy Center of Wisconsin. *Making the Energy Efficiency Case to Customers: Overcoming the Five Key Barriers to Participation*. http://www.ecw.org/publicpowerguidebook/COWSFinancingPaper.pdf. 2009.

organization structure of corporate tenants versus independently-owned tenants, who may have varying roles within the decision-making process.

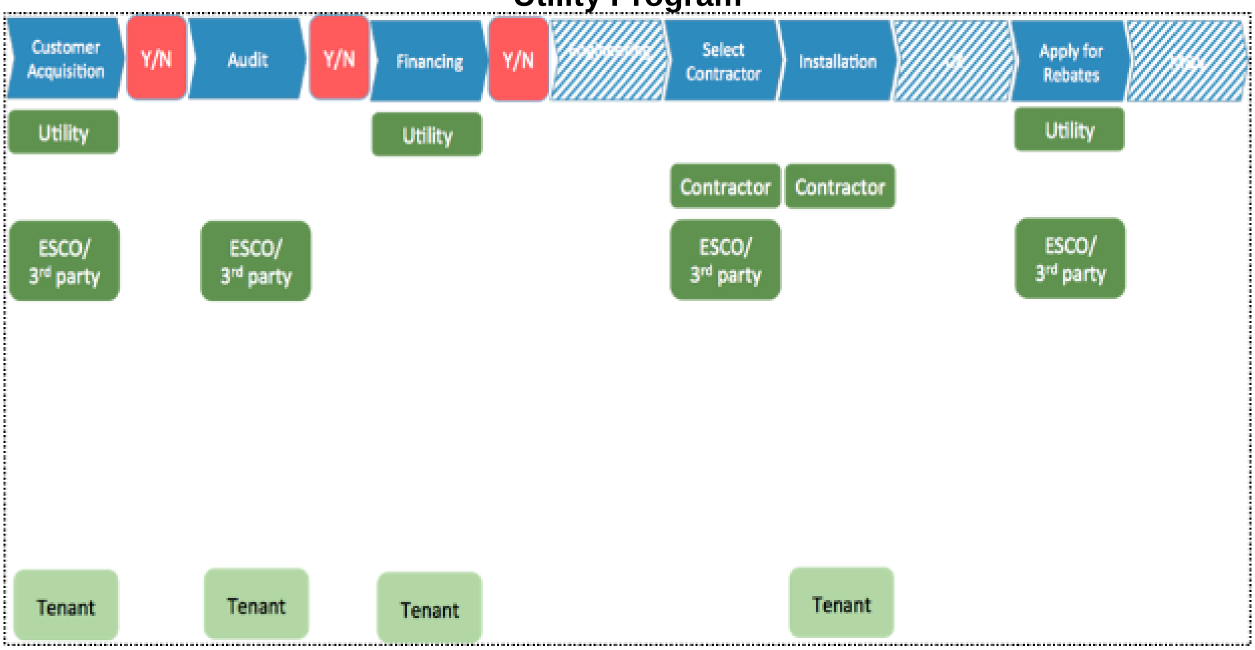
Table 17: Roles with Corporate Tenants versus Independently Owned Tenants

Corporate Tenant	Independent Tenant
• Store employee • Store manager • Corporate Manager	• Store employee • Business Owner

Source: UC Davis EEC

In comparison to the process for DER, the typical process for implementing more limited energy efficiency measures, such as direct install measures, is significantly less complex. Figure 28 shows the phases and stakeholders for a typical direct install project (usually lighting). The boxes with blue stripes represent phases in the DER process which do not apply for direct installations.

Figure 28: Typical Lighting-based, Tenant Only, Deemed Measures Direct Install Utility Program



Source: UC Davis EEC

This process is significantly less complicated than for more intensive measures, and is accordingly the most common type of program currently implemented in the MTLC market. However, the trade-off is that achievable energy savings are much lower than a DER due to restrictions on what technologies can be changed without involving the building owner. Therefore direct installations have limited scope as a tool for market transformation.

Opportunities and Recommendations for Engaging the Multitenant Light Commercial Market

General Recommendations for Market Stakeholders

In EEC interviews, stakeholders were asked about future events that might affect the MTLC market. Many mentioned the necessity for better outreach and education. In terms of outreach, one utility representative mentioned they were creating an online "no-touch" audit tool for customers to start the retrofit process. Another utility representative believed that there would be a non-residential version of the program Energy Upgrade California, which provides a one-stop information website that includes energy efficiency tips, rebates, incentives, and financing options in the customer zip code. For technological solutions, many stakeholders mentioned emerging technologies in lighting, HVAC, and occupancy sensors. Also mentioned was the possibility of EMS, which are usually not used in smaller tenant spaces, and wireless monitoring and controls.

Take Advantage of New Legislation

In addition to Title 24, California has several laws, programs and initiatives, in various phases of implementation, which will dramatically affect the MTLC market and DER.

Assembly Bill 802 (AB 802), the Building Energy Use Benchmarking and Public Disclosure Program, mandates the establishment of a new statewide building energy use benchmarking and public disclosure program for certain covered buildings over 50,000 square feet, defined as all nonresidential buildings and multifamily buildings with 5 or more utility accounts.[13] The California Energy Commission (CEC) will conduct a rulemaking to develop regulations and establish the infrastructure for this new benchmarking program. The regulations are anticipated to become effective in 2017.

Assembly Bill 758 (AB 758), the Comprehensive Energy Efficiency in Existing Buildings Law, is a groundbreaking law that requires the CEC, in collaboration with the California Public Utilties Commission and stakeholders, to develop a program to achieve greater energy efficiency in the state's existing buildings.[14] This program will require all existing buildings, typically built prior to 1980, to implement energy efficiency retrofits that will decrease energy use significantly below efficiency required by current Title 24 standards. The program has three tracks: The No Regrets Strategy, Voluntary Pathways, and Mandatory Approaches. The "No Regrets Strategy" provides access to resources such as education and outreach, data reporting and management, code support tools and compliance, and workforce training and development. The "Voluntary Pathways" will provide technical tools for benchmarking, audits and commissioning, and

13 http://energy.ca.gov/benchmarking/.

14 http://www.energy.ca.gov/ab758/.

outreach to the contracting industry. Other measures include focusing on small and medium-sized buildings, such as MTLC buildings, developing property valuation practices for energy efficiency and innovative financing options, and energy efficiency solutions for rental properties. Finally, the "Mandatory Approaches" will be useful to facilitate market transparency and move more mature measures into wider use. This track will be based on the outcomes of what is successful in the market from the first two tracks (CEC, 2015).

The CEC is hopefull that the "No Regrets Strategy" and the "Voluntary Pathways" tracks will be successful and the need for mandatory policy will be reduced. One positive outcome from this process is the ongoing collaborative effort of stakeholders in commercial building, architecture, finance, clean energy, technology, and various state agencies. While reaching consensus among all parties will be difficult, collaboration will hopefully create a new and exciting landscape for California to realize these ambitious energy efficiency goals.

Multiple laws and programs are creating synergies that will affect how the MTLC market is served. AB 758 has a significant education and outreach component, which is currently lacking in the MTLC market. In addition, the bill includes financing vehicles for these projects as well as assistance for low-income customers.

Adopt Green Leases

The term "green lease" is starting to enter the lease conversation now that it has begun to penetrate the office space market. As a Real Estate Investment Trust (REIT) stakeholder explained, during the team's interview process, "My portfolio is office buildings and my tenants are very sophisticated. They are demanding green or LEED certified buildings. It's not that the property is worth more or we can get more money for rent. It means I can rent the building." Green leases are currently seen less frequently in the MTLC market. Smaller corporate retail chains that are focused on sustainability issues, such as Starbucks or Subway, however, are at the forefront of incorporating green language into their leases. These chains require that CAM agreements and operations follow certain standards as defined by their company initiatives.

A green lease can take on many formats. It may be a green lease with specific clauses integrated into the lease or it may be a normal lease with a green rider that might mandate energy efficient light bulbs, light timers, and so on. Based on the Retail Industry Leaders Association (RILA) Green Lease Primer, the basic premise of the green lease includes five attributes (RILA, 2013):

1. Improve the base efficiency in building and common areas. Address improvements to the base building shell, including common areas.
2. Align economic incentives to encourage "green" initiatives. Address misalignments between the party that is investing in property improvements and the party that receives the benefits.

3. Improve tenant space. Address improvements to the tenant's space consistent with the premise's permitted use, that is, sustainable materials, sub-meter, energy efficient lighting, and high efficiency HVAC.
4. Increase access to information on resource use. Make energy and water use and waste generation data visible to both parties.
5. Clarify access to and control of key areas of the property and who has the right to implement projects, such as rooftops for solar or parking lots for electric vehicle (EV) chargers.

While developing green leases partially addresses the split incentive problem, success depends upon leasing agents using them in real-world applications. Even the large retail REITs, which have sustainability divisions developing green leases, find that their leasing agents are not using green leases during negotiations with prospective tenants. A lot of education needs to occur within the real estate and property management arenas and among customers in order to implement green leases.

One industry association noted they are moving away from the name "green lease," and just calling it a lease. Their goal is to erase the distinction between types and make the green lease the new standard. To facilitate this change, large portfolio owners will have to make top-down management directives regarding lease use.

Adopt Targeted Outreach Strategies

Numerous shopping malls are owned or managed by REITs and large corporations. These entities typically have sustainability departments as part of their corporate initiatives and therefore pursue energy efficient retrofits. More coordination is needed between the different parties as energy efficiency is not always a priority for leasing brokers. Even as REITs and large corporations work on energy efficiency initiatives, their large portfolios should encourage account representatives from the local utilities to engage with the owners and the tenants to explain program options and rebates. As this owner type starts to build energy efficiency momentum throughout their portfolios, the smaller non-REIT building owners will eventually have to follow suit to compete for tenants.

Smaller strip malls are the most difficult audience to reach and the most underserved. This market segment is so varied that it will require a more one-on-one approach to make connections and deliver energy efficiency programs. When third-party implementers make direct contact with owners, property managers, and tenants, they can immediately identify the decision makers and the best way to deliver the programs. Third-party implementer Ecology Action from Santa Cruz currently works for several utilities and provides a good example of this direct contact approach, which involves a comprehensive audit as they try to generate trust, accurate cost estimates, information on the retrofit's impact on their bills, and attempts to persuade customers to cover a portion of the retrofit. They get approximately 30 percent of the total cost from the tenant.

Recommend Targeted, Deep Energy Savings Packages

As stated previously, the main market tool to implement deep energy savings in MTLC buildings is DI programs. While DI programs are inexpensive, and require little time from the tenant and building owners, these programs only provide a limited set of energy saving measures with little material savings.

At the other end of the spectrum, there are Energy Service Companies (ESCOs), which provide a comprehensive program to pursue deep energy savings including data collection, financing, and deep energy saving measure installations. However, ESCOs rarely pursue MTLC buildings because individual MTLC buildings are small, providing limited opportunity for energy savings and little financial incentive.

In Chapter 4, researchers describe a program to achieve targeted, deep energy saving packages for MTLC shopping centers. The program would pursue deeper energy savings than DI programs, but would do so in a cost-effective manner, with technologies that are designed and targeted for the MTLC market.

Follow the Building Lifecycle

In designing and planning how best to reach MTLC buildings, an important element to consider is the building lifecycle. Three major components make up a building lifecycle: 1) construction and maintenance of the building, 2) installation and maintenance of building systems, and 3) management of tenants as they rent out space and when building ownership changes hands.

One of the most opportune times to implement DER within a building is the initial construction; setting a strong energy efficiency standard from the start establishes not only tenant expectations, but also a building standard. Regularly scheduled maintenance for the building and its systems also provide excellent opportunities to consider implementing energy efficiency measures.

In addition to the physical building lifecycle, there is also the cycle of tenants moving in and out of a building space. Whether the building has a high degree of turnover or not, the conclusion and negotiation of leases present an opportunity for both the owner and the tenant to consider building improvements, especially when multiple tenants are re-visiting agreements on the lease as multiple energy efficiency measures could be implemented at once. Finally, changes in building ownership also present an opportunity for building improvements to lower energy consumption, as guided by AB 802.

Create Turnkey Solutions

Realizing DER savings is important, but it can be difficult without the proper resources or approach. One way to circumvent these difficulties is to provide an integrated, complete solution to building owners and tenants at a single service point. The most successful utility programs provide a single point of access for tenants to:

- Identify opportunities in advance (small set of solutions)

- Provide clear cost and benefit analysis
- Simplify the paperwork application
- Find contractors
- Oversee projects

Conclusion

The MTLC market is large, in terms of square footage and energy consumption. It is also extremely diverse in terms of size, business type, equipment, owner-tenant relationships, and leasing structures.

Within California, MTLC buildings have a comparable EUI to all commercial buildings (13.3 kWh/sq-ft compared to 13.3 kWh/sq-ft). It may appear that the MTLC market is not worth pursuing, since it is doing as well, in terms of EUI, as the larger commercial building population. However, MTLC small and medium-sized retail/service buildings, such as convenience and neighborhood shopping centers, are the highest energy consumers among key California MTLC segments (18.4 kWh/sq-ft). In addition, previous research has found significant potential for energy savings in these buildings. For these reasons, the research team focused on MTLC shopping centers in this project.

Taking advantage of the potential savings in the MTLC market will not be simple. Key market barriers to energy efficiency include split incentives, financing, information gaps, and time constraints. However, there are also some key opportunities and recommendations that can be taken advantage of, including increasing energy costs and laws that are putting pressure on buildings to become more efficient.

CHAPTER 3: Energy Technology Assessment

Hundreds of energy-efficient technologies are available to MTLC shopping centers. To develop effective retrofit programs for these buildings, it is critical to identify and focus on the most appropriate energy-efficient technologies. The research team used the results of its market research, outlined in Chapter 2, to identify a small subset of energy-efficient technologies that are most appropriate for MTLC shopping centers. Researchers identified technologies for property-wide application, as well as individual tenant spaces, including building envelope solutions (for example, window replacement, awnings, and internal shading devices), intelligent interior and exterior lighting, and advanced HVAC technologies. For each technology, the team provides an overview and potential performance improvements, and evaluates energy savings through literature review and simulations. In addition, team researchers conducted a survey of utility representatives who serve the MTLC market and stakeholders who own, manage, or lease MTLC properties to understand their perceptions of specific energy-efficient solutions and their motivations for selecting and installing certain measures over others.

Data and Methods

Multitenant Light Commercial Technology Evaluation

To select the most appropriate technologies for the target MTLC market, researchers used the results of its market research, as well as input for industry experts (see Appendix B). To evaluate energy saving and environmental impacts the team conducted literature searches to identify relevant studies, used existing energy simulation tools, such as the United States Department of Energy's EnergyPlus software, and also used a new simulation tool (the MTLC Toolbox) that they developed as part of this research project (Chapter 4).

Energy Technology Simulations

The team developed simulations by establishing a baseline scenario where they defined a typical MTLC building with key features/characteristics and its resulting energy use (see Chapter 4). Researchers then made energy efficiency upgrades, such as window replacement or shades, and simulated the impact of these upgrades on energy savings. The research team ran simulations in select California climate zones in both the heating and cooling seasons.

Cost Savings

In addition to calculating energy savings, team researchers also evaluated retrofit cost savings, when possible, in terms of electric and gas costs. As natural gas is considerably cheaper than electricity per kWh equivalent, cost savings can be a useful metric for analyzing technologies. Researchers estimated gas prices at $0.034 per kWh and electricity at $0.185 dollars per kWh.

Multitenant Light Commercial Target Stakeholder Survey

Researchers conducted a MTLC target stakeholder survey (TSS) to gather information on perceptions of energy-efficient solutions from utility representatives who serve the MTLC market and stakeholders who own, manage or lease the properties. Utility representatives included employees of the electric utility, as well as administrators of the programs that support the incentive process, such as third-party programs or trade professionals who collaborate with utilities to encourage adoption of energy-efficient lighting products in the MTLC market. Building stakeholders included building owners, property managers, facility managers, and tenants. Each of these stakeholders plays a critical role in the adoption of energy efficient products. The utility representatives and their program partners are motivated to create incentive programs that will maximize the claimable electricity savings that result from successful programs, while the building stakeholders make the final decision on whether to implement energy efficiency upgrades or participate in incentive programs to offset costs.

Survey Development

Researchers collected survey data through two separate online surveys, one for utility stakeholders (Utility Group) and the other for building owners, property managers, and tenants (Buildings Group). The Utility Group survey had 15 questions, while the Building Group survey had 18 questions. Each survey had slightly different questions designed for its respective audience. In some cases, team researchers conducted follow-up phone interviews and in-person visits to supplement a respondent's online survey data. Surveys were intended to be completed in less than twenty minutes and were designed to capture information on the perception of the following electric lighting, daylighting and envelope technologies:

- Window awnings
- Skylights paired with photocontrols
- Tubular daylighting devices paired with photocontrols
- Energy-efficient window glass
- Window film
- LED replacement lamps (screw or pin-based)
- Tubular LED (TLED) lamps
- LED retrofit kits for existing fixtures
- Occupancy sensors
- LED parking and area lighting (outdoor)

Survey questions focused on these topics:

- Markets served within MTLC tenant groups.

- Perception of the cost of electric lighting, daylighting, and lighting-related envelope technologies.
- Perception of the energy-efficiency value of selected lighting-related measures.
- Motivating factors contributing to the decision to implement energy-efficiency related building retrofit projects.
- Perception of responsibility for installing technologies intended to reduce energy use.

Questions did not seek answers that required technology expertise to answer accurately. Instead, the survey focused on the respondent's opinion and perception of technologies based on their own knowledge of the solution and its intended market. In the utility survey, researchers asked respondents to answer questions based on what they believed would benefit their customers, while the building stakeholder survey was more direct because these strategies and technologies would be adopted by survey participants in their own buildings and leased spaces.

Survey Participant Recruitment

- Utility group survey: The team approached several contacts from California utilities with the hope that these contacts would pass the survey along to the appropriate program representatives via email. An introductory message set the context for the survey and included a definition of MTLC facilities, the objective of the project, and a deadline by which to complete the request. Utility representatives were asked to complete the survey from the perspective of what measures they believed would benefit their customers.
- Building group survey: Access to building stakeholders proved more challenging. Without established relationships with building owners, property managers, or tenants, data mining for contacts and encouraging participation in the absence of a tangible motivation and timely reward presented obstacles. Team researchers approached tenants in the local Davis, California area to encourage participation, with some success. Ideally, the survey would reach audiences located across California and in the most populated climate zones. With the time and resources allocated to this subtask, however, the team focused on local respondents.

Survey Participants

Twenty stakeholders from multiple MTLC market sectors participated in the TSS. Researchers categorized survey participants as members of the Buildings Group (tenant, property manager, building owner) or the Utility Group (utility employee, utility program partner) based on their general stakeholder role identified prior to survey deployment. As part of the online survey, participants were asked to further identify their specific affiliation / role by selecting from a list of seven options. Table 18 details the various affiliation options and number of survey respondents in each category. [15]

Table 18: Summary of Survey Participants by Participant Type

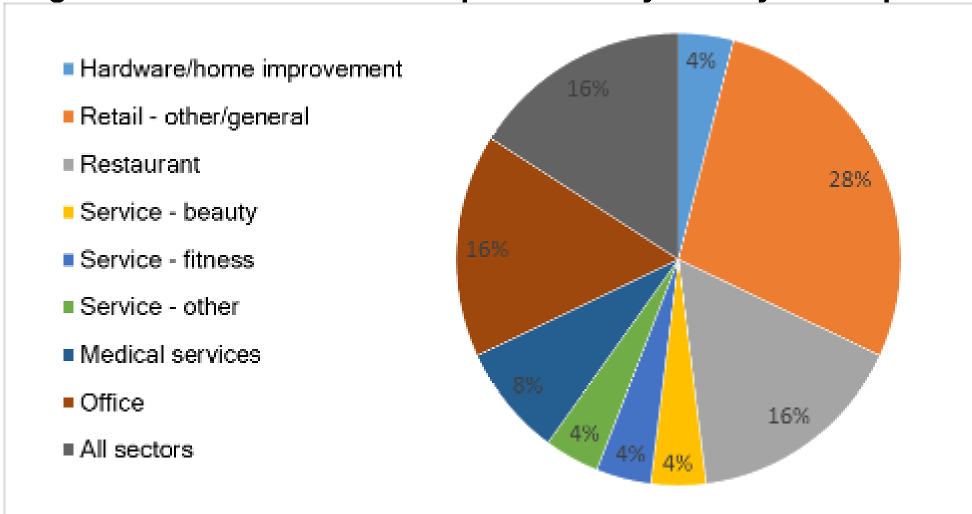
Participant Type	Number
Landlord/property manager of multi-tenant light commercial building	4
Tenant in multi-tenant light commercial building	7
Building owner	3
Utility representative for investor-owned utilities	2
Utility representative for municipal utility district	2
Utility program partner	2

Source: UC Davis EEC

Researchers also asked respondents to identify which MTLC market sector they represented. Building owners and property managers selected a market sector based on the business type of their tenants. Utility Group members selected market sectors based on their customer's business type. Choices included a range of retail types and service industries. A majority of participants represented the general retail and service sectors (see Figure 29).

15 One respondent self-identified as "Other", and was re-categorized as a tenant and member of the buildings group based on their statement that they were a single tenant in a two-story, commercial space.

Figure 29: Market Sectors Represented by Survey Participants



Source: UC Davis EEC

Multitenant Light Commercial Technology Evaluation Findings

Researchers identified technologies for property-wide application, as well as individual tenant spaces, including building envelope solutions (for example, window replacement, awnings, and internal shading devices), intelligent interior and exterior lighting, and advanced HVAC technologies. For each technology, the team provides an overview and potential performance improvements, and evaluates energy savings through literature review and simulations. In some cases the team also evaluates cost savings.

Building Envelope

The building envelope controls the light and heat that enter and exit a building through the windows, walls, doors or skylights. In climates where building cooling loads constitute a significant share of total building energy use, the amount of heat that enters the space is important to consider. Envelope energy retrofits that limit heat penetration into the building, such as window shades, glazed window glass, or window film, offer energy savings when properly installed and controlled. The ability to limit radiant heat from entering a space is determined by a technology's Solar Heat Gain Coefficient (SHGC). Exterior shading devices, such as awnings and exterior louvers, are very effective at limiting solar heat gain because they directly block daylight from entering a space. In addition to SHGC, exterior envelope performance is characterized by the amount of light allowed to enter a space and the amount of heat allowed to exit, which is defined by the technology's Visible Light Transmittance (VT) and U-Factor (U-Value), respectively.

Facade Window Replacement

Approximately 75 percent of MLTC buildings in California contain single-pane windows and, depending on building type, between 40 and 79 percent of buildings have unglazed windows (Itron Inc., 2014). Single-pane and unglazed windows are not very energy efficient and are thus good candidates for whole window replacement. Replacement windows should be considered at the façade level. The orientation of the façade will dictate the most suitable replacement window or fenestration (windows and doors) package.

Windows are available in many options ranging from basic, single–pane, clear glass to triple glazed, argon-filled, low-E glass. Space between panes in double and triple glazed windows improves heat insulation and soundproofing and is filled with a single gas or mixture of gases to insulate and prevent condensation. Windows may be filled with natural air, argon gas, krypton gas, or a mixture of argon and krypton. Low-E glass windows are coated with a thin layer of metallic chemicals. Careful specification of window and glazing systems is essential to building energy efficiency and comfort.

Typical commercial building windows are static: they cannot be opened to let in outside air or moved to change the angle of the sunlight hitting the building. Static windows and skylights, when used without shading devices, can lead to glare and excess heat gain from uncontrolled daylight penetration into the building. To avoid this, windows should be paired with indoor or outdoor shades, awnings, or window film to better control the light and heat that enters the space.

Dynamic window technology, such as electrochromic ("smart") glass, changes from light to dark and back again based on environmental conditions or user needs (see Figure 30). This can decrease a window's VT as the sun sets to minimize glare from direct sunlight, or increase VT to allow daylight penetration into the building during the day. The cost of dynamic glass has historically been very high; however, the cost has begun to come down and is expected to drop further as demand for more energy-efficient and zero-net energy buildings grows.

In applications where daylighting is desired, a window with a high VT should be selected. Because daylight entering a space also brings the potential for glare and heat gain, windows with high VT should be paired with indoor or outdoor shading systems. A dynamic shading system or window film is ideal to allow daylight penetration only when required.

Figure 30: Electrochromic Glass

Source: UC Davis

Performance Improvements

The addition of control systems for electrochromic and other dynamic windows, when integrated with lighting and HVAC systems using standard communication protocols, could greatly enhance the features and cost-effectiveness of window replacements for the MTLC retrofit market. In addition, the inclusion of dynamic windows with variable U-values introduces additional benefits.

Energy Savings

Windows directly impact heating and cooling systems. A case study conducted for the USDOE on window choices and their effect on HVAC loads states that "the total consumption of all heating and cooling energy in the United States is due to losses attributed to the inefficiency of building fenestration". Current energy consumption of United States commercial window stock (realized as heating and cooling energy consumption) is estimated at 4.1 Quadrillion Primary BTU (quads) (Arasteh et al., 2006). For the retrofit market, current technologies such as the "Sales" and "Low-E" products described in Figure 31, could save approximately 4 to 15 percent in total commercial heating and cooling loads (Arasteh et al., 2006).

Figure 31: Estimated Energy Savings for Commercial Building Fenestration Retrofits

- Sales – The average properties of windows sold today.
- Low-E – A typical two pane spectrally selective low-e window in an aluminum frame.
- Dynamic Low-e – A two pane low-e window with dynamic solar heat gain control.
- Triple Pane Low-e – Today's highest-performance product; triple pane low-e in aluminum frame.
- High R Dynamic – Very highly insulating windows with dynamic solar heat gain control.
- Integrated Facades – These systems are intended to use highly insulating and dynamic products and to save additional energy through daylighting (hence their potentials for lighting saving)

Annual Energy Savings Potential of Commercial Window Technologies

Window Type	Energy Savings over Current Stock			
	Heat, quads	Cool, quads	Lighting, quads	Total, quads
Sales (Business as usual)	0.03	0.17	-	0.20
Low-e	0.33	0.32	-	0.65
Dynamic Low-e	0.45	0.53	-	0.98
Triple Pane Low-e	0.71	0.31	-	1.02
High-R Dynamic	1.10	0.52	-	1.62
Integrated Facades	1.10	0.52	1.0	2.62

Stock use is 0.85 quads Heating, 0.54 quads Cooling. See Table 2.

Source: Lawrence Berkeley National Laboratory (Arasteh et al., 2006)

Simulations conducted as part of this research confirmed these estimates. Basic window replacements produced annual savings of approximately 4 percent compared to windows installed in typical MTLC buildings constructed between 1980 and 2003 (baseline model). Basic replacement windows, had an improved SHGC (0.25) and U-factor (3.236) as compared to the baseline window technology, and represent the minimum window performance characteristics currently allowed by building code. The majority of savings from higher performance window glass came from decreased cooling loads ("electricity") in the summer months (Table 19 and Figure 32). Savings from reduced cooling loads alone was 7 percent. Savings from decreased heating loads ("gas") was negligible. This savings estimate was consistent across diverse climate zones, and annual savings ranged from approximately 3 to 5 percent for heating and cooling loads combined.

Researchers also looked at the impact of slightly more advanced window retrofits called SuperNeutral™ 54 glass (SN54), a Low-E window. According to industry experts, this technology is used in a majority of window replacements. SN54 glass reduces glare, has an improved U-factor, and a low SHGC (between 0.23 and 0.28, depending on glazing). Through simulations, team researchers found that this technology saved approximately 3 to 7 percent (Table 19, Figure 32 and Figure 33) as compared to the baseline model. Increased savings were attributable to decreased heating losses during the winter months ("gas"). SN54 windows are most appropriate for colder climates and deliver improved savings over basic replacement windows.

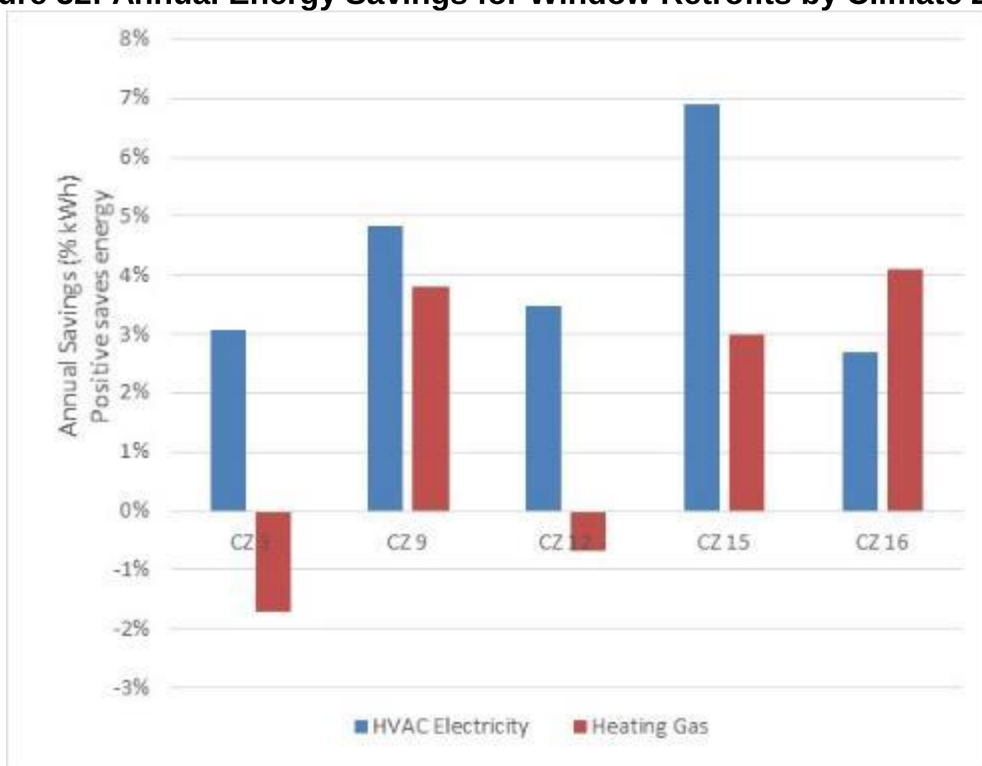
Table 19: Annual Energy Savings for Window Retrofits by Climate Zone

Climate Zone	Basic Windows, Electricity	Basic Windows, Gas	SN54 Glass, Electricity	SN54 Glass, Gas
CZ 3	3.1%	-1.7%	2.7%	19.3%
CZ 9	4.8%	3.8%	4.5%	27.5%
CZ 12	3.5%	-0.7%	3.4%	12.8%
CZ 15	6.9%	3.0%	7.1%	29.9%
CZ 16	2.7%	4.1%	2.5%	16.8%

West-facing front facade, 50 percent window-to-wall ratio

Source: UC Davis EEC

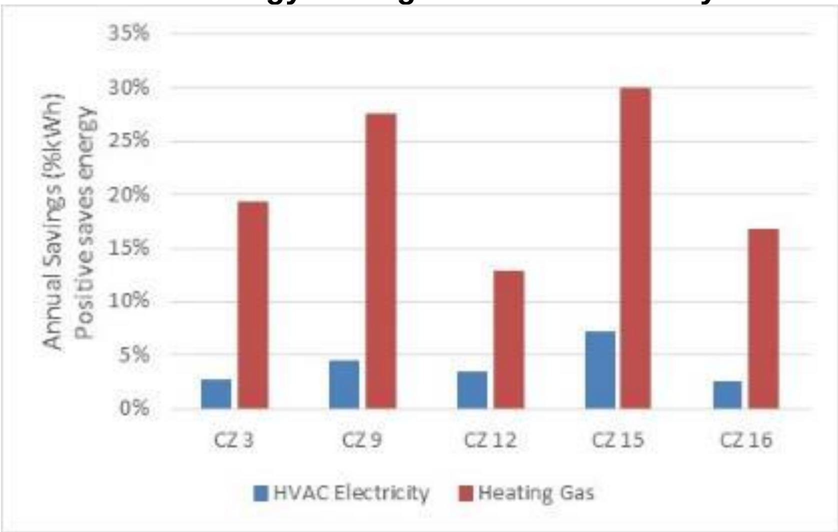
Figure 32: Annual Energy Savings for Window Retrofits by Climate Zone



West-facing front facade, 50 percent window-to-wall ratio

Source: UC Davis EEC

Figure 33: Annual Energy Savings for SN54 Glass by Climate Zone



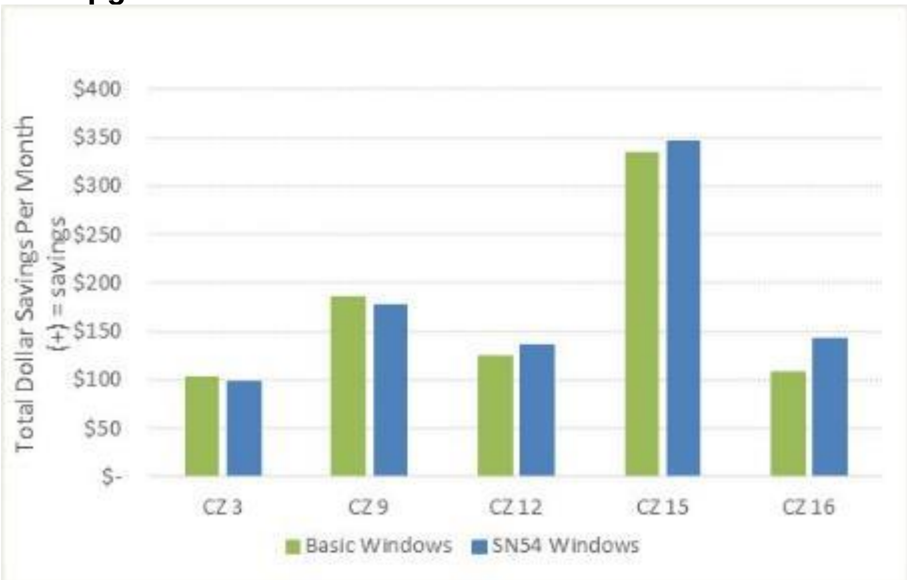
West-facing front facade, 50 percent window-to-wall ratio

Source: UC Davis EEC

Cost Savings

Cost is an essential criterion in determining what energy retrofit measures offer value as an investment. Because electricity and gas vary in cost and window retrofits differentially impact cooling and heating systems, researchers evaluated monthly cost savings, in addition to energy savings, for basic window replacements and SN54 window replacements in various climate zones (Figure 34).

Figure 34: Average Monthly Cost Savings Attributed to Upgraded Facade Window for Select Climate Zones



Source: UC Davis EEC

Researchers found that in some climate zones, SN54 windows had reduced cost savings as compared to basic window replacements due to increased thermal capacitance, or energy stored within, for buildings with high internal heat loads from people, lighting, and equipment, such as food service and general retail.

Awnings

Awnings are physical structures mounted to the exterior wall of a building to provide shade for a window, wall, door or sidewalk (Figure 35). By shading the building from direct sunlight, awnings effectively limit solar heat gain. Construction materials and style of awnings vary : some are made of fabric stretched over a frame and others use solid sheets of metal or other material. Awnings are either fixed in place or adjustable with the use of motors. Located properly, they limit glare in interior spaces. Additionally, awning systems can provide a covered space for pedestrians. When extended out over the sidewalk they provide shade and protection from rain. This protected space for pedestrians can encourage window-shopping and is especially valuable to retail spaces.

Figure 35: Multitenant Light Commercial Building with Window Awnings

Source: iStockPhoto.com

Performance Improvements

A recent addition to the awning marketplace is the integration of electronic controls systems to automatically control when or what amount of light is allowed to penetrate an interior space. Using motorized controls and light sensors, retracted awnings allow sunlight into the interior space to warm a cold room, or extend out to provide shade when hot. These awnings can provide energy savings in a variety of climates. When appropriate, MTLC retrofit packages should include automatic controls and retractable awnings.

Energy Savings

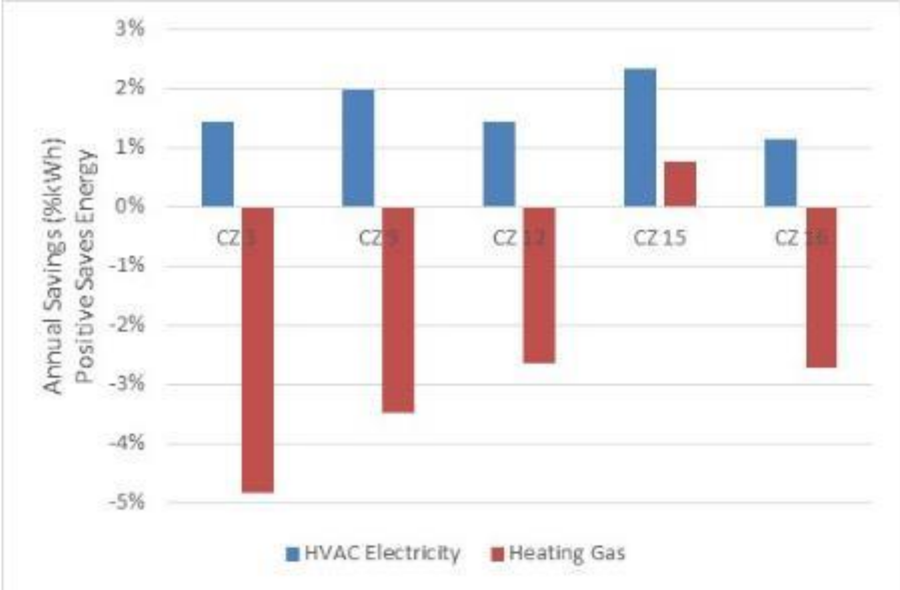
Awnings have been used as exterior shades as far back as the ancient Syrian and Egyptian civilizations to great success. A study by the University of Florida on window management strategies estimates canvas awnings, during parts of the day when sunlight directly strikes the window, can reduce heat gain for west windows, east windows, and south windows by 70-75 percent, 75-80 percent, and 50-60 percent, respectively (Hammer, 1991). However, in cold climate zones, the use of awnings can increase heating loads. Through simulations, researchers found that the addition of front façade awnings increased heating loads ("gas") during winter months, but saved 1-3 percent of the total cooling electricity use per year, as compared to similarly orientated baseline buildings without awnings. Awnings are most effective at saving energy when used in warm climate zones, where cooling loads well exceed heating loads. Table 20 and Figure 36 detail the energy savings attributed to the addition of awnings, by climate zone. Negative savings values indicate increased energy use as compared to the baseline building.

Table 20: Annual Energy Consumption Change Attributed to Addition of Awnings, Listed by Climate Zone for West-Facing Facade

Climate Zone	Awning Electricity	Awning Gas
CZ 3	1.4%	-4.8%
CZ 9	-2.0%	3.5%
CZ 12	-1.5%	2.6%
CZ 15	-2.3%	-0.2%
CZ 16	-1.1%	2.7%

Source: UC Davis EEC

Figure 36: Annual Energy Consumption Change Attributed to Use of Awnings by Climate Zone for West-Facing Facade

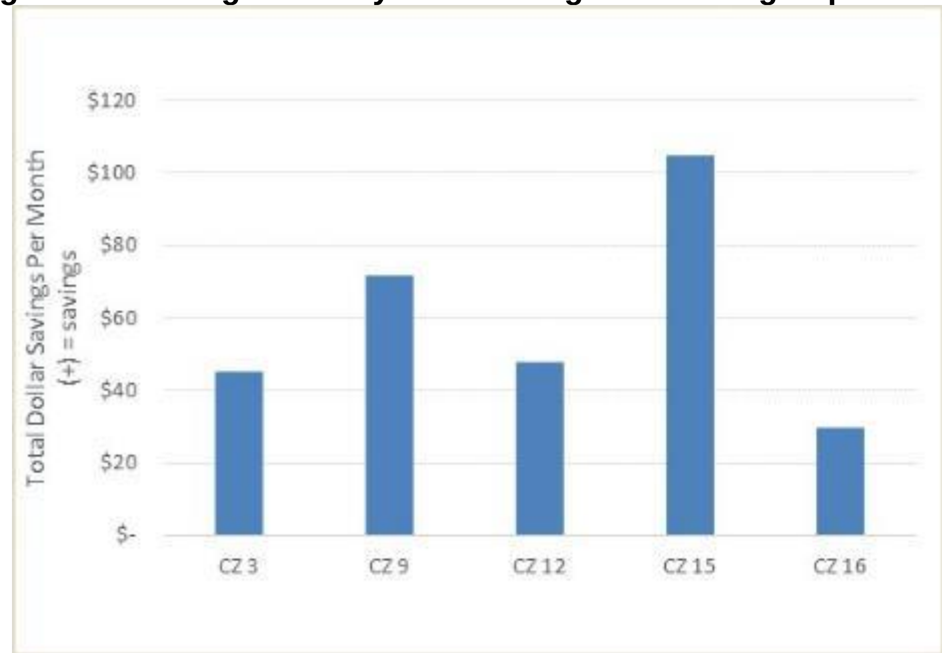


Source: UC Davis EEC

Cost Savings

Researchers evaluated average monthly cost savings for awning retrofits and found that awnings resulted in cost savings in all climate zones (Figure 37).

Figure 37: Average Monthly Cost Savings for Awning Replacement



West-facing facade in climate zone 12

Source: UC Davis EEC

Exterior Window Louvers

Exterior louvers are shading devices located directly over the outside of windows and typically are permanently mounted to the wall around the window. Louvers are made up of multiple angled slats and are constructed with a variety of materials to suit the needs of the application and climate zone.

Horizontal louvers, constructed from a series of horizontally mounted slats, are most effective on south-facing windows to limit glare and solar heat gain from direct daylight, while vertical louvers are most effective on east and west-facing windows. Figure 38 shows horizontal louvers used in a commercial application.

The control of outdoor louvers can be fixed (non-adjustable) or dynamic (adjustable) based on the sun’s position. Dynamic louvers can be manually operated or automated. Automated louvers are adjusted based on defined response to wind, light, or temperature.

Figure 38: Horizontal Louvers on Commercial Building

Source: Llambi

Performance Improvements

MTLC retrofit packages should consider using retractable or adjustable louvers. In areas where decreased cooling load is overshadowed by increased heating loads, the addition of retractable louvers or louver angle controls could improve performance during cold months, effectively producing the annual energy savings necessary to justify inclusion of the technology in building retrofits.

Energy Savings

A 2009 study by Palmero-Marrero, focused on the effectiveness of louvers and shading devices, demonstrated that exterior louvers resulted in 50 to 60 percent energy savings in hot, extreme climates and 3 to 9 percent energy savings in temperate areas (Palmero-Marrero, & Oliveira, 2010). Team researchers ran simulations for horizontal louvers in California climate zones. As compared to a baseline MTLC building, the team found that the internal energy use of heating (gas) and cooling systems (electricity) was significantly affected by the addition of outdoor window louvers.

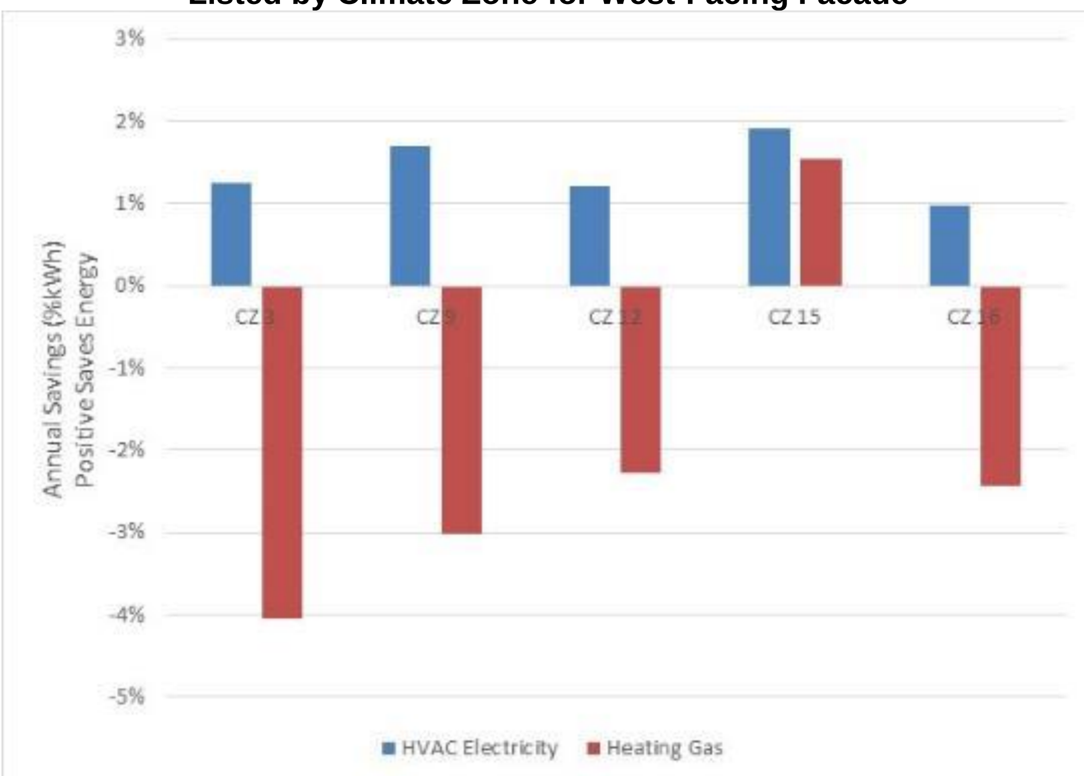
Table 21 and Figure 39 show simulated annual energy savings based on California climate zone.

Table 21: Annual Energy Savings Attributed to Addition of Horizontal Louvers, Listed by Climate Zone for West-Facing Facade

Climate Zone	Louvers Electricity	Louvers Gas
CZ 3	1.3	-4.0%
CZ 9	-1.7%	3.0%
CZ 12	-1.2%	2.3%
CZ 15	-1.9%	-1.0%
CZ 16	-1.0%	2.4%

Source: UC Davis EEC

Figure 39: Annual Energy Consumption Change Attributed to Use of Horizontal Louvers, Listed by Climate Zone for West-Facing Facade



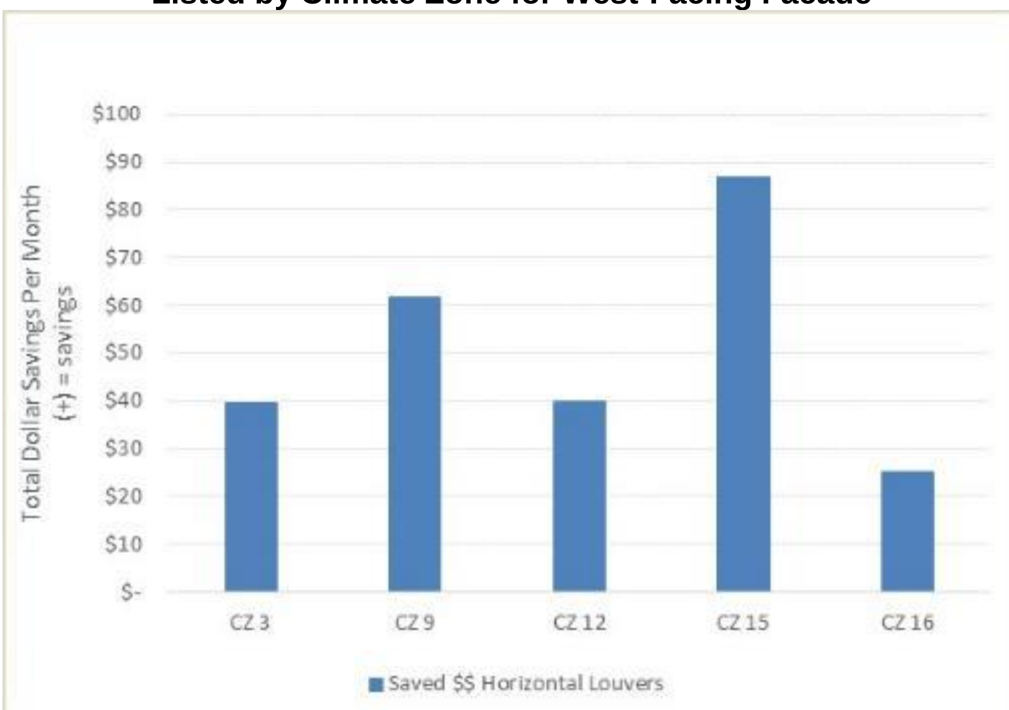
Source: UC Davis EEC

In California climates, researchers found energy savings attributed to the addition of outdoor, horizontal louvers ranged from approximately 1 to 2 percent for west-facing buildings, results which are much less than those achieved by Palmero-Marrero's simulations for temperate climates. Savings were primarily attributed to reduced cooling loads during summer months and overall savings were most prominent in more temperate, California climate zones. This is in contrast to the results obtained by Palmero-Marrero, who found that shading in harsh climates delivered the most savings. One explanation for these differences may be that for California simulations, where cooling loads are more sensitive to changes in shading, maximum savings can be achieved, as compared to very hot climates, where cooling loads are less directly affected by window shading because the overall outdoor temperature is such that significant cooling is required.

Cost Savings

Researchers evaluated average monthly cost savings for exterior window lover retrofits and found that louvers resulted in cost savings in all climate zones (Figure 40).

Figure 40: Average Monthly Cost Savings Attributed to Use of Window Louvers, Listed by Climate Zone for West-Facing Facade



Source: UC Davis EEC

Interior Roller Shades and Blinds

Internal shading devices, such as roller shades and blinds, are ideal for decorative purposes and privacy (Figure 41). The convenience of these devices in allowing access to shading controls from the inside space, without special consideration to weathering and durability, has made the energy efficiency of such devices less of a priority. The drawback to these devices, over exterior shading technologies, is that they allow exterior radiation to penetrate the space before being reflected or absorbed. The reflected radiation off of the shading device is then re-radiated into the interior space, with a small percentage being reflected back outside. Building location and orientation should be considered when selecting interior shading solutions. West and east-facing windows in California are typically most suited for vertical blinds.

Roller shades are composed of fabric or other flexible materials on a roll that can be drawn across the window aperture to reduce visibility, reflect heat, and limit glare. The material of roller shades varies from heavy blackout fabric to high VT films. Roller shades also provide some protection from solar heat gain and heat losses, but are much less effective than exterior shading devices for these purposes. Roller shade operation can be manual or automated.

Interior horizontal blinds are horizontally oriented slats mounted above a window or door to control the flow of daylight into a space. To block daylight, the slats are rotated to a closed position. Vertical options are also available. Slats are most often manually rotated.

Figure 41: Interior Roller Shades and Horizontal Blinds

Source: SunProject, Inc.

Performance Improvements

Roller shades can be integrated with building control systems, allowing the shades to be controlled based on programmed schedules or other system sensors. A timed system will adjust the blinds based on preset historical data for the location. Photosensors detect light levels in the space and the control system uses that input to adjust the blinds according to predefined user settings. Occupancy sensors tell the control system that the room is occupied or unoccupied and the control system adjusts the blinds accordingly. When the room is unoccupied, the blinds may be closed to reduce heat loss or opened to promote solar heat gain, depending on user needs. MTLC retrofits should consider the inclusion of automated controls for interior shading systems to increase savings and enhance amenities.

Energy Savings

Internal shading devices vary in material, color, and design type; and each has unique thermal properties. Opaque materials with very light colors, especially white, have been shown to have the lowest solar absorption rate compared to darker and/or translucent shades. As shown in Table 22, simply changing the color of an interior blind from white to green reduced savings to 30, from 60 percent (Hammer, 1991).

Table 22: Roller Shade Heat Reduction

Shade Type	South	West
White Opaque	64%	68%
White Translucent	56%	60%
Dark Green	30%	33%

Source: Hammer, 1991

A 2011 study by Wankanapon and Mistrick simulated the effects of interior roller shades on heating, cooling, and lighting loads for an office space. Table 23 extracted from the study, lists total energy savings from 5 to 36 percent for various types of roller shades in an area of high cooling load.

Table 23: Energy Savings for Roller Shades Used in Areas with High Cooling Load

% savings compared to total energy of base case	No Shade	ws_95	ws_189	ws_400	ds_95	ds_189	ds_400
North		19.7%	34.8%	35.2%	10.8%	34.4%	35.1%
South		21.5%	28.2%	33.5%	6.8%	16.2%	26.2%
East		25.6%	34.7%	36.2%	10.2%	24.4%	29.3%
West		18.7%	28.7%	31.5%	4.9%	18.5%	24.1%

Total energy savings percentage (heating+cooling+lighting savings) compared to the base case of no shade for Houston, Texas.

Source: Wankanapon & Mistrick, 2011

Window Films

Films can be applied to windows or skylights to decrease the amount of daylight and heat that enters the space. Window film can be applied directly to the glass, installed as an insert to the window or skylight frame, or mounted on a roller shade. Film performance is defined by VT, Color, SHGC, and U-Factor. Films that are applied directly to the window or installed as window inserts are static systems. Films mounted on a roller shade can be deployed in the same ways as typical roller shades, with manual or automatic controls.

Energy Savings

Studies indicate that the addition of films to the outside of commercial building windows can save as much as 22 percent in cooling loads. Application of the technology to the inside of windows, however, was shown to have minimal impact (1 to 2 percent) on cooling loads.

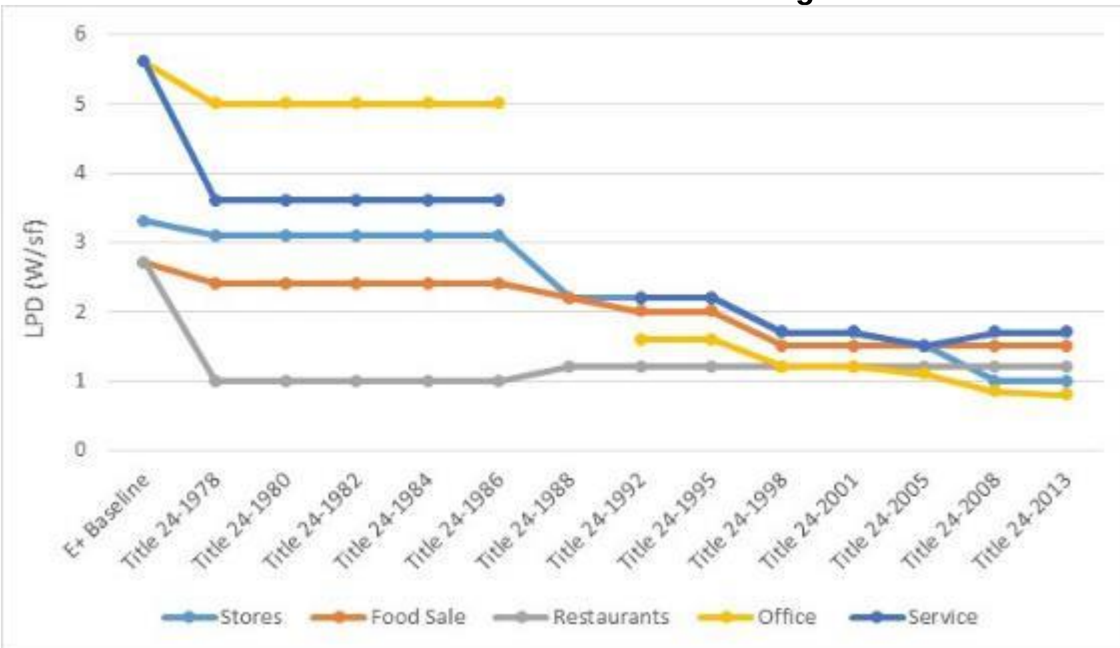
Lighting Systems and Controls

In California, lighting energy use in buildings is regulated through California's Building Energy Efficiency Standards (Title 24). Changes to lighting regulations typically occur in three-year cycles. Electric lighting energy use can be characterized by lighting power density (LPD) (W/sq-ft) or annual lighting energy use intensity (W/sq-ft/yr).

Research and development (R&D) on fluorescent lighting technology, including improvements to light source efficacy and overall luminaire efficacy, has led to continued reductions in the allowed LPD contained in Title 24. LPD was unchanged for over a decade until in 1992 when Title 24 was completely updated and LPDs reduced to reflect improvements in lighting technology. These measures are estimated to have saved 50-75 percent over the former Title 24 code.

R&D throughout the 1990s contributed to the continued decrease of LPD in nonresidential spaces. Fluorescent dimming began to take hold in the 1990's as well, coupled with increased R&D in daylighting and other lighting controls systems, leading to major code revisions. Beginning with the 2005 code, and continuing through the present, energy savings with each cycle continue to reach 40-50 percent compared to the previous cycle. The addition of LED technology will continue to drive down allowed LPD over the next decade. Figure 42 shows allowed LPD by business type and Title 24 publication from 1978 to 2013.

Figure 42: Lighting Power Density by Space Type Over Time in California Commercial Buildings



Source: UC Davis EEC and California Energy Commission

In addition to LPD, a lighting system can be defined by the source technology available and/or used at the time of the LPD allowance. For the MTLC sector, three source technologies are considered, each defined by a typical lighting efficacy.

- Linear fluorescent T12 lamps
- Linear fluorescent T8 lamps
- LED lighting technology

The performance and savings detailed in this report assume lighting system retrofits from fluorescent T12 or T8 technology to LED technology, and/or lighting controls upgrades. General information on LED lighting and controls solutions is provided in the following sections.

Light-Emitting Diode Technologies

The development and engineering of LEDs goes back more than a half century, with the first practical application of LEDs coming in 1962. LEDs for general illumination building applications emerged in the early 2000s. LEDs produce light by different physical processes than conventional lighting sources. LEDs do not use electrical filaments, electrodes, or gaseous discharge processes to produce light. Instead, LEDs emit light through a process called solid-state electroluminescence. Electroluminescence is an optical and electrical phenomenon in which a material emits light in response to the passage of an electric current or to a strong electric field. White light is achieved by mixing colored light from multiple, single-color LEDs or adding phosphor coatings to the

LEDs, which absorb single-color light and emit multiple colors that appear white when combined.

LEDs are highly directional, spot sources. Light is emitted from a very small amount of actual surface area on the LED chip so the output must be diffused using secondary methods such as lenses or reflective optics.

The efficacy of LEDs is rapidly improving, with some commercial products delivering as much as 170 lumens per watt (lm/W). Product life also continues to increase, with current rated life in the range of 25,000 to 100,000 hours. Correlated color temperature (CCT) can be provided for almost any range, but CCT outside a typical range of 2,500K to 5,000K is usually not desirable for most applications.

There are many advantages to using LED technology as compared to traditional incandescent, fluorescent, or HID sources, including:

- The lifetime of an LED product is significantly longer than most alternatives, which reduces product replacement, maintenance, and recycling costs.
- LEDs are fully dimmable, last longer when dimmed, and are not affected by on-off cycling, which makes them well suited for use with lighting controls solutions.
- LEDs are good for certain applications in cold environments, since efficacy and product life both increase with lower operating temperature.

There are many factors to consider when selecting, installing, or comparing different LED lamps or luminaires. LED lighting solutions should operate per manufacturer's claims over the life of the product and deliver similar, if not better, photometric and electrical performance as compared to the products they claim to replace. Information on key factors to consider for LED lighting retrofits are provided below. Lighting professionals should be consulted as part of the retrofit process to ensure the most appropriate products are used.

- Heat management: Operating temperature directly affects the lifespan of the LED so effective heat management is critical to achieving the rated performance. Heat management occurs at the luminaire level in the housing and heat sink, which moves heat away from critical components and dissipates it into the environment. Precision machining, visible heat sink fins, and luminaires with a large surface area for dissipating heat are desirable as they indicate that heat management has been addressed.
- Optics and housing materials suitable for rnvironment: Environmental factors such as dust and humidity are more important with longer life spans because the cumulative effect of mild environmental factors over years, and even decades, can cause any luminaire to fail.
- Light output and distribution: For retrofit projects, how the light will be delivered to the space should be modeled before assuming a one-for-one retrofit from past technologies to LEDs. LED luminaires may not provide the same illuminance

levels on task surfaces with a similar distribution pattern to predecessor technologies. Photometric data should be evaluated and the existing layout should be modeled with new LED products to help determine if a new lighting layout is needed.

- Dimming: Dimmable lamps and luminaires are preferable. Dimming can save additional energy, extend the life of an LED product, and allow for customized control of illumination levels. For projects that must comply with California's Building Efficiency Standards (Title 24), the LED luminaire may be required to dim between 10 and 100 percent power.
- Product life: In the field, the lifespan of LEDs appears to be limited by the various components and materials of the complete luminaire assembly, rather than specifically by the LED source. In particular, the LED driver, or any other electronic components, is likely to fail or require maintenance long before the LED module because of the relatively short lifespan of electrolytic capacitors. A capacitor, which can be found in most electronics, is a basic electric component that stores electrical energy. It is important to consider the lifetime of system components and not just the lifetime of the LED source.

Other quality issues surrounding LED products include visible flicker, color consistency, color rendering, and power factor.

Energy Savings

Researchers found minor changes to the overall heating and cooling energy use when upgrading to different lighting technology (Table 24). Over the course of the year, reductions in cooling load, achievable due to the reduced heat generated by the updated lighting systems, were offset by increased heating needs during cold months. Lighting energy savings were significant; however, simulated savings suggest that USDOE reports and others may be overestimated energy savings. When the overall lighting design is considered, and spaces are designed to industry recommended light levels, lighting electricity use savings between fluorescent and LED technology is about 75 percent of what published reports have claimed.

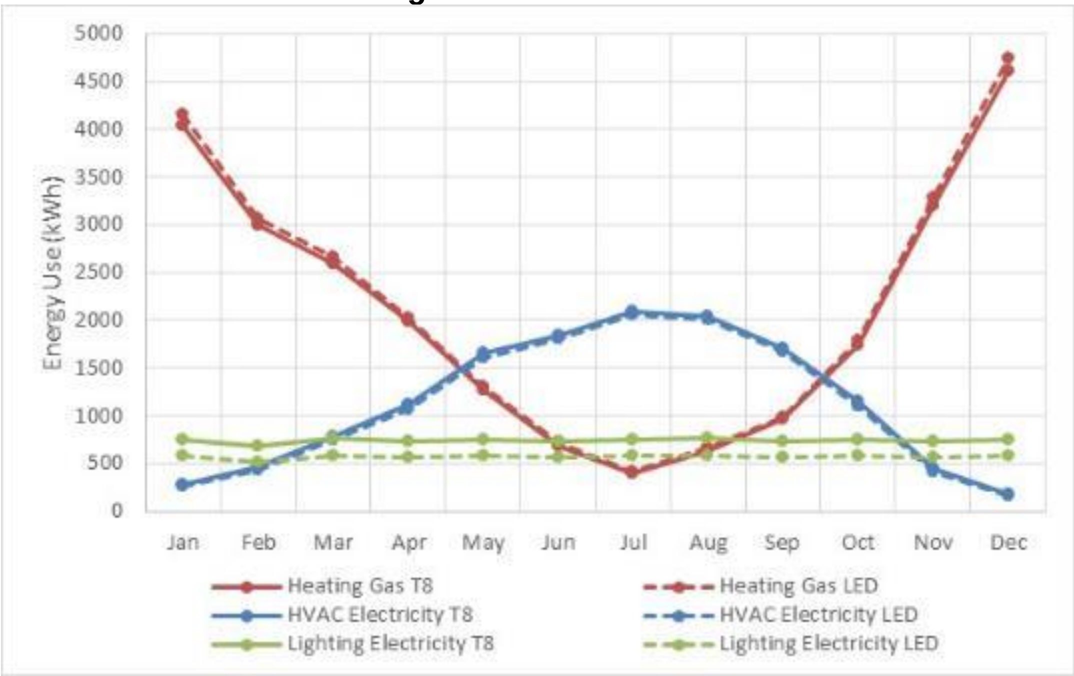
Team researchers found that the change from T8 fluorescent to LED technology generated approximately 25 percent annual savings for an average MTLC tenant (Figure 43). A much more drastic improvement of 32 percent, was found when lighting technology was converted from T12 to T8 lighting technology (Figure 44). These measures saved approximately 4,000 kWh a year in a T8 conversion and about 5,000 kWh when switching to LED.

Table 24: Energy Use and Savings for Lighting Retrofit Scenarios

	Heating Gas (kWh)	HVAC Electricity (kWh)	Lighting Electricity (kWh)
T12 Energy	24,211 (-4%)	14,329 (+4%)	11,750 (+32%)
T8 Energy	25,105 (---)	13,719 (---)	8,891 (---)
LED Energy	25,785 (+3%)	13,344 (-3%)	6,810 (-23%)

Source: UC Davis EEC

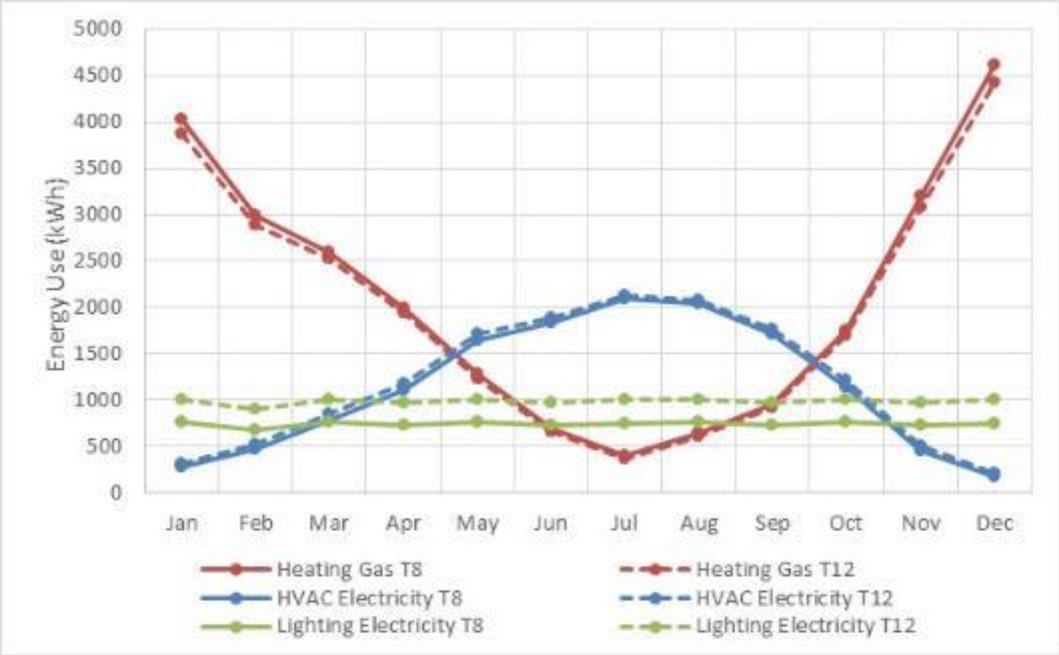
Figure 43: Energy Use for T8 to LED (Baseline) Technology in General Retail Multitenant Light Commercial Establishment



South-facing facade in climate zone 12

Source: UC Davis EEC

Figure 44: Energy Use for T12 and T8 Technology in a General Retail Multitenant Light Commercial Establishment



South-facing facade in climate zone 12

Source: UC Davis EEC

Tubular Light-Emitting Diode

Tubular LED lamps (TLEDs) are available to replace common linear fluorescent light sources such as 2' and 4' T8 lamps. TLEDs use an array of LEDs distributed along the length of the lamp tube to deliver the same form factor as a linear fluorescent lamp. TLEDs are often marketed as a one-to-one replacement for fluorescent lamps, but a large majority of tubular LED replacement lamps require a different electrical system.

New electrical components and rewiring are often necessary to make an existing fixture compatible with the new lamps. Based on the particular LED replacement lamp product being considered, a TLED retrofit will typically require changing the electrical wiring, replacing the ballast with an LED driver, or altering the existing lamp holders (or "tombstones") to accommodate the new lamp.

"Drop-in" tubular LED replacement lamps incorporate a driver into the lamp. This allows the tubular LED to use existing fluorescent ballasts, with no additional rewiring. With these products, the tubular LED bi-pins connect directly to the existing G13 lamp holders. The thermal performance of this technology must be evaluated while installed in-situ to ensure lamp life will not be compromised by exposure of the driver components to higher temperatures.

The majority of LED replacement lamps with internal or integrated drivers require line voltage be supplied directly to the lamp holders, bypassing the fluorescent ballast. Internal driver LED lamps may be either single or double-ended, with power running to one or both ends. LED replacement lamps with external or remote drivers differ and require their driver be connected to either the existing tombstone, or directly to the lamp, while using the tombstone merely for stability.

TLED replacements that do not require wiring alterations may be considered a repair and do not trigger the Title 24 code compliance process. An existing linear fluorescent luminaire with TLED lamps is not recognized as an LED lighting system for compliance purposes.

Energy Savings

Assuming safety and performance considerations are addressed, TLEDs can deliver significant energy savings compared to existing linear fluorescent lamps. Linear lamps account for 83 percent of installed commercial lamps in California (Itron Inc., 2014). The top three market sectors using linear lamps are commercial offices (30 percent), schools (16 percent) and retail establishments (14 percent). Less than 0.5 percent of installed linear lamps use LED technology. According to the survey report, across most of the commercial sector, existing fluorescent lamps are primarily standard performing products (700 – 800 series T8 lamps with approximately 80 – 90 lm/W or T12 technology).

Equivalent TLEDs are available, which are 10 to 50 percent more effective than standard fluorescent lamps. A recent search of the Lighting Facts website revealed three products with lamp efficacy greater than 140 lm/W and light output equivalent to a standard T8 lamp.[16] For indoor commercial lighting, which accounts for approximately 26,000 GWh annually, conversion of linear fluorescent technology to LED can save at least 2,600 GWh each year, assuming just a 10 percent improvement in efficacy between incumbent technology and TLED replacements. Savings could be much greater and are contingent on the specific product installed.

Light-Emitting Diode Omnidirectional A19 Lamps

A variety of LED A19 alternatives are now available to replace traditional incandescent, halogen, and CFL lamps. For example, the Design Lights Consortium (DLC) Qualified Products List includes multiple LED A19 lamps ranging from 6 to 23W with a luminous efficacy range of 52 to 100 lm/W. Results from the USDOE Commercially Available LED Product Evaluation and Reporting (CALiPER) program show that the cost per lumen of A19 LED lamps dropped by 50 percent between August 2010 and November 2011. In addition, LED replacement lamps have longer lifetimes than incandescent and CFLs, with rated lifetimes ranging from 10,000 to 50,000 hours

Information on LED A19 performance is available from a variety of sources. For example, the UC Davis CLTC hosts a database that provides access to LED replacement

16 http://www.lightingfacts.com.

lamp performance data for statistical analysis and comparative evaluation.[17] It includes data from multiple sources, including CLTC test labs, other research programs, certified laboratories, and lighting manufacturers.

Light-Emitting Diode Directional Lamps/Track Lighting

Track lighting is typically used in general retail spaces, restaurants, galleries, museums, and some residential spaces. For sensitive applications, LEDs can reduce damage to organic art and historical pieces caused by ultraviolet radiation, which is more prevalent with incandescent and halogen sources. In all applications, LED systems require less maintenance, which translates directly to cost savings. Traditional track lighting typically uses incandescent or halogen pin or screw-base lamps (with and without reflectors) in combination with track heads and an energized track. LED retrofit options for track lighting include LED lamp replacements and a full retrofit of track heads with dedicated LED units. Dedicated LED track heads that fully replace the existing track head are designed with components (drivers, diode arrays, housings, heat sinks, and optics) built to function together as a unit. Dedicated LED track heads can often be installed on the same track used by traditional pin and screw-base lamps. LED track heads are available from a variety of manufacturers to replace existing systems.

According to the CSS report, with the exception of the retail sector, less than 5 percent of commercial pin and medium screw base lamps use LED technology (Itron Inc., 2014). In the retail sector, just 13 percent of these lamps use LED sources.

Energy Savings

Lamps used in track lighting are predominantly incandescent, halogen, or metal halide (MH), so switching to LEDs can reap deep energy savings. Four studies looking at replacement of halogen lamps with LEDs, or existing halogen systems with new LED track systems, produced energy savings from 60 to 80 percent. PG&E estimates that within its service territory, conversion of existing MR16 lamps, which are the most used directional light source (for track and other applications) to dedicated LED units could save 77 percent, with associated annual savings of approximately 420GWh. Most dedicated LED track heads range in efficacy between 40 to 90 lm/W with savings estimates similar to those stated above for directional lamps.

Dedicated Light-Emitting Diode Luminaries and Luminaire Retrofit Kits

Linear fluorescent troffers and surface mount luminaires are ubiquitous to many applications, including commercial offices and classrooms. In California, troffers account for 30 percent and surface mount luminaires account for 16 percent of all installed linear fluorescent technology. Troffers comprise a major portion of the lighting in commercial spaces nationwide and represent more than 50 percent of the luminaires currently in use in the United States.

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17 ledperformancedatabase.org.

Implementing LED technology as part of a luminaire retrofit can be done in two ways.

1. Installing an LED retrofit kit: These kits have the light source replacement, related electrical components, lenses, and, in some cases, reflectors in a single package. Since necessary electrical components are included, the kit will work as long as it is the right size for the existing troffer or fixture. Luminaires with atypical dimensions may not support all retrofit kits, so samples should be tested with the existing fixture and/or space to ensure compatibility and a successful retrofit.
2. Replacing the existing luminaire with a dedicated LED luminaire: This provides the opportunity to incorporate on-board sensors into the new luminaires if wireless or external controls are not being used. LED luminaires offer a simple electrical installation since the entire luminaire is being replaced. They also typically offer a higher efficacy than lamp replacements or retrofit kits and reduce installation complications. LED fixtures typically have an external driver, which makes it simpler to replace in the event of a failure. A single LED fixture may be offered with a variety of current, color, and control options.

In some cases, replacing or modifying a luminaire triggers Title 24 compliance; but, the standards do not specify what technology must be used to fulfill requirements. There are ample savings opportunities in many commercial applications, regardless of LPD and controls requirements contained in the current standards.

Energy Savings

The energy savings from LED troffer retrofits vary. LED retrofit kits are more effective than fluorescent luminaires by approximately 10 percent, an increase from an average of 60 to 66 lm/W for retrofit kits, and 69 lm/W for replacement lamps. LED luminaires offer higher efficacies, an average of 89 lm/W, a 44 percent increase from fluorescent troffers. The DLC Qualified Products List includes luminaires and retrofit kits from 70 to 138 lm/W. According to a CaliPER study, LED retrofit kits (41W) and replacement luminaires (42W) consume significantly less power than 2 or 3-lamp fluorescent equivalents (62 W).

Daylight Harvesting Controls

Control systems can be combined with photosensors, windows, skylights, and tubular daylighting devices (TDDs) to switch or dim electric lights depending on the light available. The photosensors tell the control system how much light is being provided and, based on the presets of the control system, the electric lights can be switched on, off, or dimmed to maintain a steady light level.

Using the MTLC tool, researchers simulated the effects of installing skylights in an MTLC tenant space. Lighting and HVAC energy use for the space was calculated for two scenarios. The first scenario assumed only the addition of skylights. The second scenario assumed the addition of skylights and daylighting harvesting controls. Researchers compared the two scenarios and found that the addition of skylights did not save energy unless the skylights were paired with daylighting harvesting controls for the electric lighting. Table 25 and Figure 45 show the annual energy use and savings as compared to the baseline scenario for these tenant-level MTLC solutions.

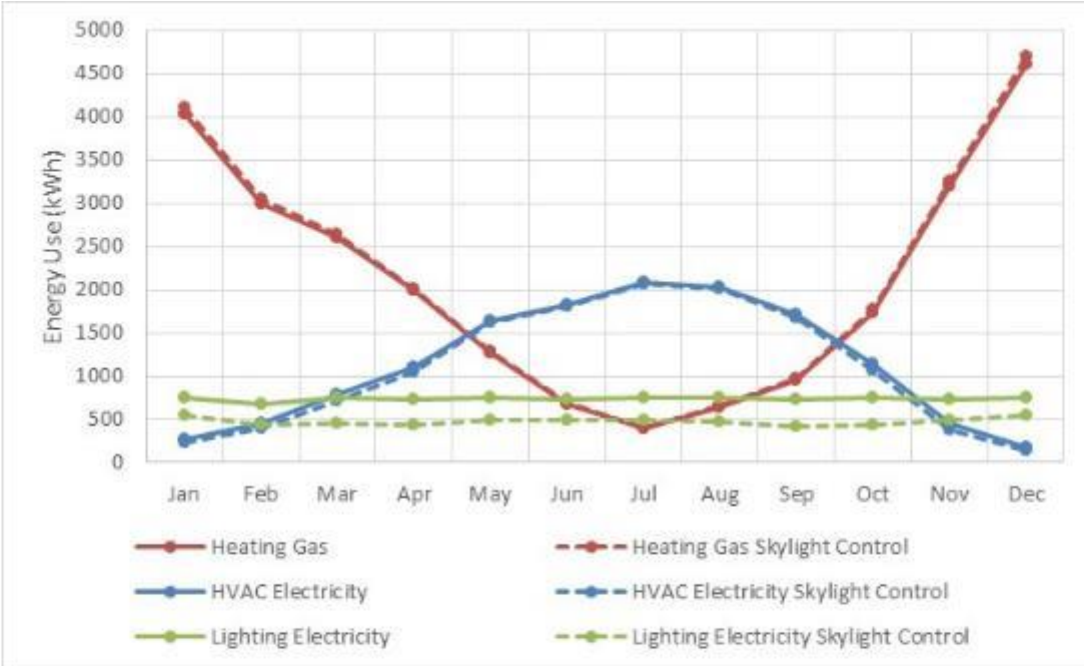
Table 25: Annual Estimated Energy Use and Savings of Two Skylight Retrofit Scenarios for Multitenant Light Commercial Tenant-Space in Climate Zone 12

	Heating - Gas Use kWh / savings	Cooling & Ventilation Electricity Use kWh / savings	Lighting Electricity Use kWh / savings	Combined Electricity Use kWh / savings
Baseline space: no skylights, no daylight harvesting controls	25,105	13,719	8,891	22,610
Skylights only	25,180 (0%)	13,823 (-1%)	8,891 (0%)	22,714 (0%)
Skylights and daylighting harvesting controls	25,578 (-2%)	13,153 (4%)	5,722 (36%)	18,875 (17%)

Source: UC Davis EEC

Researchers found that the addition of skylights/TDDs, while improving the level of daylight in the interior space, did not automatically reduce lighting or HVAC energy use. Lighting savings were only achieved if building occupants chose to manually extinguish or reduce their electric lighting. In fact, the addition of skylights/TDDs increased the HVAC load by 1 percent. This was a result of increased solar heat gain in the space, which was offset by increased cooling. In contrast, concurrently installing dimming controls along with skylights/TDDs resulted in 36 percent electricity savings as compared to the baseline.

Figure 45: Lighting and HVAC Energy Use Profile for a General Retail Multitenant Light Commercial Business Retrofitted with Skylights and Daylight Harvesting Controls



Source: UC Davis EEC

Other than skylights, energy savings can also be attributed to dimming based on available daylight provided by facade windows. Using the MTLC tool, researchers simulated a building face with both a 50 and an 80 percent window wall ratio (WWR). They found that the energy savings from dimming the front zone of the building was significant (Table 26).

Table 26: Annual Estimated Energy Use and Savings of Daylight Harvesting Controls used in Side-Daylighting for Multitenant Light Commercial Tenant-Space

	Gas (kWh)	HVAC Elec. (kWh)	Lighting Elec. (kWh)	Combined Elec. (kWh)
Baseline	26,527 (---)	14,404 (---)	8,891 (---)	23,295 (---)
50%WWR, Control	25,452 (+1%)	13,121 (-4%)	6,169 (-31%)	19,290 (-15%)
80%WWR, Control	26,900 (+1%)	13,779 (-4%)	5,711 (-36%)	19,489 (-16%)

Source: UC Davis EEC

Both the 50 and 80 percent WWR with lighting controls reduced the annual lighting energy use. Using daylighting harvesting control systems resulted in 31 percent annual savings for the 50 percent WWR and 36 percent savings in buildings with an 80 percent WWR. In addition, researchers found that the savings from daylight harvesting changed very little between west and south-facing buildings (less than 5 percent), but had much higher percentage savings for buildings with a lower HVAC energy use, such as food service establishments (about 40-50 percent savings).

Other Lighting Controls

Lighting controls can prolong lamp life, lower maintenance costs, increase energy savings, and reduce light pollution. There are several types of lighting controls, including occupancy controls, photosensors, time clocks, and energy management systems (EMS) (see Figure 46). These technologies can be used to automatically dim lights or turn them off, when doing so will not compromise safety or comfort.

Some lighting manufacturers offer luminaires with integrated controls and many light sources can be paired with external control options. Controls can be implemented with a variety of sources, including LED, induction, fluorescent, and HID lamps. The end result is a smart lighting system that optimizes energy use, offers the right amount of light output for the application, and reduces operating costs.

Controls can be layered as luminaire-integrated photosensors and motion sensors for all area luminaires with a networked control system employed to monitor and adjust lighting, or they can be as basic as a one time-clock for an entire facility. Lighting controls are often installed at the circuit or luminaire level. Specific configurations will vary according to each system type and manufacturer.

Figure 46: Photosensor (left), Dimmer (middle), Occupancy Sensor (right)

Source: WattStopper

There are a variety of lighting control strategies, each with benefits and challenges for implementation and deployment.

- Occupancy control strategies use motion-detecting sensors to reduce electric lighting by reducing light levels when the space is vacant. Motion detection uses various technologies, including image recognition, ultrasonic, audio, and passive infrared (PIR) detection. Businesses with very little downtime benefit less from occupancy sensors than a store with erratic and sometimes sparse occupancy.

- Daylight control strategies reduce electric lighting in response to available daylight in a building interior. Daylight enters through building fenestration, such as windows or skylights. This strategy pairs photosensors with dimmable light sources.
- Personal tuning most closely resembles manual control, the traditional form of lighting control that is user-defined at the switch or dimmer level. Occupants can adjust the lighting to desired levels.
- Institutional tuning, or task tuning, reduces light levels to provide adequate illuminance for the typical task performed in the space. Dimming controls are paired with a dimmable light source.
- Scheduling allows for automated lighting control, switching, or dimming lighting at predefined points in time, based on a user-defined schedule. This strategy uses time clocks or the energy management feature of control systems.
- Lumen maintenance reduces the initial light level of a new lighting system, increasing the light output over its life to maintain illuminance levels as the light source degrades. This strategy leverages the initial system overdesign, or light output that exceeds design requirements, to save energy early in the lighting system’s life.

Energy Savings

A Lawrence Berkeley National Laboratory report on the energy saving potential of indoor lighting controls provides potential energy savings for typical lighting control strategies (Williams et al., 2012):

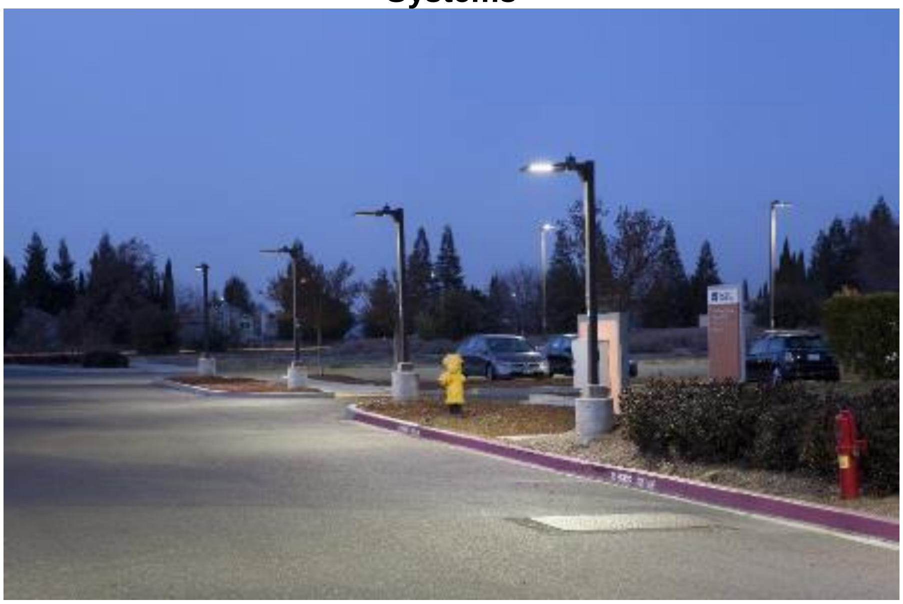
- Occupancy controls: 8 to 38 percent
- Daylighting controls: 17 to 38 percent
- Personal tuning: 10 to 50 percent
- Institutional tuning: 18 to 53 percent
- Combined multiple types of controls: 19 to 56 percent

Outdoor Lighting

LED luminaires and retrofit kits are a simple one-to-one replacement for traditional HID outdoor lighting. LED luminaire efficacy currently exceeds most HID lighting. The color quality of LED outdoor lighting far exceeds high-pressure sodium (HPS) and is comparable to most MH products. When evaluating LED luminaires, it is also important to consider optical distribution, luminaire mounting height, and environmental surroundings. In certain retrofit applications, additional energy savings may be available by decreasing the number of luminaires due to the improved light quality of LED products as compared to some HID. At MTLC sites, parking lot lighting, perimeter building lighting, pathway lighting, and signage are all excellent candidates for LED lighting retrofits.

Sensors and lighting controls can achieve significant energy savings when combined with LED outdoor lighting by automatically switching or dimming lights based on time of day, available daylight, occupancy, vacancy, or the scheduling commands of a lighting control system or building EMS. Control solutions may be integrated in the fixture, installed at the circuit level to control zones of outdoor lighting, or consist of a fully networked control system (Figure 47).

Figure 47: Light-Emitting Diode Parking Area Luminaries with Networked Control Systems



Source: UC Davis CLTC

Networked lighting control systems can maximize energy savings and minimize maintenance requirements for an MTLC site. The network can connect luminaires using pre-existing wiring, a new cable system, or a wireless communication system that employs radio frequency modules. Networked systems often allow users to see a detailed energy use profile, receive automated maintenance alerts, and adjust operating schedules. These features can often be accessed remotely, via the Internet.

Performance Improvements

The primary drawback to using occupancy-based controls in outdoor applications is the limited range of the occupancy sensor. As part of another research project, CLTC partnered with manufacturers to evaluate and refine an advanced microwave outdoor sensor with expanded coverage range and sensitivity (Figure 48). Using this sensor would increase the number of applications appropriate for outdoor lighting controls within the MTLC market. This sensor, or others of comparable performance, should be used as part of appropriate MTLC retrofit technology packages.

Energy Savings

The basic estimated energy savings associated with retrofit of HID outdoor lighting with LED technology is approximately 20 to 40 percent. This is based on comparison of products with equivalent delivered luminous flux (light output from the fixture). In many cases, due to the improved color quality of the light, less light may be preferred to maintain the same overall level of visual acuity. The addition of advanced lighting controls in outdoor applications has been shown to more than double these savings.[18] Table 27 and Table 28 provide a comparison of LED and HID technology for 70 and 150W equivalents, respectively, without controls, showing a savings of 18 and 41 percent. A case study on adaptive controls for outdoor lighting reported savings of 78 to 88 percent when switching from HPS to LED lighting (see Figure 49).

Figure 48: Schematic of Outdoor Microwave Detection Range and Sensitivity

Source: UC Davis CLTC

18 CLTC original data

Table 27: Estimated Savings for Outdoor Light-Emitting Diode Lighting Retrofits Compared to High-Intensity Discharge Technology (70 W equivalent)

Item Compared	LED	HPS	MH-pulse (magnetic ballast)	MH-pulse (electronic ballast)
Initial lamp lumens (photopic)	5026	6300	5200	6030
Mean lamp lumens (photopic)	4573	5380	3400	4824
Average luminaire efficiency ratio	0.70	0.70	0.70	0.70
Ballast factor	1	1	1	1
Average lumen depreciation factor (@EOL)	0.70	0.70	0.60	0.80
CCT	4000	1900	3000	3000
CRI	70+	22	75	75
Lamp watts	56	70	70	70
System watts	56	81	95	79
Rated lamp life	50,000+	24,000	10,000 (h)	10,000 (h)
Start-up time/restrike time	Instant	3-4/1	2-4/5-7	2-4/5-7
Component warranty (years)	10	5	5	5
Controls capability	Yes	No	Yes	Yes
Operating temperature (˚F)	-20 to 150	T>-40	T>-20	-20 to 140
Initial delivered lumens (photopic)	3518	4410	3640	4221
Mean delivered lumens (photopic)	3201	3766	2380	3377

Item Compared	LED	HPS	MH-pulse (magnetic ballast)	MH-pulse (electronic ballast)
End-of-life delivered lumens (photopic)	2463	3087	2184	3377
Lamp efficacy (lm/w)	90	90	74	86
Luminaire efficacy rating	63	54	38	53
Savings % of LED retrofit based on system wattage	--	31%	41%	29%

Comparison based on systems with initial delivered lumens equivalent to ~70 W PS-MH.

Source: UC Davis CLTC

Table 28: Estimated Savings for Outdoor Light-Emitting Diode Lighting Retrofits Compared to High-Intensity Discharge Technology (150W equivalent)

Item Compared	LED	HPS	MH-pulse (magnetic ballast)	MH-pulse (electronic ballast)
Initial lamp lumens (photopic)	13317	15800	12900	12900
Mean lamp lumens (photopic)	11985	13400	8000	8000
Average luminaire efficiency ratio	0.70	0.70	0.70	0.70
Ballast factor	1	1	1	1
Average lumen depreciation factor (@EOL)	0.70	0.75	0.60	0.60
CCT	4000	2100	3000	3000
CRI	70+	22	75	75
Lamp watts	136	150	150	150
System watts	136	170	180	165
Rated lamp life	50,000+	24,000+	10,000 (h) 15000 (V)	10,000 (h) 15000 (V)
Start-up time/restrike time	Instant	3-4/1	2-4/5-7	2-4/5-7
Component warranty (years)	10	5	5	5
Controls capability	Yes	No	No	Yes; dimmable to 60%
Operating temperature (˚F)	-20 to 150	-40	T>-20	-20 to 140
Initial delivered lumens (photopic)	9322	11060	9030	9030
Mean delivered lumens (photopic)	8390	9380	5600	5600

Item Compared	LED	HPS	MH-pulse (magnetic ballast)	MH-pulse (electronic ballast)
End-of-life delivered lumens (photopic)	6525	8295	5418	5418
Lamp efficacy (lm/w)	98	105	86	86
Luminaire efficacy rating	69	65	50	55
Savings % of LED retrofit based on system wattage	--	20%	24%	18%

Comparison based on systems with initial delivered lumens equivalent to ~1500 W PS-MH.

Source: UC Davis CLTC

Figure 49: Savings of Adaptive, Outdoor LED Lighting Compared to HPS Base Case

	STREETLIGHT RETROFIT			POST-TOP RETROFIT		
	BEFORE	AFTER		BEFORE	AFTER	
Technology	HPS without controls	LED with network controls	78% SAVINGS	HPS without controls	LED with motion sensors and network controls	88% SAVINGS
System Power	289W	101W		128W	44W (High) 9W (Low)	
Annual Energy Consumption	1,266kWh	278kWh	988kWh	561kWh	70kWh	491kWh
Annual Energy Cost	$139	$31	$108	$62	$8	$54
Annual Maintenance Cost	$18	$0	$18	$18	$0	$18
Total Annual Cost	$157	$31	$126	$80	$8	$72
Energy Cost Over 15 Years	$2,085	$465	$1,620	$930	$120	$810
Maintenance Cost Over 15 Years	$270	$0	$270	$270	$0	$270
Total 15-Year Operating Cost	$2,355	$465	$1,890	$1,200	$120	$1,080
Total 15-Year Cost for All Fixtures	$63,585	$12,555	$51,030	$12,000	$1,200	$10,800

Metrics listed are per-fixture quantities unless otherwise noted.

Number of Streetlight Fixtures	27	Pre-retrofit Lifetime	24,000 hours
Number of Post-top Fixtures	10	Post-retrofit Lifetime	100,000 hours
Cost of Labor (Including Bucket Truck Cost)	$135/hr	Lamp Cost	$20
Replacement Time	1 hour	Capacitor Cost	$70
Energy Cost	$0.11/kWh	Annual Hours of Use	4,380 hours
Occupancy Rate (Post-Top Areas)	20%	Lifetime	15 years

Source: UC Davis CLTC

Heating, Ventilation, and Air Conditioning Technologies

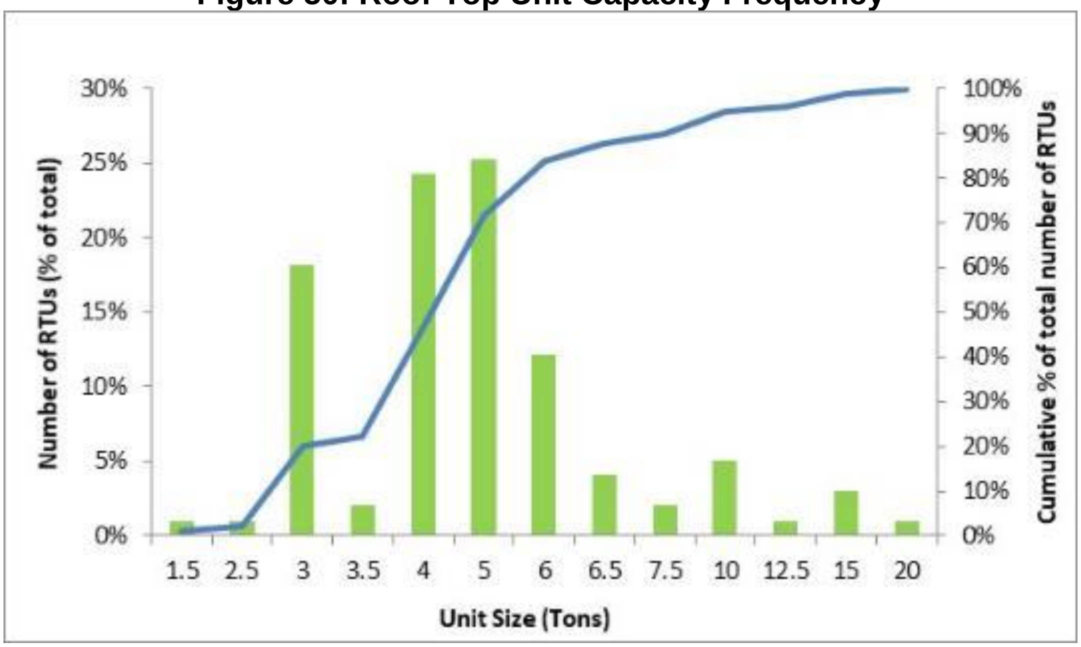
Most commercial buildings have roof top units (RTUs) that provide heating, ventilation and air conditioning (HVAC) to the area below. When cooling is needed, a blower in the RTU draws warm air in from the space below, through the cooling coil, and then provides cooled air back to the space. When heating is needed, a blower in the RTU draws cool air in from the space below, through the heating coil, and then provides the heated air back to the space. RTUs also ventilate the commercial space, through an air damper and fan, always supplying outside air. An occupancy or CO2 sensor can respond to changes in ventilation demand, bringing in more air as needed. An RTU economizer is a control system that takes advantage of outside air conditions, saving energy when cooling is needed. When the outside temperature is lower than the inside temperature, the economizer opens the outside air damper of the RTU and brings in cool air. This saves energy as the air is not being cooled mechanically.

Based on findings outlined in Chapter 2, researchers selected the most appropriate HVAC technologies for the MTLC market. Specifically, they selected technologies that focus on retrofit RTU optimization controls, thermostats, and evaporative cooling. In addition, researchers evaluated the potential benefits from HVAC system downsizing.

Heating, Ventilation, and Air Conditioning Controls

There are a variety of load management technologies available, including technologies for enabling the end user, building manager, and/or a utility provider to influence and understand the operation of their HVAC systems. Based on UC Davis Western Cooling Efficiency Center (WCEC) field surveys in MTLC buildings, the research team found most RTUs to be small (2 to 10 ton, 5-ton on average), with one compressor, and a single-speed fan (Figure 50). On average these RTUs were 12 years old and had not been maintained routinely. In addition, they were usually not equipped with controllable dampers for economizer operation. Researchers found that there is a significant potential to improve operation of these units by incorporating modern load management technologies.

Figure 50: Roof-Top Unit Capacity Frequency



Source: UC Davis WCEC

Heating, Ventilation, and Air Conditioning Controller Retrofit Kits

Researchers evaluated available retrofit kits and selected four retrofit technologies that showed potential for providing energy savings in MTLC buildings. These devices are likely to reduce energy consumption and fit an infrastructure and market-model consistent with the needs of small and medium-sized businesses (see Table 29). With the exception of the Jade economizer controller, all of the retrofits feature a variable speed drive for the evaporator fan, which, when coupled with intelligent control algorithms, claim to effectively reduce the RTU's power consumption under part-load and fan-only operation. Certain devices also have additional features such as advanced economizers, dampers for split face evaporator coils, and variable speed drives for the compressor.

Table 29: Controller Retrofit Kits

Category	Manufacturer	Product
Controller Retrofit Kits	Enerfit	Enerfit
	Transformative Wave Technologies	CATALYST
	DTL Controls	Digi-RTU
	Honeywell	Jade W7220 Economizer Controller

Source: UC Davis WCEC

Energy Savings

Although there are slight differences among the retrofit devices chosen, independent research, through both simulations and field studies, has demonstrated that the selected devices can provide energy savings as great as 50 percent. A simulation study by Pacific Northwest National Laboratory that explored both CATALYST style (staged fan controller) and Enerfit/DIGI-RTU style (continuous VFD control) retrofits showed potential annual energy savings from 22 to 90 percent (Wang et al., 2013). Furthermore, field testing of an array of advanced retrofit devices including Enerfit, CATALYST, and Digi-RTU by the San Diego Gas and Electric Company found RTU energy savings between 24 and 27 percent (White & Esser, 2013). Other tests also demonstrate potential savings, such as a simulation performed by the National Renewable Energy Laboratory (NREL), which demonstrated 29 to 75 percent savings in fan energy with Enerfit, and a field test of CATALYST by the Snohomish County Public Utility District, which demonstrated at least a 20 percent annual energy savings (Criscione, 2012).

Economizer functionality, which all the selected retrofit options provide, can reduce air conditioning power consumption 8-20 percent when applied to units that currently lack economizers, and savings can be significantly greater for systems with malfunctioning economizers (Criscione, 2009).

Advanced Thermostats

Advanced thermostats promise to provide the energy savings that traditional programmable thermostats cannot. Advanced thermostats not only provide the functionality to set operating schedules, but they can also provide broader functionality through features such as network access, occupancy detection, automatic learning (self-programming), fault detection and diagnostics, and demand response adjustments. The WCEC, based on work with PG&E, the Heschong Mahone Group, Inc., and other laboratory and field studies, identified a list of advanced thermostats that demonstrate potential for MTLC market adoption and potential energy savings. Of the thermostats considered, researchers selected four as most applicable to the MTLC market (Table 30).

Table 30: Advanced Thermostats

Manufacturer	Product
Ecobee	Smart Thermostat
Nest	Nest Learning Thermostat
Honeywell	WiFi Smart Thermostat
Radio Thermostat of America	Various Models

Source: UC Davis WCEC

Energy Savings

Although specific features and control strategies vary by device, the advanced thermostats considered are similar enough that an approximate potential energy savings for thermostat upgrade within the MTLC market could be developed. In 2014, the WCEC conducted a field study to evaluate both the energy savings and usability of advanced thermostats installed in schools, restaurants, and entertainment businesses.

Researchers obtained energy savings results by comparing pre and post-installation site-level power measurement, normalized for temperature and operating hours. They developed and calibrated, to each site studied, a custom disaggregation algorithm to extract HVAC energy use from other electrical loads and to isolate the impact of the thermostat upgrade on site-level energy usage. To evaluate the usability of different thermostats, researchers surveyed users to evaluate their interest and understanding of HVAC efficiency, and to identify shortcomings of the installed thermostats that hindered usability.

In analyzing the results, researchers found that advanced thermostats do offer the potential for energy savings, but savings are heavily dependent on both the implementation of the technology and the end user's incentives to save energy. Specifically, advanced thermostats do not provide more control than traditional thermostats; however, they often simplify and minimize user interaction required to establish an energy-efficient control scheme. For end users who do not have a strong interest in, or understanding of, energy efficiency, advanced thermostats can offload user's responsibility and provide reasonably efficient control without user intervention.

Evaporative Cooling Technologies

Evaporative cooling (EC) combines the natural process of water evaporation with an air-moving system. Outside air is pulled through moist pads where it is cooled by evaporation and circulated through a building by a large blower.

MTLC buildings in California offer a few unique challenges to the implementation of EC technologies: 1) MTLC buildings are small (frequently less than 50,000 square feet), and 2) 60 to 70 percent of RTUs on MTLC buildings are under 5 tons capacity.[19] Most current EC technologies, appropriate for use in retrofit applications, target larger RTU units (10 to 30 tons), leaving limited options for MTLC building retrofits.

Another challenge is the split incentives between the building owners and their tenants. Under most net leases the tenant is responsible for paying energy expenses and the building owner has little incentive to invest in efficient cooling systems. With gross leases, the building owner pays energy expenses and tenants have little incentive to save energy. In either case it can be difficult to get both parties to agree to implement energy efficiency retrofits. Furthermore, the duration of leases in MTLC buildings are short (1-3 years) in comparison to the lifetime of the air-conditioning unit (10-20 years). A new air-conditioning system is a long-term investment that tenants are unlikely to benefit from much. In addition, hybrid evaporative cooling systems, which are often the most suitable EC technology for direct RTU replacement, are considerably more expensive compared to a traditional AC unit.

Some businesses will benefit from EC systems more than others. Offices require little cooling as they have low internal loads. The low hours of operation would result in minimal benefit from improved cooling efficiency. Small medical facilities, grocery stores, and restaurants have high internal loads and ventilation rates. Since these businesses have higher cooling and ventilation needs, they would receive increased benefits from EC systems.[20]

EC systems are commonly classified into Direct Evaporative Cooling (DEC), Indirect Evaporative Cooling (IEC), Indirect-Direct Evaporative Cooling (IDEC), Hybrid Cooling (HYB) and Condenser Air Pre-coolers (PRE). All these technologies provide cooling and ventilation to the building with the exception of pre-coolers, which are used to improve the efficiency of existing vapor-compression equipment. Table 31 summarizes the characteristics of these technologies.

Performance Improvements

Laboratory tests have assessed the performance and characteristics of different EC technologies. The findings show that all the EC technologies tested (except for DEC) can produce comparable capacity with higher efficiency than Direct Expansion (DX)-only

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19 WCEC 2013.

20 Dean, 2012.

technologies. Performances at high dry-bulb temperatures degrade less for EC systems than for DX systems. The studies agree that there is potential for significant savings over existing DX technologies. IEC or IDEC systems could be very cost effective in meeting ventilation loads in spaces that need continuous ventilation. In HYB systems, the capacity provided by the EC component may allow the manufacturer to downsize the compressor, thereby reducing power use and frequent cycling.

Table 31: Summary of Evaporative Cooling Technology Characteristics

Technology	Main features	Technology Status	Evaporative Effectiveness	Comfort Impact	Ventilation Load (Energy savings at peak energy saved)	Cooling Room Load (Energy savings at peak energy saved)	Water Use (g/ton-h)	Product Examples
Direct	Adds moisture supply air stream	Mature	80 %	Humidity Increase, Drafts, limited capacity	90 %	N/A	1.5-2.5[21]	Many types
Indirect	No moisture added to occupied space	Low volume production	90-120 %	No humidity increase, limited capacity	90 %	N/A	2.5-6.5[22]	Coolerado M50. Seeley Climate Wizard
Indirect-Direct	Indirect followed by direct	Low volume production	100-120 %	Slight humidity increase	90 %	N/A	4.14[23]	Airmax

21 California Utilities Statewide Codes and Standards Team, 2011.

22 Woolley, Mande, & Modera, 2014.

23 Western Cooling Efficiency Center. "AirMax Hybrid Rooftop Unit Performance: Western Cooling Challenge Laboratory Test Results." *Southern California Edison: Design & Engineering Services.*

Technology	Main features	Technology Status	Evaporative Effectiveness	Comfort Impact	Ventilation Load (Energy savings at peak energy saved)	Cooling Room Load (Energy savings at peak energy saved)	Water Use (g/ton-h)	Product Examples
Condenser Pre-coolers	Evaporative cooling of condenser coil	Low volume production	N/A	Increased capacity	20 %	20 %	1.5-4.2[24]	Dual-Cool, Evaporcool, Flash Cool, Ene-Cut,
Hybrid	Evaporative and compressor-based cooling	Low volume production	N/A	Increased capacity	90 %	20 %	1.8[25]	Coolerado H80

Adapted from SWEEP and WCEC, 2007

Source: Southwest Energy Efficiency Project and UC Davis WCEC

24 WCEC, 2014.

25 Kozubal & Slayzak, 2010.

Several utilities in California are testing, or have recently field-tested, advanced EC technologies. Through its Western Cooling Challenge program, the WCEC installed, and is currently monitoring, more than 20 units of varying configuration, including hybrids, evaporative precoolers, and indirect evaporative systems. Data collected from these installations will be useful in evaluating actual performance under different weather and load conditions. Additionally, these real-world applications provide the chance to identify and study installation and maintenance problems. Table 32 includes the findings from published data of several recent reports.

Table 32: Summary of Evaporative Cooling Field Test Findings

Technology Category	Manufacturer and Product	Project info	Utility	Location	CZ	Demonstration Year	Type of Building	Energy Savings	Peak Savings
IDEC	Coolerado IEC	Five units and two sites (tested against energy model)	SMUD	Sacramento	12	2004-2006	School and Residence	25%	66%
HYB	Coolerado H80	One unit tested against a traditional DX unit	SCE	Irwindale	9	2011	Full Service Restaurant	39%	43.7%
PRE	Evaporcool	Added evaporcool to an existing 50 tons chiller	PGE	Marysville	11	2012	Air Force Base (Dining Facility)	22%	20%
PRE	Evaporcool	Added evaporcool to an existing 80 tons chiller	SMUD	Sacramento	12	2008-2009	Assisted Living Facility	5.1%	13.4%
PRE	FlashCool	Added flashcool to two AC units 37.5-Ton older Lennox unit and a 40-ton newly installed Trane	SMUD	Rancho Cordova	12	2011	Two-story, Multi-Tenant Office Building	29.4% 44.1%	11.2% 16.7%
IDEC	Speakman and DEG OASys	5 residential older IDEC were replaced with prototype OASys. 1 was monitored	SMUD	Sacramento Area	12	2004-2005	Residential Buildings	non quantified	non quantified
IDEC	Speakman and DEG OASys	2 units installed replacing 2 SEER 10 units (4 tons)	PGE	Jackson, Auburn	12-11	2005	K-12 (Relocatable Classrooms)	71%	84%
IEC	Unspecified	Two 4-ton RTUs and one 5-ton RTU service the open dining room. Added one IEC in addition to the existing three units. The IEC1 unit was integrated so that it supplies all OAS during the cooling season	PGE	Rocklin	11	2011	Restaurant	70%	60%
PRE	Unspecified	Two 50-ton RTUs. Retrofited existing equipment with two PRE	PGE	Woodland	12	2011	Office	non quantified	non quantified
PRE	Unspecified	Two 130 ton RTUs, one 75 ton RTU, and one 10 ton CRAC. Retrofited existing equipment with four PRE (of appropriate sizes for each application)	PGE	Vacaville	12	2011	Office	13%	15%
PRE	Unspecified	One 35 ton and one 50 ton RTUs. Retrofitted existing equipment with two PRE (of appropriate sizes for each application)	PGE	Fresno	13	2011	Office	non quantified	non quantified
PRE+IEC	Unspecified	Three makeup-air-only air handlers and 35 RTUs of various sizes from 5 to 20 ton. Retrofitted six 20-ton RTUs with system, provide the makeup air with the retrofitted units, convert other RTU to heating and cooling only, and shut down the makeup air handlers	PGE	West Sacramento	12	2011	Big Retail Store	15%	35%
PRE+IEC	Unspecified	35 RTUs of various sizes from 5 to 10 ton. Retrofitted ten 10-ton RTUs with this systems	PGE	Woodland	12	2011	Big Retail Store	non quantified	non quantified

Source: UC Davis WCEC

In general, the reports identified the difficulty in comparing the performance of EC systems with traditional DX systems. For example, the cooling capacity of a DX system is measured at the evaporator coil as the product of the air mass flow rate across the coil and the enthalpy decrease between the return air from the conditioned space and the discharged supply air. In contrast, evaporative coolers typically use 100 percent outside air and thus cannot be characterized using traditional rating systems, which are based on operation with 0 percent outside air. DEC and IEC systems usually supply air at a higher temperature than a conventional air conditioner, so they need a much higher airflow rate to provide adequate cooling. Capacity is calculated as the air mass flow rate into the room multiplied by the difference of dry-bulb temperature between a reference room temperature (usually 80° F) and the supply (outdoor) air. Because of airflow and temperature differences, the two capacities are not directly comparable.

Reducing Heating, Ventilation, and Air Conditioning Connected Load

The issue of "right-sizing" has become a contentious issue within the HVAC research community. For many years the assumption was that an oversized HVAC system would operate less efficiently and contribute to a larger peak demand, which negatively impacts both the utility and the ratepayer. This assumption has led to increased pressure from regulators and utilities for HVAC installers to "right-size" HVAC systems based on calculations of a particular building's cooling load. California Title 24 specifies that a packaged, single stage DX system may not be sized more than 121 percent above the calculated building load.[26] Recent research and investigation, however, has suggested that traditional 'right-sizing' practices may not always be the best option for all interested parties. In most cases, the argument about peak demand—that right sizing an air conditioner caps peak demand—is largely undisputed, and it is an essential issue both for utilities and ratepayers, however, the issue of energy savings is less clear.

The primary reasons for 'right-sizing' an air conditioner are related to three fundamental concepts.

- Start-up inefficiency and cycling: When an air conditioner starts, it typically requires a 'cool-down' period of about three minutes before the evaporator coil temperature is sufficiently low to cool and dehumidify the indoor air stream. During this period, the system power draw remains fairly constant, and thus the system operates extremely inefficiently. The traditional argument states that an oversized system will reduce a building's internal air temperature below the set point faster than a right-sized unit, thus leading to more frequent cycling, and therefore more frequent inefficient start-up periods. Livermore-Berkeley National Laboratory scientists Max Sherman and Iain Walker debate this point, arguing that the cooling load and the building's thermal design characteristics are more significant factors in the cycling frequency– and that if a building is properly designed, it will warm up slowly enough that the cycle time of the HVAC system is insignificant.
- Occupant comfort and humidity control: Oversized systems are often attributed to poor humidity control, due to a shorter on cycle and the large quantity of condensate that is re-evaporated from the cooling coil during the AC's off-cycle. Logic follows that both of these factors would contribute to a higher indoor humidity; however, this effect is likely to be insignificant. Sherman and Walker make the argument that the quality of the system's design is a much larger factor in determining the ability of a system to control indoor humidity. In a

26 http://www.energy.ca.gov/title24/.

system that allows significant sensible heat gain through the ducting (that is from ambient conditions or solar effects), increased return air temperature is likely to significantly reduce the air conditioner's dehumidification capacity during the on-cycle, and contribute to thermo-siphon effects during the off-cycle, which will draw re-evaporated condensate back into the occupied space. Furthermore, proper drain pan insulation, drainage, and installation can dramatically minimize the quantity of water available for re-evaporation into the air stream. Also, it is not clear that indoor humidity control is actually a concern for oversizing in California. For dry, 'western' climates, prevalent throughout much of California, ambient humidity is so low that humidity control is an uncommon goal for an HVAC system, and the additional sensible cooling capacity obtained through condensate re-evaporation may actually be a net benefit.

- Human factors: While a right-sized system may, in principle, produce a more efficient HVAC system, the way in which users interact with it can tip scales in favor of an oversized system. Sherman and Walker use the example of setback periods. Most modern thermostats use setback periods, in which the indoor air temperature is allowed to drift higher during unoccupied periods. When the space is reoccupied, the HVAC system must work to bring indoor conditions back to the desired set point. Under these circumstances, an oversized system will be able to return to desired conditions much faster than a 'right-sized' system, and thus provides greater overall occupant comfort. If occupants determine it takes too long for a conditioned space to return to a comfortable condition after a setback period, they may be inclined to avoid the setback period entirely and thus use significantly more energy to maintain stringent indoor conditions even during unoccupied periods.

The best way to enable RTU downsizing is to reduce a building's total cooling load. This can be done via a wide range of efficiency improvements to fenestration, lighting, envelope, and/or mechanical systems. Older, less efficient, and often poorly maintained buildings dominate the MTLC market. Typically these buildings are leaky, use inefficient lighting technologies (that is T12 Fluorescents and halogen spotlights), and have poorly maintained, often leaky HVAC systems. Load reductions from improvements in any of these areas can provide compound benefits by both reducing the total energy consumption and enabling the use of a smaller capacity packaged AC unit. If efficiency measures are completed without also downsizing the HVAC system, it is likely that, while aggregate savings may be achieved, the HVAC system will be oversized for the retrofitted cooling load, and thus may operate less efficiently with unnecessarily high peak power levels.

To better evaluate the potential for AC unit downsizing, team researchers developed an HVAC downsizing assessment tool as part of this project. The tool allows the user to determine the actual capacity of an installed air conditioner, a building's cooling load, and the load reductions and capacity improvements achievable through lighting, building envelope, and evaporative cooling retrofits. Together these areas help to define and quantify the financial advantage for retrofitting an MTLC building, and help to determine barriers to building efficiency. The downsizing tool can be used to evaluate the potential for system downsizing and effects on connected loads and peak demand. As previously mentioned, the effects of downsizing equipment on energy savings is less clear. In the end, the decision to downsize should be made based on the benefits of reducing connected load and peak demand.

Findings for Multitenant Light Commercial Target Stakeholder Survey

Researchers analyzed the results of the online survey for the 20 participants from the Buildings Group (tenant, property manager, building owner) and Utility Group (utility employee, utility program partner) to understand their perceptions of specific energy-efficient solutions.

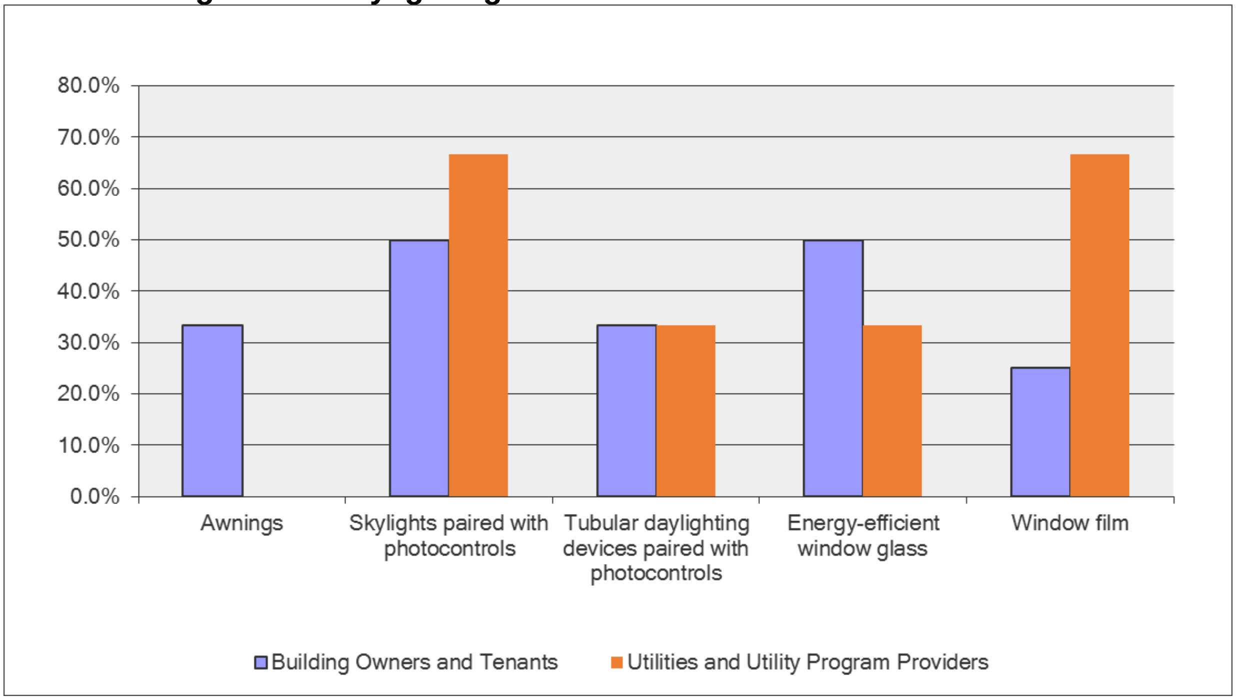
Envelope and Daylighting

Researchers asked survey participants to consider a subset of five envelope and daylighting technologies: 1) awnings, 2) skylights paired with photocontrols, 3) tubular daylighting devices (TDDs) paired with photocontrols, 4) energy-efficient window glass, and 5) window film. Researchers wanted to understand stakeholder interest and perceptions of the measures independent of electric lighting solutions.

Researchers first asked participants to select two envelope/daylighting measures that MTLC businesses would be most interested in learning more about. The majority of survey participants selected skylights paired with photocontrols (67 percent of the Utility Group and 50 percent of the Building Group); however, only 30 percent of either group selected TDDs paired with photocontrols, which is a very similar technology set. For both groups, solutions for windows ranked second most interesting, with the Utility Group showing interest in window films, and the Buildings Group showing interest in complete window replacements (see Figure 51).

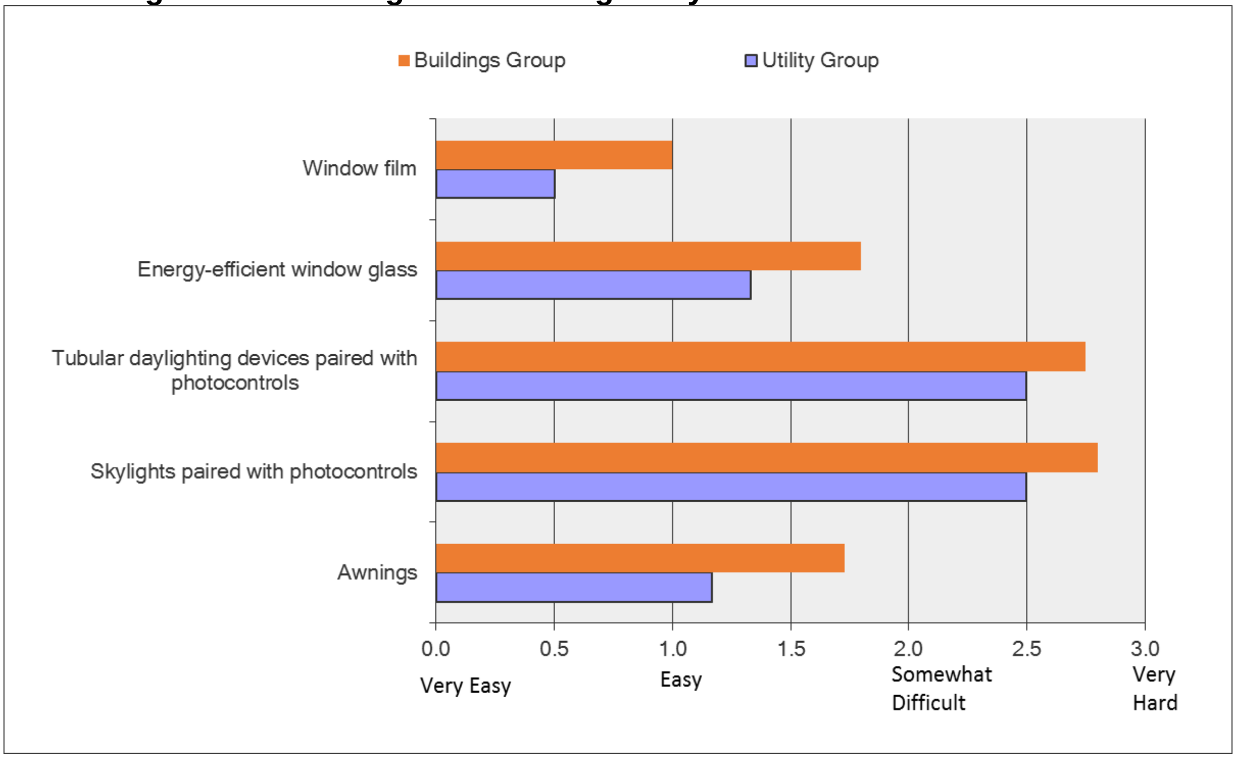
When asked about use and installation of these solutions, survey respondents indicated that window films were the easiest technology to install and use, followed by window awnings and window replacements. Skylights and TDDS paired with photocontrols were seen as the most difficult to work with (see Figure 52). Interestingly, the easiest and most difficult technologies to work with were also of most interest to survey participants.

Figure 51: Daylighting Solutions of Interest to Stakeholders



Source: UC Davis EEC

Figure 52: Ranking of Technologies by Ease of Use and Installation



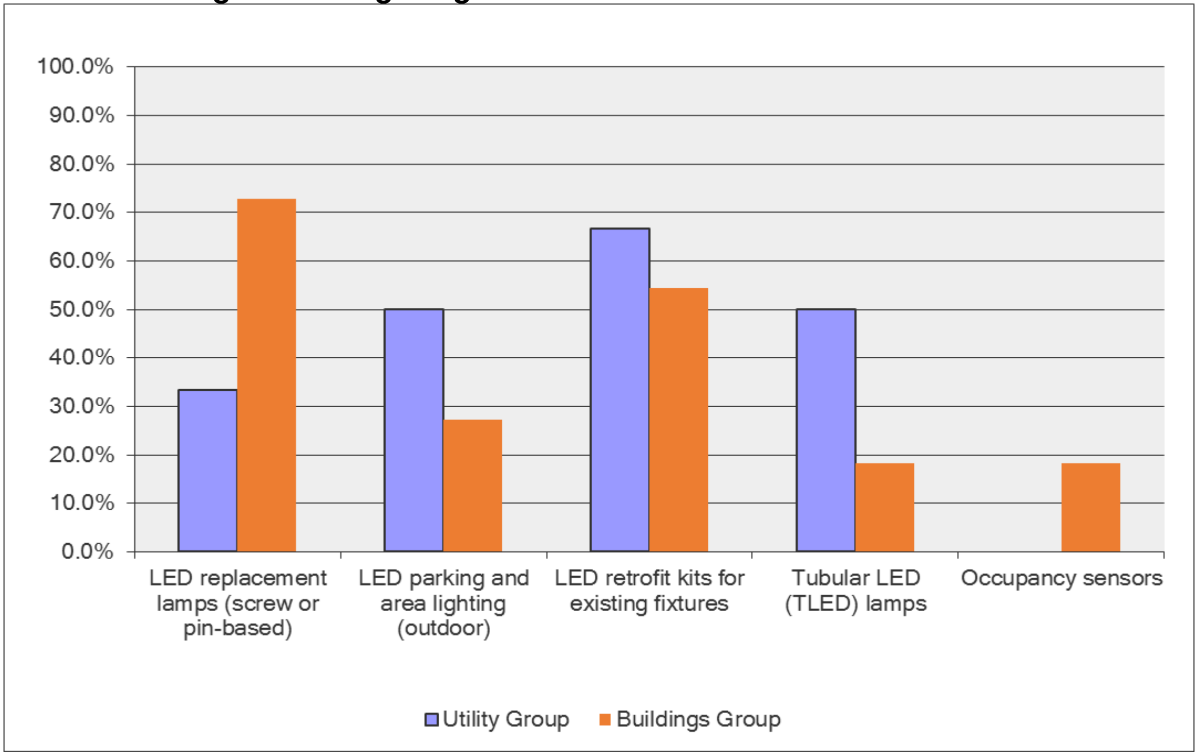
Source: UC Davis EEC

Electric Lighting and Controls

Researchers asked survey participants to consider a subset of five lighting and control technologies: 1) LED replacement lamps (screw or pin-based), 2) LED parking and area lighting (outdoor), 3) LED retrofit kits for existing fixtures, 4) Tubular LED (TLED) lamps, and 5) Occupancy sensors. Researchers wanted to understand interest and perceptions of the measures independent of envelope and daylighting solutions.

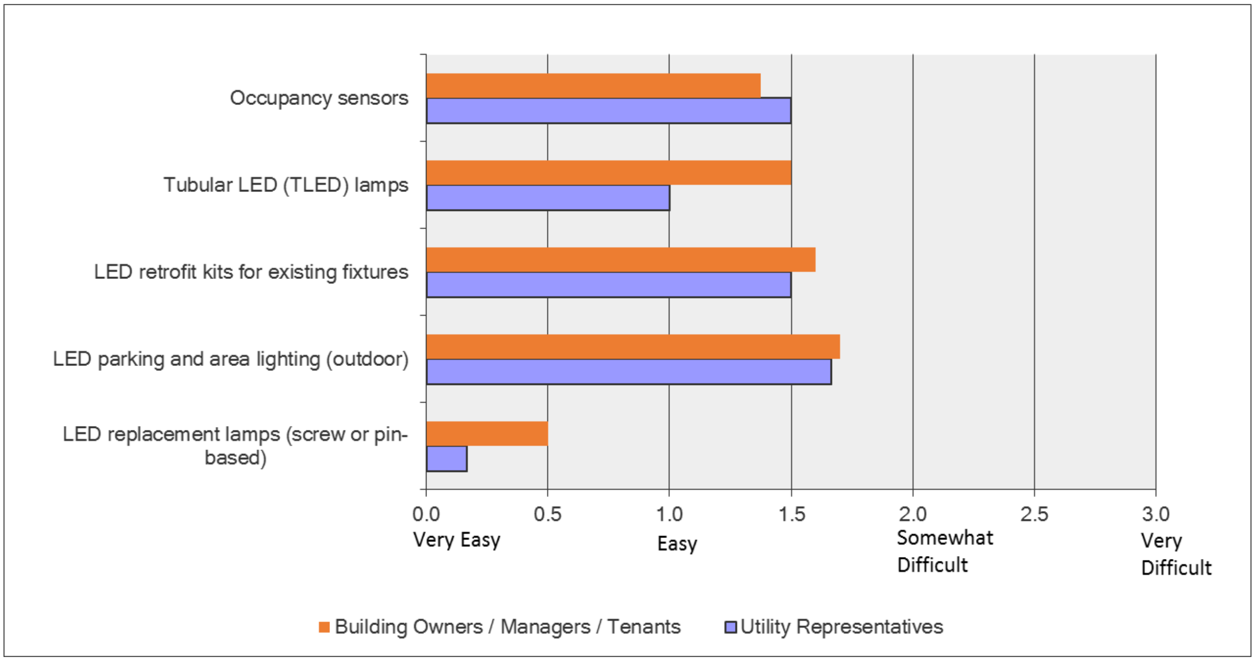
Researchers first asked participants to select two measures that MTLC businesses would be most interested in learning more about. The Utility Group felt that MTLC businesses were most interested in learning about LED retrofit kits for existing luminaires; however, the Buildings Group felt MTLC businesses were most interested in learning more about LED screw and pin-based replacement lamps (Figure 53). All electric lighting and controls solutions were generally seen as easy to install and use, with screw and pin-based LED replacement lamps ranking as easiest by both survey groups (Figure 54).

Figure 53: Lighting Solutions of Interest to Businesses



Source: UC Davis EEC

Figure 54: Ranking of Electric Lighting Technologies by Ease of Use or Installation



Source: UC Davis EEC

Energy Conservation Measure Considerations and Value

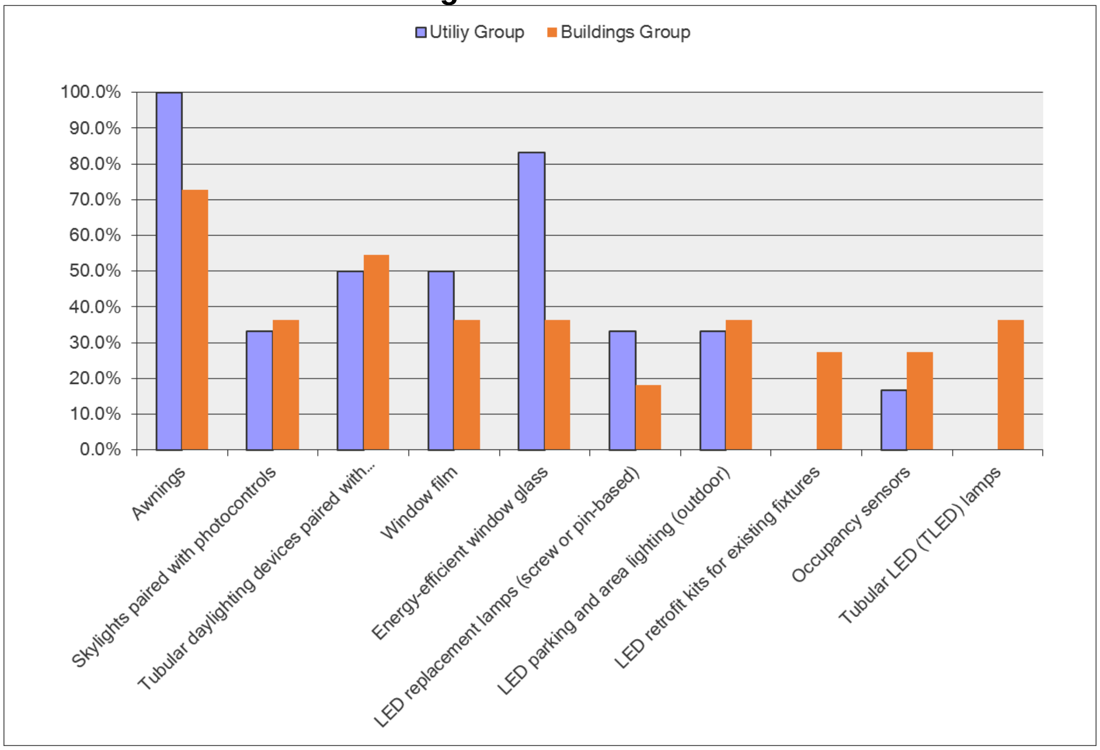
Apart from gaging interest in specific technologies and strategies, the TSS sought to understand MTLC stakeholders' value of these measures. The survey included questions that asked participants to rank measures according to their perceived value to the business or property. In addition, researchers asked participants to identify and rank the reasons and influencing factors that drive their energy-efficiency project decisions.

Technology Value to Stakeholders

Generally, survey participants saw limited value in adopting daylighting solutions recommended for MTLC businesses. The Buildings Group and Utility Group felt that awnings provide the least value to MTLC businesses. In addition, the Utility group felt that window retrofits were clearly not beneficial. Approximately half of both groups felt that TDDs paired with photocontrols were not valuable, but skylights with photocontrols could be. The Utility Group also felt that window films lacked value for businesses (Figure 55).

In contrast, 87 percent of respondents thought that energy-efficient electric lighting added value to MTLC properties. Specifically, the Utility Group thought LED retrofit kits for existing luminaires and TLED replacements were highly valuable, while the Buildings Group thought LED screw and pin-based replacement lamps would be the most valuable energy conservation measure (ECM) for their facilities. Survey participants felt that all other measures were approximately equal in their value to MTLC businesses.

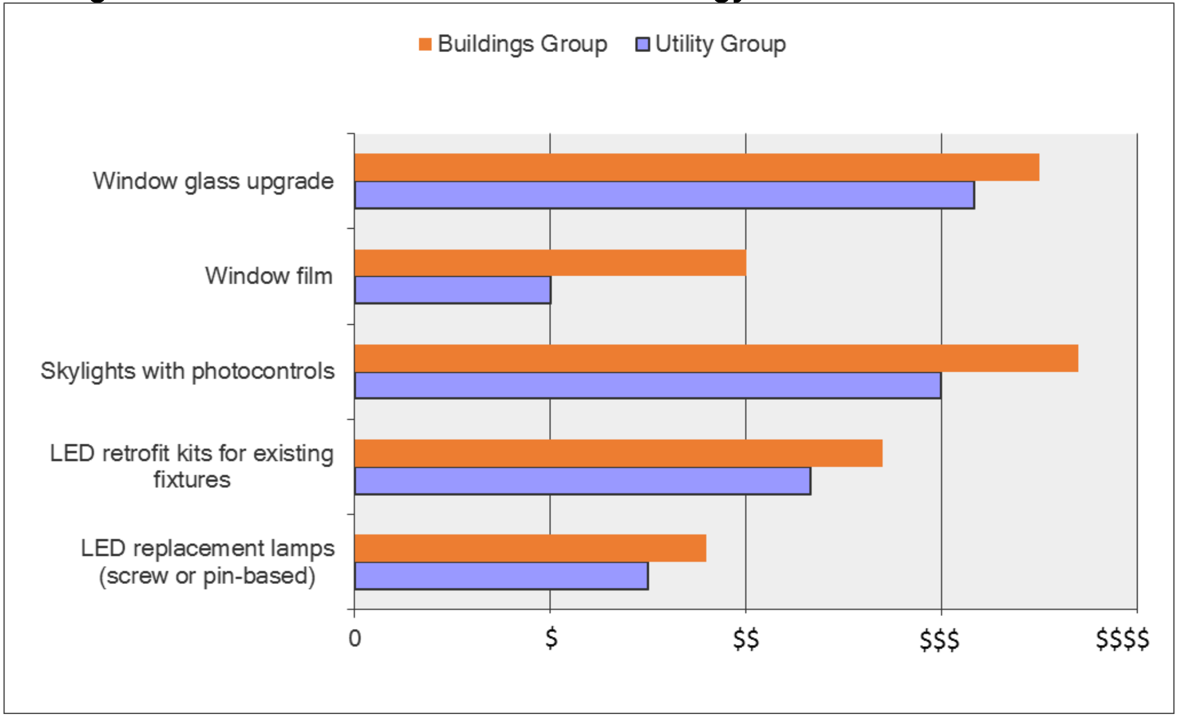
Figure 55: Ranking of Technologies by Lack of Perceived Value / Benefit to Multitenant Light Commercial Businesses



Source: UC Davis EEC

Researchers also asked survey participants how much they thought certain ECMs cost to adopt including product costs and installation. With respect to electric lighting, the team sought to understand the perceived cost difference between adoption of LED lamp replacements and whole fixture retrofits. Both groups felt that replacements were 50 percent less expensive to adopt than fixture retrofits (Figure 56).

Figure 56: Perceived Cost of Selected Energy Conservation Measures



Source: UC Davis EEC

For daylighting solutions, researchers were interested in understanding how stakeholders viewed the cost of static technologies (window replacements and window film) as compared to the same technology paired with lighting controls. The Utility Group felt solutions that required changes to the building envelope, either wall or ceiling, were expensive and, relatively speaking, their cost varied little with the addition of lighting controls. Interestingly, upgrading windows was seen as more expensive than adding skylights paired with photocontrols. The Utility Group viewed the addition of window films as the least expensive measure. The Buildings Group selected LED replacement lamps as the least expensive measure to adopt.

Considerations for Retrofits

The decision to complete energy-efficiency retrofit projects can be made for many reasons including positive effects on customers, increased sales, and improved employee morale. Researchers asked survey participants to identify the most important reason for an MTLC business to complete an energy-efficiency retrofit project. A majority of respondents indicated that decreasing energy costs was the most important reason to complete a project. Figure 57 shows the various reasons provided to survey participants for completing a project and the percent distribution of reasons selected by participants as most important.

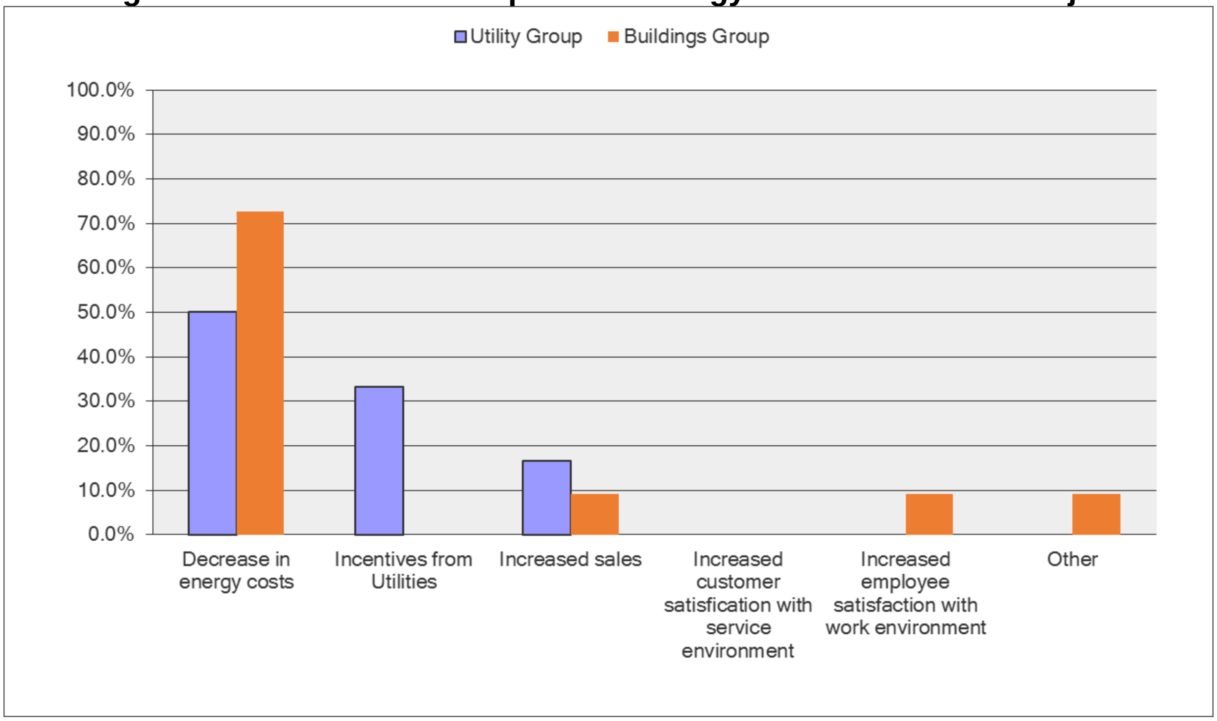
As a follow up, the team asked participants to rank the importance of many additional factors on the overall decision-making process. Researchers were interested in determining the most influential factors and identifying gaps between the Utility and

Building groups project requirements. In this way, future utility programs could include only those technologies that satisfied customer's financial requirements or other project goals.

On average, stakeholders viewed all factors provided in the survey as being moderately to very important. The most important factor to consider for an ECM, according to the Utility Group, was simple payback, while the Buildings Group considered purchase and installation costs to be the most important (Figure 58). Upon closer examination of this variance, researchers found that the Utility Group had a shorter acceptable simple payback period than that of the Buildings Group (Figure 58).

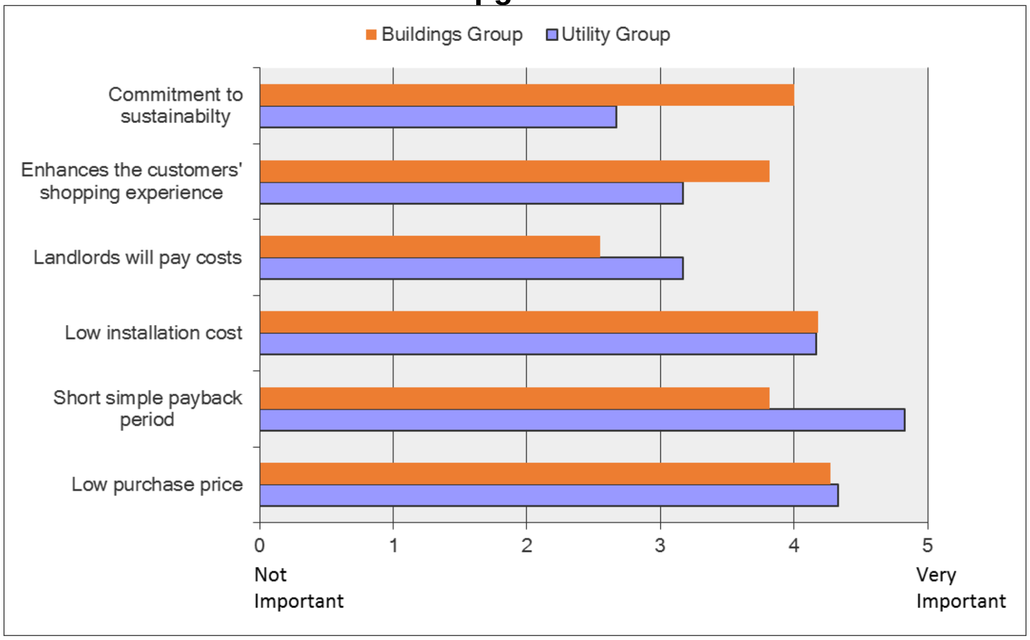
Short payback periods can indicate the increased level of importance placed on total cash availability over time. The importance of low first cost to the Buildings Group combined with a longer acceptable payback period suggests the immediate amount of cash available to most MTLC stakeholders may be limited for ECMs, and as long as initial costs are within this limit, they are willing to accept smaller annual savings. Details on acceptable payback periods are shown in Figure 59.

Figure 57: Reasons to Complete an Energy-Efficient Retrofit Project



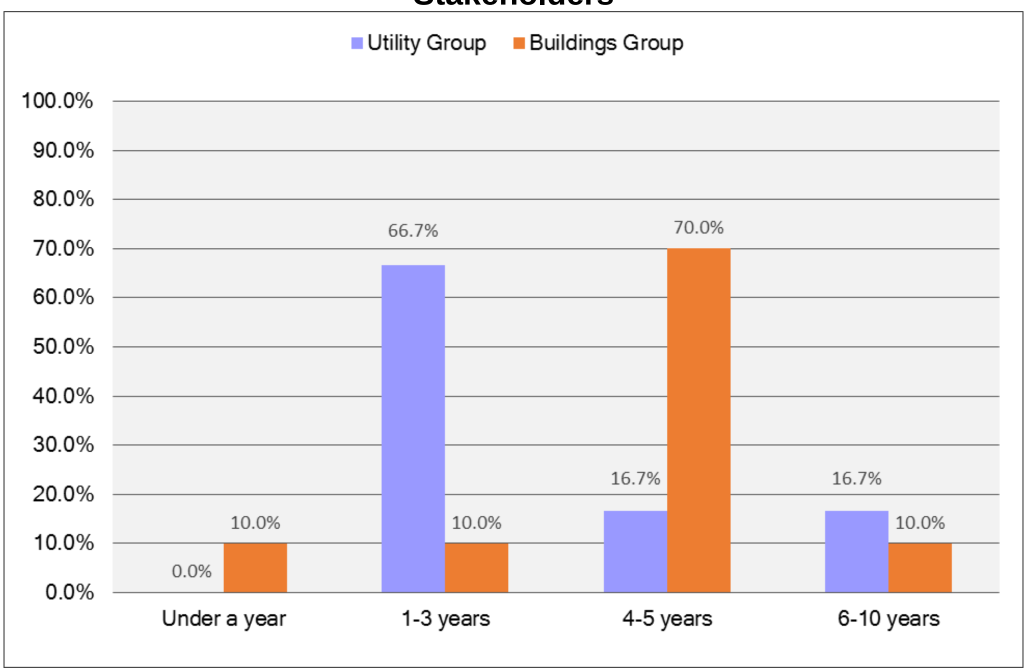
Source: UC Davis EEC

Figure 58: Factors that Influence the Decision to Complete an Energy-Efficiency Upgrade



Source: UC Davis EEC

Figure 59: Acceptable Payback Period for Multitenant Light Commercial Stakeholders



Source: UC Davis EEC

Conclusion and Summary of Energy Conservation Measures for Multitenant Light Commercial Businesses

Multitenant Light Commercial Technology Evaluation

Table 33 summarizes the energy conservation measures and technologies most appropriate for MTLC buildings, including key performance targets for each. Products that meet these targets are expected to deliver the energy savings and peak demand reductions as noted. Reductions are stated as a percent savings for a representative, standard MTLC building.

Table 33: Energy Conservation Measures Summary

Measure / Technology	Key Performance Targets	Potential Energy Savings (%)	Potential Peak Demand Reduction (%)
Tubular LED lamps	80 CRI or better, CCT based on installation / application but no more than 5000K, lifetime: 50,000+ hours	10%-50% based on application	10%-50% of lighting power based on application
Screw-base and pin-base LED lamps	90 CRI or better, CCT based on installation / application, CCT not to exceed 5000K, lifetime: 50,000+ hours	50%-75% for most applications	50%-75% of lighting power based on application
LED troffer / luminaire retrofit kits	85 CRI or better, CCT based on installation / application but no more than 5000K, lifetime: 50,000+ hours	20%-40% for most applications	20-40% of lighting power for most applications
Occupancy sensors	5-minute time out, dual technology sensor, if auto-ON mode is used set to 50% only	10%-50% for most applications	10%-50% of lighting power for most applications
Daylight harvesting controls + existing windows	Stepped dimming or switching for all daylight zones per Title 24 requirements.	15%-30% reduction in electric lighting energy for luminaires	15-30% of lighting power for most applications

Measure / Technology	Key Performance Targets	Potential Energy Savings (%)	Potential Peak Demand Reduction (%)
		within daylit zones	
Skylight/TDDs + daylight harvesting controls	Skylight/TDD properties per Title requirements, only install in combination with daylighting harvesting controls	15%-30% reduction in electric lighting and HVAC energy use for luminaries within daylit zones	15%-30% of lighting power for most applications
LED parking and area luminaires + occupancy controls	75+ lm/W system efficacy, CCT not to exceed 5700K, Lifetime: 50,000+ hours	20%-40% reduction due to conversion to LED only, additional 10-30% savings from addition of controls	No peak savings.
Window glass replacements	Minimum requirements per Title 24, Part 6.	5%-15%	0%-10% (lighting and HVAC)
White/cool roofs	Minimum 0.55 solar reflectance after 3 years, Minimum 0.75 thermal emittance	Varies	Varies
HVAC Controls	Fan motor VFD, demand control ventilation, advanced economizer control, and FDD.	30%-75% primarily due to reduced fan power expenditures.	0%-30% based on ability to down size fan motor and compressor by VFD.
Advanced Thermostats	7-day scheduling ability, utility DR signal response, user friendly programming.	Up to 20% based on better management of temperature setbacks.	DR enabled thermostats may be able to respond to utility signals to reduce load.
Evaporative Precoolers	70% evaporative effectiveness of water from air stream for pre-cooling.	20%-30% during peak demand periods. 5%-15% annually.	Peak demand reductions up to 25% in hottest climate zones.

Measure / Technology	Key Performance Targets	Potential Energy Savings (%)	Potential Peak Demand Reduction (%)
RTU Replacement / RTU Downsizing	Sizing as specified by ASHRAE manual J, or by using monitoring data and downsizing tool.	Energy savings may be 0%-10%.	Peak demand savings may be up to 30%.

Source: UC Davis EEC

Multitenant Light Commercial Target Stakeholder Survey

Although the potential for statewide energy reductions for lighting energy use in MTLC buildings is significant, there is a lack of publicly available information on what perceptions decision-making stakeholders hold on the energy efficient technologies. While the sample size for this survey was very small, the results of the TSS can be used as a starting point for broader deployment of the survey, followed by building stakeholder research focusing on segments that offer the most potential for uptake and energy reduction.

While the owners/tenants and utility stakeholders generally agreed on the overall value of recommended technologies, perceived costs, and influential factors, gaps do exist between utility programs and MTLC business owner needs. For example,

- Nearly 60 percent of MTLC business owners and tenants surveyed had never participated in a utility incentive or rebate program.
- MTLC owners/tenants were very interested in LED lamp replacements and basic lighting controls, such as occupancy sensors, but utility stakeholders were looking ahead to full fixture retrofits and more advanced control solutions.
- The utility's inability to claim savings for efficiency programs that include measures required by California energy-efficiency codes deeply affects this divide. MTLC business owners have limited cash available for ECMs, and while building energy codes may require basic measures during a lighting retrofit project, the lack of utility incentives may inhibit execution of projects all together, thus negating any savings to California.

Results indicate stakeholders see limited value in adoption of envelope or daylighting solutions for MTLC businesses. These technologies are seen as expensive and difficult to install and use; however, stakeholders were still interested in learning more. Survey participants were most interested in learning about the solutions ranked simplest and most difficult to install/use. This data suggests that significant stakeholder education is needed to better explain the functionality and benefits of envelope and daylighting measures to alleviate possible misconceptions regarding technology cost and complexity.

In contrast to stakeholder opinions on daylighting solutions, 87 percent of respondents thought that energy-efficient electric lighting adds value to MTLC properties. LED retrofit kits and lamp replacements were highly valued due to perceived low cost and ease of installation.

The most important factor in the decision making process, according to utility stakeholders, was simple payback, while owner/tenants considered purchase price and installation costs to be the most important. The importance of low first cost to owners/tenants, combined with their willingness to accept a longer payback period (as compared to utility stakeholders), suggests the immediate amount of cash available to most MTLC businesses is limited for ECMs, and as long as initial costs are within their limits, they are willing to accept smaller annual savings as compared to that required to achieve the payback periods imposed by utilities.

CHAPTER 4: Programmatic Tools for Achieving Deep Energy Savings in Multitenant Light Commercial Buildings

Introduction

As the market currently stands, little work is being done to tap into the energy savings potential of MTLC shopping centers. Implementing energy efficiency retrofit projects in MTLC spaces is inhibited by the high cost of the retrofit process, ineffective packaging of technologies, and incomplete understanding of savings through retrofit packages. As part of this project, the research team analyzed current market shortcomings and proposed solutions to improve data collection, analysis, and the retrofit technology recommendation process for the MTLC market. These solutions can provide the foundation for new energy efficiency programs seeking to target the MTLC sector.

In this chapter researchers describe:

- Limitations in current energy efficiency programs that target MTLC buildings and suggested improvements.
- A unique approach to collecting audit data and analysis.
- A new modeling tool to effectively recommend technology packages that achieve more savings and gain a better understanding of the interactive impact of a retrofit package.
- The role of scale in implementing energy retrofit technologies to bring down costs.

Market Void

There is currently no program that provides cost-effective, deep energy savings with technologies targeted to the MTLC market. As described in Chapter 2, the main market tool to implement deep energy savings in MTLC buildings is Direct Install (DI) programs. While DI programs are inexpensive, and require little investment of time from the tenant and building owners, these programs only provide a limited set of energy saving measures with little material savings.

At the other end of the spectrum, there are Energy Service Companies (ESCOs), which provide a comprehensive program to pursue deep energy savings including data collection, financing, and deep energy saving measure installations. However, ESCOs rarely pursue MTLC buildings because they are small, providing limited opportunity for energy savings and little financial incentive.

Figure 60 outlines the current process for implementing energy efficiency retrofits. It also describes the limitations of DI programs, at one end of the spectrum, and ESCOs, at the other end of the spectrum, in addressing DER savings in the MTLC space. However, a middle ground solution does exist.

Figure 60: Retrofit Process Diagram, Current Market Flaws, and Proposed Solution

	Solicit Building Participation in Audit	On-site Audit	Follow-up Analysis	Retrofit	Energy Measurement & Verification
Process	A tenant/building will likely participate in an audit if it is relative energy inefficient, it is within their lease agreement/ ownership of property, and it is not cost prohibitive	Identify how energy is being used in the building and recommend areas for improvement which may include a change in building/system use or upgrading equipment	Analyze measurements collected from the on-site audit to develop retrofit solutions to customer	Perform building and system maintenance and improve equipment to align with occupant needs	Measure energy consumption and savings to verify if expectations from equipment improvement matches reality
Current Limitations		**DI Limitation:** Limited audit only looking for specific ECMs it can implement **ESCO Limitation:** Costly due to use of engineers and extensive measurements	**DI Limitation:** Analysis is limited to findings from DEER database **ESCO Limitation:** Engineering analysis is costly	**Universal limitation for MTLC space:** Implementing deep energy saving retrofit measures is expensive	
Proposed Solution		Utilize California Conservation Corps to collect data to identify more extensive set of measures than DI and more cheaply than ESCO	Use newly developed modeling tool for analysis and to more completely understand savings than DI and more cheaply than ESCO	Implement retrofit measures on the building level to minimize transaction costs and to purchase measures in bulk	

Source: UC Davis EEC

As a result of its research, the team identified three programmatic tools to achieve targeted retrofit packages for MTLC shopping centers. These tools will enable deeper energy savings than DI programs, but will do so in a cost-effective manner, with technologies that are designed and targeted for the MTLC market. The three programmatic tools are related to the audit, analysis, and retrofit processes:

1. Audit: Use the California Conservation Corps to conduct on-site audits.
2. Analysis: Use simulation tools like the MTLC Toolbox to conduct energy efficiency analyses.
3. Retrofit: Implement retrofit installations at the building level.

California Conservation Corps Audits

In Chapter 2, researchers provided an overview of energy audits as they apply to the MTLC market. As Figure 60 shows, the market currently offers inexpensive but limited DI program audits. Expensive ESCO energy audits are also an option and will lead to a more complete understanding of energy saving opportunities, but they are cost prohibitive for many MTLC buildings. To improve the quality of audits, while keeping costs low, researchers recommend using the California Conservation Corps (CCC) to conduct on-site audits. The CCC's audits collect more data than DI audits, enabling more ECMs to be recommended and deeper savings can be achieved. Using the CCC also has the advantage of a lower price point compared to ESCOs because the CCC employs blue-collar workers instead of engineers. Furthermore, the CCC is currently state-funded to perform free audits.

The CCC, created in 1976, is a state agency focused on young people and the environment. Corps members are young men and women between the ages of 18 and 25 who work outdoors for a year to improve California's natural resources.[27]

In 2013, the CCC started the 'Energy Corps,' an energy program funded through the "Clean Energy Job Creation Fund," also known as Proposition 39, to assist California public schools with energy surveys and energy-efficiency projects. Trained corps members visit schools to conduct energy audits. They conduct "whole building," ASHRAE compliant surveys that include lighting and control systems, internal plug loads, HVAC, and the building envelope. The data collection process was developed by energy experts to meet industry standards.[28]

Multitenant Light Commercial Toolbox Analysis

Building Energy Simulations

Various groups have conducted whole-building energy simulations to understand the effects of specific measures on overall building energy consumption. These studies follow a basic format where researchers develop prototype building models using construction materials and equipment representative of a particular building era or type. In many cases, they develop multiple prototypes as part of a study, one of several building vintages. Researchers then produce a baseline simulation for each prototype model and use the resulting energy consumption to represent the energy-use of existing buildings of that era or type for comparison purposes.

In most cases, energy simulation studies have examined a select group of ECMs that are believed to improve the energy performance of the building. Measures are applied to the building models, energy simulations performed, and resulting energy consumption compared to the baseline. In some cases, multiple measures are applied, most typically in an additive way that ignores dependencies among the set of measures, to understand the energy performance of an ECM package. While researchers often document the tools, software, and calculations they used to perform the analyses, parties interested in the particular measures typically have no method to modify the

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27 http://www.ccc.ca.gov/Pages/default.aspx.

28 http://www.ccc.ca.gov/work/programs/prop39/Pages/default.aspx.

design characteristics of the baseline building or ECMs to produce results tailored to their specific interests.

Limitations of existing simulation studies are especially relevant to the MTLC market. Existing studies most often use reference building models developed by the USDOE, which include a variety of building types such as hospitals, office buildings, restaurants, and schools. The USDOE reference models also include a multi-tenant, retail building, or strip mall, however, each tenant space within the model is assumed to be a general retail establishment. As this project's research has shown, many more tenant types (restaurants, offices, salons, and so on) exist within an MTLC building, each with its own unique equipment and operating characteristics. In addition, MTLC establishments in California are built to energy-efficiency standards that are often more stringent than those found in other parts of the country. As such, the USDOE reference buildings do not sufficiently represent California's building characteristics, limiting their usefulness for the typical California MTLC stakeholder.

Improvements to the Standard Model

Some researchers have tried to address limitations of existing simulation studies. For example, a 2012 study by the Heschong Mahone Group, Inc. (HMG), on behalf of SMUD, examined the energy impacts of several promising measures in a multi-tenant, retail environment. While the study's reference building included some components and characteristics of the standard USDOE strip mall building model, researchers modified other components to better align with typical California building characteristics. These modifications were based on building and equipment characteristics contained in the Database of Energy Efficient Resources (DEER) developed by California utilities and other stakeholders.[29]

DEER, originally developed in 1994, uses a series of building prototypes as a baseline by which to compare the energy impacts of various conservation technologies. The original prototype buildings were based on characteristics obtained through a series of building surveys sponsored by California utilities. The surveys, conducted between 1986 and 1990, consisted of one on-site survey and four mail-in surveys aimed at collecting building and equipment information from IOU commercial customers. A majority of the DEER prototype building characteristics were based on a single, on-site survey of 855 commercial establishments in Northern California.

Over the years, DEER prototype buildings and use profiles have been updated, and building vintages added, to reflect changes in building construction and available equipment. While the rationale for some updates appears well documented and in-line with California building code requirements or other sources of change, other updates to

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29 http://www.deeresources.com.

the database have no justification on record. In particular, changes between the 2005 DEER building prototypes (used by the HMG study) and original 1994 Building Prototypes, for existing building vintages, are poorly documented. For example, equipment power densities for buildings constructed prior to 1991 were significantly increased in the 2005 DEER, as compared to the original 1994 DEER, increasing by 40 percent to 50 percent.

As part of the HMG study, the prototypical baseline strip mall model was modified across three building vintages to align with some building vintage characteristics specified in DEER. Baseline building model vintages included in the HMG study were:

- Pre 1978 – Buildings constructed before implementation of Title 24.
- 1978-1992 – Buildings constructed after implementation of Title 24 – Era 1.
- 1993-2001 – Buildings constructed after implementation of Title 24 – Era 2.

Modifications included changes to both the building construction characteristics and associated equipment. Equipment modifications included changes to lighting power density, equipment power density, and HVAC system efficiency. Changes to the building construction included wall composition (steel frame to brick), roof U value, wall U value, ceiling height, and operating hours.

The HMG study, using the modified building model, conducted simulations to understand the energy savings impacts of select ECMs. The ECMS were selected to best meet a goal of 30 percent energy reduction and a five-year or less simple payback. Savings of selected measures were determined by comparing the building's energy performance with an ECM to its performance without that ECM, then savings were added from individual measures to reach the 30 percent goal.

While the HMG study tried to modify some building characteristics to better align with California's building stock, team researchers found that many components of the models and equipment contradict building code requirements or the DEER values they claim to use. While more work is needed, the study demonstrates a significant step forward in addressing California's MTLC building sector.

Multitenant Light Commercial Toolbox Purpose and Functionality

The team developed an MTLC Toolbox to improve and expand on existing simulations and studies in three important ways:

- The MTLC model building represented a typical tenant space found in California and it could be modified in terms of operation and equipment to represent a variety of different tenant types. Previous studies addressing the MTLC sector had only focused on general retail space.
- For each tenant type, the MTLC Toolbox allowed researchers to identify specific business operating and equipment characteristics. The Toolbox included customized hours of operation, equipment power densities, lighting power densities, occupancies, wall construction, roof construction, and HVAC systems.

These parameters were based on historical California building code requirements, engineering evaluation, and industry expertise.

- The MTLC Toolbox enabled stakeholders to modify designs to meet their individual needs. The Toolbox was developed primarily for owners and tenants of multi-tenant commercial buildings. It provided users with the opportunity to analyze their current energy efficiency metrics and identify steps they could take to reduce their overall energy consumption.

Background

The MTLC Toolbox was a user-interface that functioned with the USDOE software EnergyPlus. The functional combination of the MTLC Toolbox and EnergyPlus allowed for a simple, accurate, and easy to understand energy efficiency analysis.

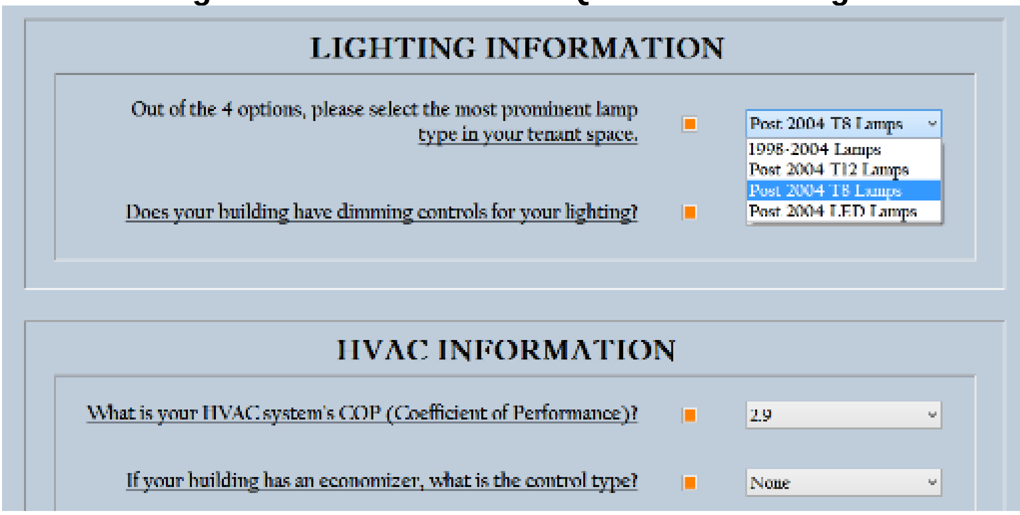
EnergyPlus is an open-source building energy simulation software, which is typically used for a comprehensive and customized building energy analysis. The level of detail and customization required to develop an accurate model for a building makes the raw software extremely difficult for an average person to use. The developers of EnergyPlus did not create the software for people to use directly. They designed it primarily to function with an externally developed user-interface, which was precisely the purpose of the MTLC Toolbox.

The MTLC Toolbox applied the analytical strength of EnergyPlus by using a comprehensive building model developed by the California Lighting Technology Center and the Western Cooling Efficiency Center. Through their extended research in the MTLC building sector, the Centers developed a representative market model for MTLC buildings in California. The existence of this open-source, easy to use tool was an important and unique contribution of this project to building simulation and energy efficiency research. Specific system requirements for using the MTLC Toolbox are outlined in Appendix D.

Functionality

Researchers developed the MTLC Toolbox to allow users to explore potential energy savings through technology and construction retrofits. The Toolbox developed a baseline model for the user based on their current equipment specifications. The user was directed to a questionnaire asking them to make selections based on their building specifications (see Figure 61).

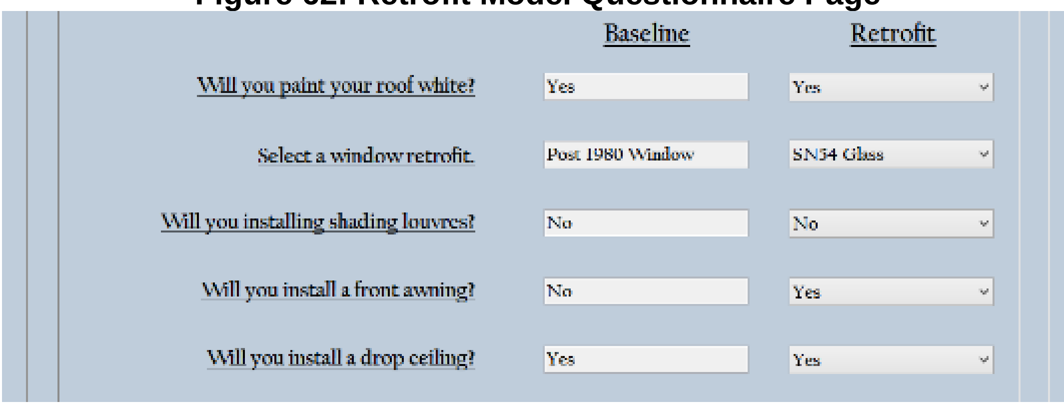
Figure 61: Baseline Model Questionnaire Page



Source: UC Davis EEC

After the baseline model was developed, the user ran through a similar questionnaire to select new, recommended equipment for each parameter they customized in their baseline model (see Figure 62). The MTLC Toolbox used the retrofitted selections to create a retrofit building model. The retrofit model then ran through an EnergyPlus simulation and the energy consumption outputs of the retrofit model were compared to the outputs of the baseline model to determine energy savings.

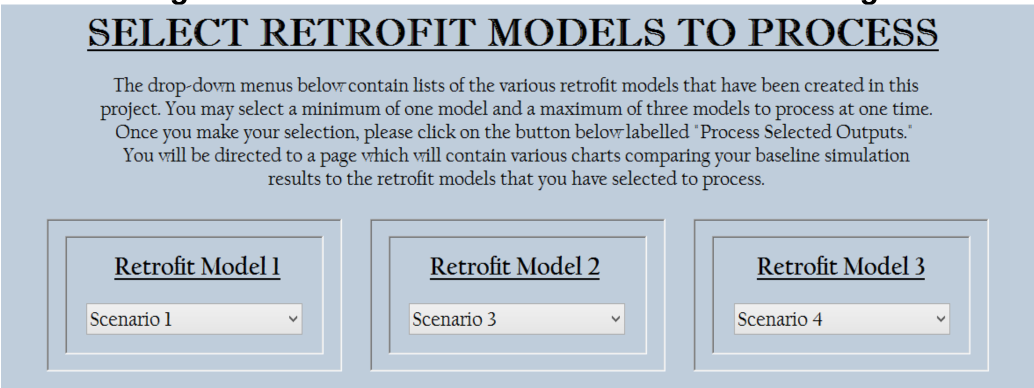
Figure 62: Retrofit Model Questionnaire Page



Source: UC Davis EEC

With the MTLC Toolbox, users could create as many retrofit combinations as desired. For example, if the user wanted to view energy savings based only on HVAC retrofits, they could create a model that contains only retrofitted HVAC equipment, with all the other equipment remaining the same. Similarly, the user could view a model with only lighting upgrades, envelope upgrades, or any combination of upgrades they saw viable for their building. Once the simulations for all the retrofit models were finished, users could compare the outputs of up to three retrofit models at one time, view the savings for each retrofit model, and identify the retrofit model that was most viable to implement in their building (see Figure 63).

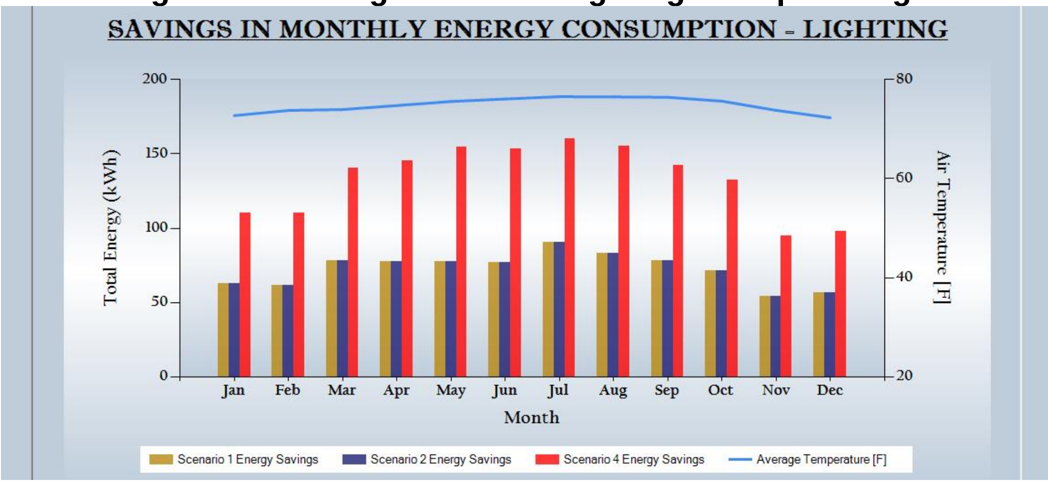
Figure 63: Select Retrofit Models to Process Page



Source: UC Davis EEC

The output page contained all of the results, represented through various charts. Energy consumption reduction was assessed through monthly analysis, while demand reduction was assessed through hourly analysis. The first chart is an annual overall energy consumption reduction plot, showing the differences in energy consumption between each retrofit model as compared to the baseline model. The next two charts are also energy reduction plots based on the difference between the retrofit models and the baseline, but are split into two categories: Lighting and HVAC (see Figure 64). The final chart consists of the maximum possible demand reduction, which was based on power usage values.

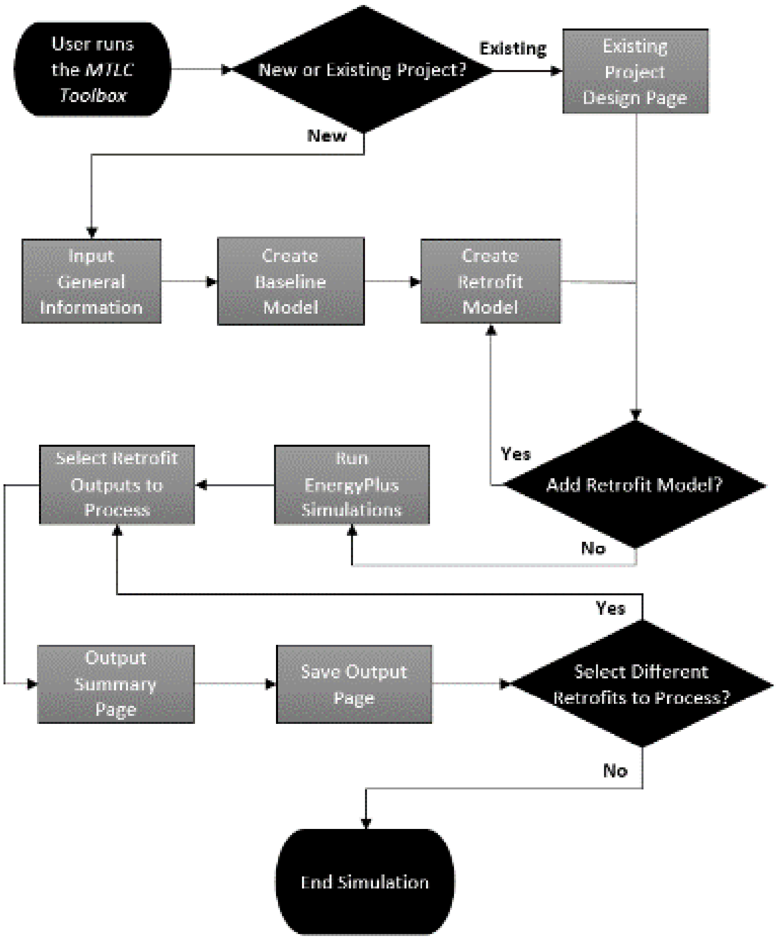
Figure 64: Savings Chart for Lighting – Outputs Page



Source: UC Davis EEC

Figure 65 shows a detailed flowchart of the user-interface experience.

Figure 65: Process Diagram of Using Multitenant Light Commercial Toolbox



Source: UC Davis EEC

Parameters

Although the general baseline model is an accurate representation of a typical MTLC building in California, several parameters in the model vary based on certain building or tenant space specifications. Variable factors that influence baseline model parameters include lighting specifications, HVAC equipment, exterior envelope characteristics, and geographical location. To achieve this level of customization, the MTLC Toolbox contained short questionnaires, which asked the user to make specific selections regarding the equipment and characteristics of their tenant space. The MTLC Toolbox added the customized information to the baseline model and runs simulations based on the specified selections.

After selecting existing building parameters such as tenant type, building orientation, window-wall-ratio, and climate zone to build a baseline model, users then compared energy performance against performance with one of more than 3000 possible ECM packages. Packages could be composed of lighting power density reductions, HVAC efficiency improvements, and energy-efficient technologies such as cool roofs, skylights, and daylight harvesting controls.

Table 34 shows the factors users could select to create a baseline model and retrofit models.

Table 34: Key Variables Used for Energy Simulations of Multitenant Light Commercial Buildings and Tenant Spaces

Parameter	Variables	Baseline Value
Business Type	Mercantile, Office, Food Service, Food Store, Salon Service	Mercantile (retail)
Building Location	1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16	Climate zone 12
Building Orientation	North, South, East, West	West
Tenant Space Location	Left End Unit, Right End Unit, Center Unit	Center Unit
Roof USDOE reference building (circa 1980-2003, updated to comply with Title 24, Part 6 requirements for R-value)	Standard roof, white roof	Standard roof
Drop Ceiling	No drop ceiling, drop ceiling with R-value = 14	No drop ceiling
Window-Wall Ratio	50%, 80%	50%
HVAC	COP = 2.9, 4.1, 5, 6 Standard cooling, Evaporative precooling No economizer, economizer Automatic fan control, ON	COP = 2.9 Standard cooler No economizer Automatic fan control
Duct Leakage	Leaky = 18%, Tight = 3%	Leaky = 18%
Envelope Leakage	$4.5 \cdot 10^{-5}\, kg/(s \cdot ft^2)$ at 1 Pa	$4.5 \cdot 10^{-5}\, kg/(s \cdot ft^2)$ at 1 Pa
Skylights	None, skylights (compliant with T24-2013 requirements)	None
Awnings	None, awning on front-façade windows	None
Window Louvers	None, exterior horizontal window louvers, 0° tilt	None

Parameter	Variables	Baseline Value
Windows	Pre-1980: (U-factor = 6.927, SHGC = 0.54) Post-1980: (U-factor = 4.088, SHGC = 0.38) Post-2004: (U-factor = 3.236, SHGC = 0.25) SN54: (U-factor = 1.65, SHGC =0.25) VT: 0.6 for all Diffuse (top window in 80% WWR only): (U-factor=1.02, SHGC = 0.13, VT = 0.1)	Post-1980: USDOE reference building (circa 1980-2003) U-Factor (W/m^2*K): 4.088 SHGC: 0.38 VT: 0.6
Horizontal Louvers (outdoor)	None, Fixed louvers with 0° downward inclination	None
Indoor Lighting	LF T8, LED lighting, T12 lighting LPD based on business type. See section on Lighting Equipment.	Linear fluorescent T8 lighting LPD (retail) = 1.14
Indoor Lighting Controls	Manual switches only, daylight harvesting controls	Manual switches only
Outdoor Lighting (not modeled in MTLC tool)	N/A	N/A

Source: UC Davis EEC

In the following sections, researchers provided details on each of the parameters and modifications made to tailor the MTLC Toolbox to the California market. Toolbox factors were either fixed or variable. Fixed factors were those that researchers specified to best represent MTLC buildings in the California market. Variable factors were those that users identified based on their particular building characteristics and are noted in **bold** font.

Business Characteristics and Location

Business Type

The research team identified eight different MTLC business types commonly found in the MTLC market based on audits of 83 MTLC businesses located in Northern California (see Chapter 2). The research team selected five common MTLC business types for inclusion in the MTLC Toolbox:

- Mercantile

- Food Sales
- Food Service
- Office
- Salon Service

These business types aligned well with a recent California study that surveyed more than 8000 non-residential establishments for building and energy characteristics. Within this sample set, the top five business types found in MTLC buildings, excluding businesses identified as miscellaneous (27 percent), were Office (24 percent), Mercantile/Retail (18 percent), Food Service (14 percent), Healthcare (8 percent), Warehouse (5 percent) and Food Sales (4 percent). Researchers assumed salon services were part of the miscellaneous category. In addition, the survey found that offices, food service, and retail establishments were most often found in MTLC buildings, as opposed to occupation of an entire single building or commercial campus (that is, multiple buildings).

Business Operating Hours and Equipment Use

In the MTLC Toolbox, selecting a particular business type dictated business operating hours, occupancy density, internal electric equipment loads, and lighting power density. Business operating hours were based on the results of the MTLC building audit (see Chapter 2). The research team calculated average business hours for each of the five business types (rounded to the nearest 15-minute increment). Researchers based daily lighting hours-of-use on the average business hours of each business type. Table 35 shows the daily schedule for each business type, including the percentage of each type included in the audit.

Table 35: Sample of Business Hours by Multitenant Light Commercial Business Type

	Total Establishments (%)	Open (M-F)	Close (M-F)	Open (Sat)	Close (Sat)	Open (Sun)	Close (Sun)
Mercantile	21.90%	9:15	19:30	9:30	19:30	9:30	18:45
Food Sales	6.80%	8:45	22:00	8:45	22:00	5:15	13:30
Food Service	31.50%	9:00	20:00	8:45	19:30	8:15	18:30
Office	1.40%	9:00	18:00	10:00	15:00	10:00	15:00
Salon Service	38.40%	9:00	19:00	9:00	18:00	9:30	19:15

Source: UC Davis EEC

In addition to lighting hours-of-use, accounting for the total internal electric loads is a key variable in the determination of a building’s baseline and retrofit energy use. Internal loads, shown in Table 36, represent the total, maximum electric load of an

MTLC business. Researchers established these values from the USDOE reference building parameters (Deru et al., 2011). To account for variation in this load due to daily business hours and weekend schedules, the team implemented an electric load schedule in the MTLC Toolbox (see Figure 66). This schedule determined what percentage of the maximum electric load was used each day and hour.

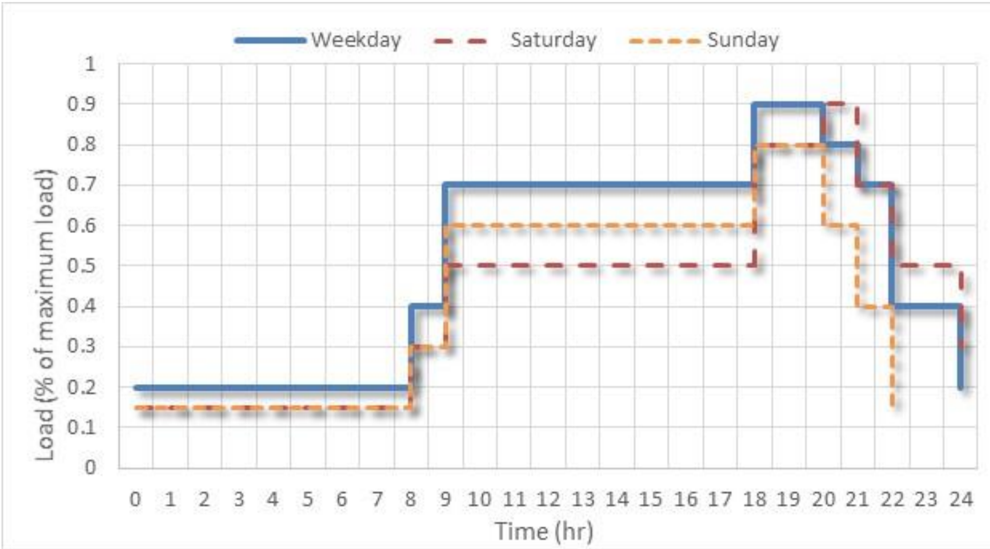
Table 36: Maximum Internal Load by Business Type

Building Type/Zone	Area ft²	Vol. ft³	ft²/ person	1989 Lights Wft²	2004 Lights Wft²	Elec. Proc. W/ft²	Gas Proc. W/ft²	Vent. cfm	Exhst cfm	Infil. ACH	SWH gal/h	@@ElecLoad@@
Medium Office	**53,628**	**697,161**										
Perimeter_bot_ZN_3	2,232	20,086	200.0	1.57	1.0	0.7	0.0	223.2	0.0	0.26	0.0	0.7W/ft2
Perimeter_bot_ZN_2	1,413	12,716	200.0	1.57	1.0	0.7	0.0	141.3	0.0	0.28	0.0	
Perimeter_bot_ZN_1	2,232	20,086	200.0	1.57	1.0	0.7	0.0	223.2	0.0	0.26	0.0	7.5W/m2
note: rest of data cut off in img												
Retail	**24,692**	**494,171**										
Back_Space	4,089	81,836	300.0	1.17	0.8	0.8	0.0	613.4	0.0	0.37	0.0	0.5W/ft2
Core_Retail	17,227	344,775	66.7	3.37	1.7	0.3	0.0	5168.2	0.0	0.22	0.0	5.4W/m2
Point_of_Sale	1,623	32,487	66.7	3.37	1.7	2.0	0.0	487.0	0.0	0.40	0.0	
Front_Retail	1,623	32,487	66.7	3.37	1.7	0.3	0.0	487.0	0.0	0.40	0.0	
Front_Entry	129	2,585	66.7	3.37	1.1	0.0	0.0	0.0	0.0	0.54	0.0	
Supermarket	**45,002**	**900,272**										
Office	956	19,131	200.0	1.98	1.1	0.8	0.0	95.6	0.0	0.41	0.0	1.0W/ft2
DryStorage	6,694	133,914	300.0	1.11	0.8	0.8	0.0	1004.1	0.0	0.32	0.0	
Deli	2,419	48,390	125.0	2.78	1.7	5.0	2.5	725.7	0.0	0.29	5.0	10.8W/m2
Sales	25,025	500,642	125.0	2.78	1.7	0.5	0.0	7507.6	0.0	0.20	0.0	
Produce	7,657	153,181	125.0	2.78	1.7	0.5	0.0	2297.1	0.0	0.27	0.0	
Bakery	2,250	45,014	125.0	2.78	1.7	5.0	2.5	675.0	2500.0	0.34	5.0	13.6W/ft2
Full Service Restaurant	**5,502**	**55,035**										
Dining	4,001	40,025	15.0	2.54	2.1	5.6	0.0	5335.3	0.0	0.52	0.0	146.4W/m2
Kitchen	1,501	15,009	200.0	1.52	1.2	35.0	111.3	112.5	4000.0	0.63	133.0	
Attic	5,502	30,239	0.0	0.00	0.0	0.0	0.0	0.0	0.0	1.00	0.0	
Strip Mall	**22,500**	**382,500**										
LGStore1	3,750	63,750	66.7	5.60	2.2	0.4	0.0	1125.0	0.0	0.38	0.0	
SMStore1	1,875	31,875	66.7	5.60	2.2	0.4	0.0	562.5	0.0	0.31	0.0	
SMStore2	1,875	31,875	66.7	3.30	1.7	0.4	0.0	562.5	0.0	0.31	0.0	
SMStore3	1,875	31,875	66.7	3.30	1.7	0.4	0.0	562.5	0.0	0.31	0.0	0.4W/ft2
SMStore4	1,875	31,875	66.7	3.30	1.7	0.4	0.0	562.5	0.0	0.31	0.0	4.3W/m2
LGStore2	3,750	63,750	66.7	2.70	1.3	0.4	0.0	1125.0	0.0	0.31	0.0	
SMStore5	1,875	31,875	66.7	2.70	1.3	0.4	0.0	562.5	0.0	0.31	0.0	
SMStore6	1,875	31,875	66.7	2.70	1.3	0.4	0.0	562.5	0.0	0.31	0.0	
SMStore7	1,875	31,875	66.7	2.70	1.3	0.4	0.0	562.5	0.0	0.31	0.0	
SMStore8	1,875	31,875	66.7	2.70	1.3	0.4	0.0	562.5	0.0	0.45	0.0	

Source: Deru et al., 2011

Figure 66 details the schedule used for all business types.

Figure 66: Daily Electric Load Schedule Used in Multitenant Light Commercial Tool

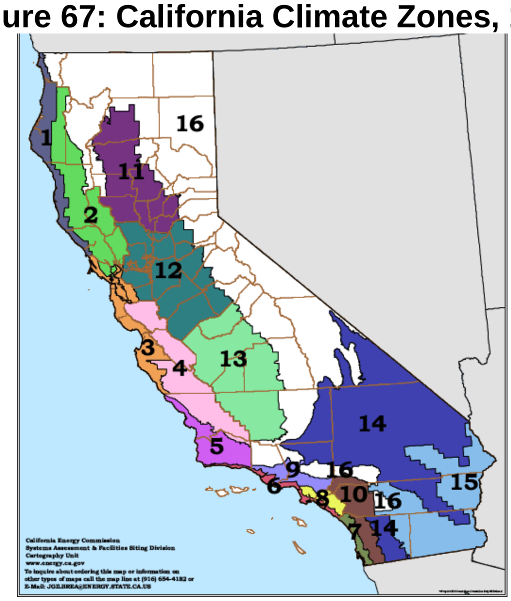


Source: UC Davis EEC

Building Location

The geographical location of an MTLC building was characterized by its location with respect to 16 unique climate zones in California (see Figure 67). Annual climate and weather characteristics, specific to each zone, directly influenced the lighting, heating, and cooling needs of MTLC tenant spaces. The MTLC Toolbox allowed users to select the climate zone appropriate to the location of an MTLC building: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16.

Figure 67: California Climate Zones, 1-16



Source: California Energy Commission (http://www.energy.ca.gov/maps/renewable/building_climate_zones.html)

Building Construction

Users could specify physical building characteristics to tailor the model building to a particular MTLC building with regards to building geometry, orientation, and the presence/absence of drop ceilings.

Building Geometry

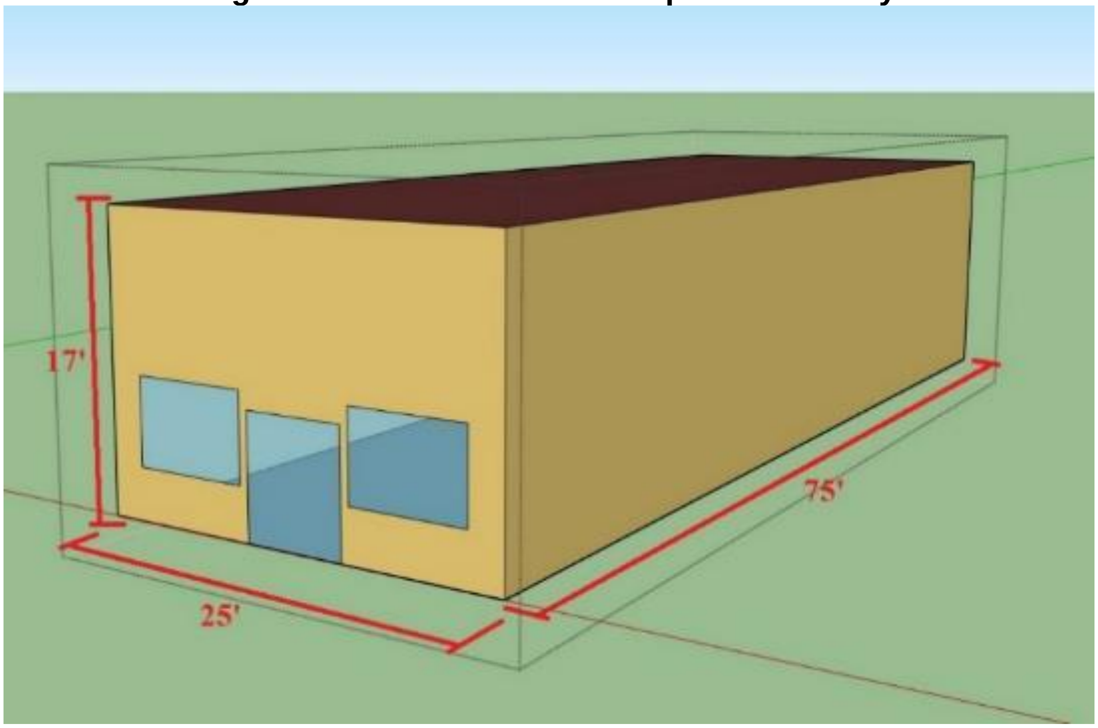
USDOE reference models include a variety of building and business types, each with specific modeling parameters. Figure 68 shows a rendering of the MTLC building used in the MTLC Toolbox and is provided in the USDOE reference Stripmall.idf file.

Figure 68: Department of Energy Reference Building for Multitenant Light Commercial "Strip Mall"

Source: Department of Energy and UC Davis EEC

The MTLC Toolbox estimated energy use for a single building tenant within the MTLC reference building. Figure 69 shows the resultant tenant space geometry. The model tenant space is 1875 sq-ft with a 17' high hard ceiling.

Figure 69: Reference Tenant-Space Geometry



Source: Department of Energy and UC Davis EEC

Building Orientation

In MTLC Toolbox, users could specify building orientation as North, South, East, or West. This orientation was used to simulate a tenant space's energy performance with respect to cardinal orientation. The model building had windows only on the front building façade. The building orientation dictated the exposure of this façade. For example, buildings modeled with a North orientation would have a north-facing front building façade.

Building orientation affects sunlight penetration and sun exposure level of the interior tenant space, which correlates to heating, cooling, and lighting energy use. Although buildings can be orientated in many directions, the MTLC Toolbox limited the variable values to four to reduce simulation time and complexity.

Tenant Space Location

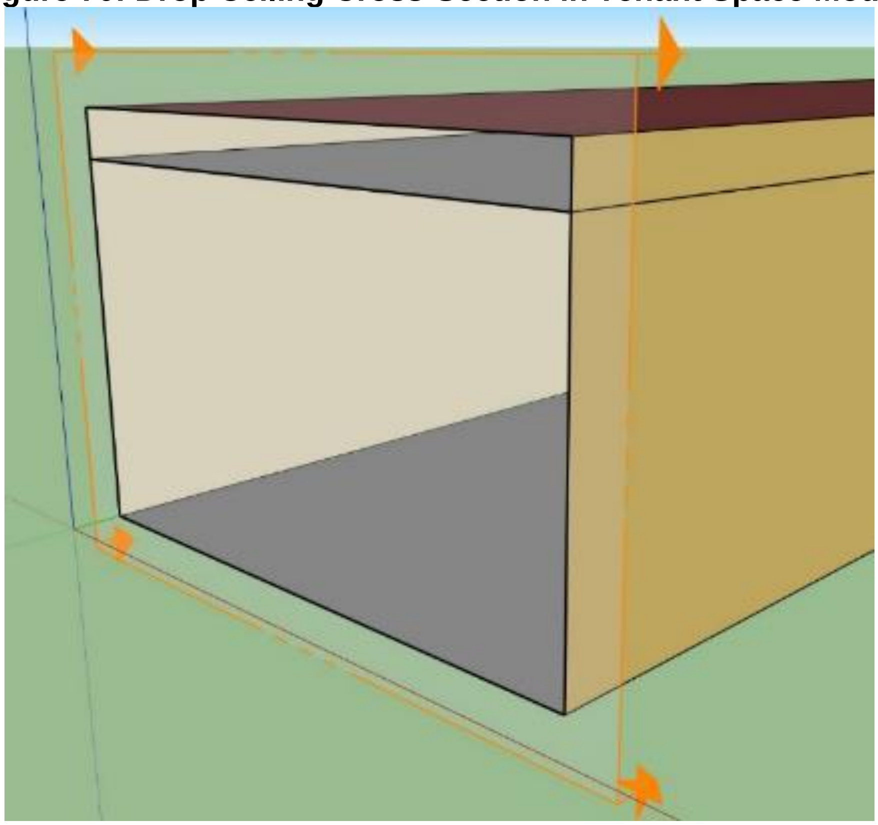
A typical MTLC strip mall contains many adjacent tenant spaces. To better estimate energy performance with respect to tenant space location within an MTLC building, Toolbox users selected one of three options for the tenant space location: left unit, center unit, right unit. Center units had a tenant on two sides, and thus had two adiabatic walls where no heat could pass through. Left and right units were simulated with a single adiabatic wall. Selection of left unit or right unit, when combined with a specific building orientation, dictated the level and duration of sun exposure on the non-adiabatic wall, which correlated to heating and cooling requirements for the space.

Drop Ceilings

Many MTLC tenant spaces have drop ceilings. A drop ceiling is often implemented as an aesthetic fix, but can impact interior space heating and cooling by separating HVAC duct losses (leaks and conduction) to a partitioned space above the main commercial space, and by serving as a buffer between roof heat transfer and the thermal balance of the commercial space (see Figure 70). Drop ceilings can also be beneficial because they reduce the overall volume of space that requires conditioning. MTLC Toolbox users selected Drop Ceiling or No Drop Ceiling.

Research has shown that roof assemblies that include drop ceilings are sometimes insulated only on the roof deck, sometimes only right on top of the drop ceiling, and sometimes in both locations. MTLC users with drop ceilings could select Insulation on Ceiling Tiles, Insulation on Roof Deck, and Both. This enhancement was required to accurately evaluate the impact of sealing duct leaks and white roof coatings in drop ceiling spaces.

Figure 70: Drop Ceiling Cross-Section in Tenant Space Model



Source: Department of Energy and UC Davis EEC

Building Envelope

Building R-Values

R-Value is a metric used to represent the thermodynamic conduction properties of a building's wall, ceiling, and floor construction. Table 37 details the USDOE reference model values, however, this model does not accurately depict wall and ceiling R-values for California commercial buildings. To better match California building stock, the research team used Title 24 building standards to modify the ceiling and wall insulation material properties in MTLC Toolbox.

Table 37: Building R-Values of USDOE Reference Building

	Material	Thickness (m)	Conductivity (W/m*K)	U-Value (W/m^2*K)	R-Value (K*m^2/W)	R-Value (h*ft^2*F/Btu)	R (combined)
Exterior Wall	Wood siding	0.01	0.110	11.00	0.09	0.5	3.61
Exterior Wall	steel frame nonresidential Insulation	0.02	0.05	2.15	0.47	2.6	3.61
Exterior Wall	½" gypsum	0.01	0.16	12.60	0.08	0.5	3.61
External Roof	roof membrane	0.01	0.16	16.84	0.06	0.3	8.91
External Roof	IEAD nonresidential roof insulation	0.07	0.05	0.66	1.51	8.6	8.91
External Roof	Metal decking	0.0015	45.01	30004.00	0.00	0.0	8.91
External Floor	HW concrete	0.1016	1.31	12.904	0.08	0.4	0.44

Source: UC Davis EEC

Title 24 standards for non-residential buildings constructed between 1978 and 2013 have very little variance in the minimum required R-value. The MTLC Toolbox used an average R-value, taken from minimum requirements in place between 1978 and 2013, to simplify calculations and reduce simulation operating time. Table 38 shows the summed R-Value (R combined) used in the MTLC Toolbox. In addition, Table 38 includes values for an internal drop ceiling, a feature often found in MTLC buildings.

Table 38: Modified Building R-Values Aligned with California Building Standards

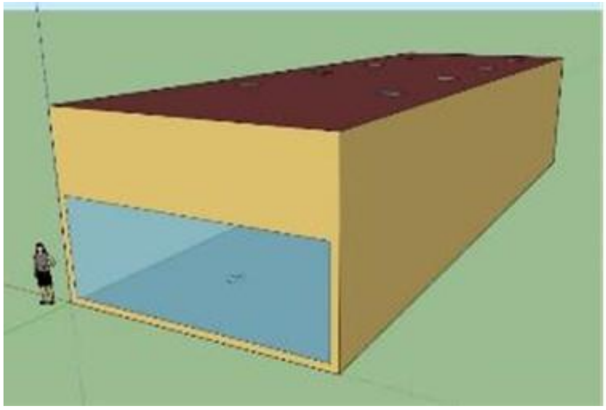
	Material	Thick-ness (m)	Conduc-tivity (W/m*K)	U-Value (W/m^2*K)	R-Value ($K*m^2/W$)	R-Value ($h*ft^2*F/Btu$)	R (com-bined)
Exterior Wall	Wood siding	0.01	0.11	11.00	0.09	0.52	10.5
Exterior Wall	steel frame nonresidential Insulation	0.02	0.01	0.60	1.68	9.53	10.5
Exterior Wall	½" gypsum	0.01	0.16	12.60	0.08	0.45	10.5
External Roof	Roof membrane	variable	0.16	16.84	0.06	0.34	19.0
External Roof	IEAD nonresidential roof insulation	0.07	0.02	0.30	3.29	18.66	19.0
External Roof	Metal decking	0.00	45	30004.00	0.00	0.000	19.0
Indoor Drop Ceiling	Drop Ceiling insulation	0.05	0.02			11.19	13.0
Indoor Drop Ceiling	Drop Ceiling	0.02	0.06	3.13	0.32	1.81	13.0
External Floor	Floor Material	0.10	0.05	0.52	1.94	11.00	11.0

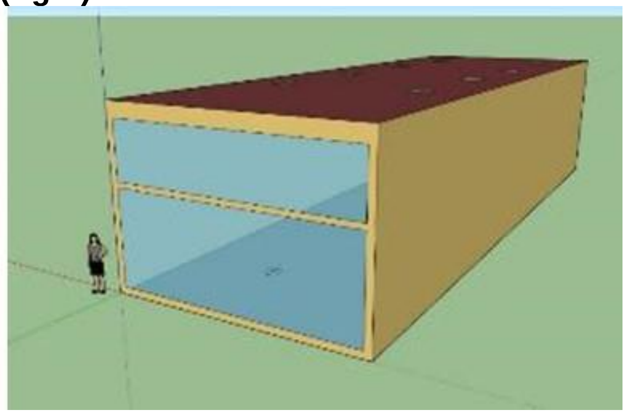
Source: UC Davis EEC

Window Wall Ratio

The size and geometry of façade windows impacts lighting, heating, and cooling energy use. Users selected from two common window-wall ratios (WWRs) in the MTLC Toolbox: 50 percent or 80 percent (see Figure 71). A 50 percent WWR is common for single story MTLC spaces. By adding an additional window above the main entrance window, increasing the window wall ratio to 80 percent, the Toolbox could better accommodate multiple real world scenarios. Note that when 80 percent WWR was selected, the properties of the upper window were different from the lower window; the upper window was modeled as diffuse glass, while the lower window was not. More information on window properties is provided below.

Figure 71: Building Models with Different Window - Wall Ratios, 50% (left) and 80% (right)





Source: Department of Energy and UC Davis EEC

Windows

Variations in the building fenestration type and glazing can significantly impact total building energy consumption. Fenestration allows sight and the passage of light. Along with window size and shape, the MTLC Toolbox considered Solar Heat Gain (SHGC), U-factor, and Visible Transmittance (VT) to characterize energy exchange across windows. Users selected from a number of different window types in the Toolbox. Window types vary with respect to U-factor (the ability of a window to insulate) and SHGC (the fraction of incident radiation that enters the tenant space). After review of commercially available windows and window properties with respect to date of installation, as well as USDOE reference window constants, the research team combined the two sources to create four window variables in the MTLC Toolbox: pre-1980, post-1980, post-2004, and SN54. SN54 is a modern, clear, low solar heat gain glass from Guardian Glass. To simplify the model, researchers fixed the VT at 0.6. This ensureed that energy use is based on the efficiency of the window SHGC and U-Factor (see Table 39).

Table 39: Window Variables and Corresponding Properties used with 50% Window-Wall Ratio in Multitenant Light Commercial Toolbox

	USDOE, Pre-1980	USDOE, Post-1980	USDOE, Post-2004	SN54 Glass
U-Factor (W/K*m^2)	6.927	4.088	3.236	1.65
SHGC	0.54	0.38	0.25	0.25
VT	0.6	0.6	0.6	0.6

Source: UC Davis EEC

For buildings with an 80 percent WWR, the upper window was qualified for conversion to diffuse glass. Diffuse glass technology is considered an optimal source for interior lighting, oftentimes with energy efficiencies that are preferable to other glazing. White

Kalwall glass at 2.5 inches thick was used as a standard for simulating the upper window retrofit when modeling an upgrade to SN54 glass (see Table 40).

Table 40: Window Variables and Corresponding Properties used with 80% WWR in the Multitenant Light Commercial Tool

	USDOE, Pre-1980	USDOE, Post-1980	USDOE, Post-2004	SN54 Glass	Diffuse Glass (upper window only)
U-Factor ($W/K*m^2$)	6.927	4.088	3.236	1.65	1.02
SHGC	0.54	0.38	0.25	0.25	0.13
VT	0.6	0.6	0.6	0.6	0.1

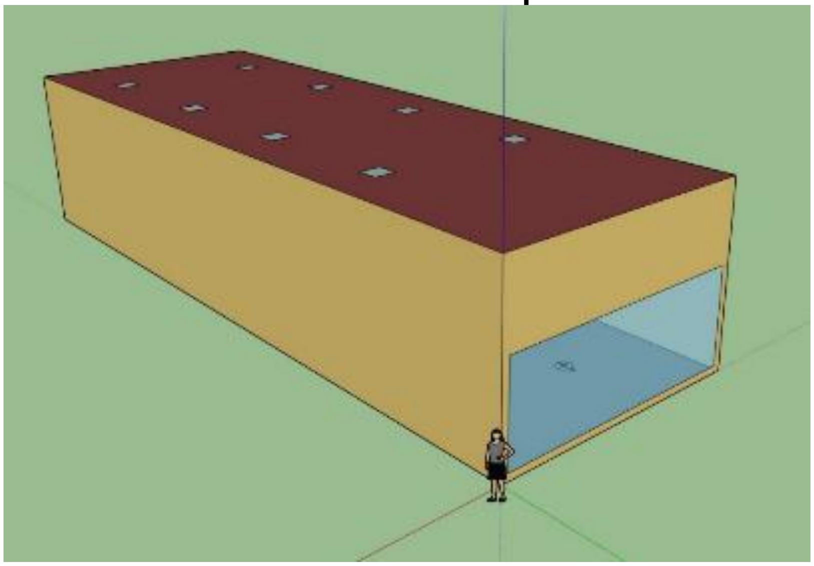
Source: UC Davis EEC

Skylights

Users selected none or skylight in the MTLC Toolbox. Researchers used a single type of skylight, which was simulated as a basic "ceiling" window due to the difficulty in modeling an actual curb style skylight using EnergyPlus (see Figure 72). However, the U-factor of the skylight and the SHGC were both based on measured data provided by a leading skylight manufacturer.

- U-Factor: 3.24 ($W/K*m^2$)
- SHGC: 0.8
- VT: 0.8

Figure 72: Rendering of Skylights Used in Multitenant Light Commercial Reference Tenant-Space



Source: Department of Energy and UC Davis EEC

Envelope Leakage

Leaks in the building envelope result in infiltration and exfiltration beyond what is necessary to ventilate the building. This excess ventilation must be treated by the HVAC system and causes an increase in heating and cooling energy.

The direction and amount of airflow into or out of a building is based on the difference in indoor and outdoor pressures, and the size and location of holes or leaks in the building envelope. Wind striking an exterior surface of a building (the windward side) pressurizes that surface and drives airflow into the building (infiltration) through leaks and any intentional openings (that is, windows, vents, and so on). Conversely, the exterior surfaces of the building, opposite the windward side (the leeward side) experience a reduction in pressure as a result of the wind. This reduced pressure results in air flowing out of the building (exfiltration) though leaks and holes on the leeward side.[30] Wind pressure can also affect relative indoor zonal air pressures and influence airflow between interior zones.

In buildings there is also buoyancy-driven movement of air into and out of a building, which is called "stack effect." Stack effect is driven by the difference in air temperature between indoors and outdoors. During the cooling season, cold air inside a building is denser than the hot air outside the building. This denser air sinks and exits the building through leaks on the lower floors (or lower parts of the walls), while drawing in makeup air from the outside through leaks in the upper floors (or the roof or upper parts of the walls). During the heating season the opposite occurs; warm air inside the building is

30 The direction of flow, either into or out of a building, depends on more than the outside surface pressure since the driving force for flow is based on the relative pressure between inside and outside.

less dense than the cold air outside the building. The warm air rises and exits the building through leaks up high, drawing in makeup air through leaks down low.

In a review of a NIST database, which included 270 buildings, Emmerich et al. found that retail buildings leak, on average, at a rate of 19.2 $m^3/h \cdot m^2$ at 75 Pa which is equivalent to $4.5 \cdot 10^{-5}\ kg/(s \cdot ft^2)$ at 1 Pa, where Pa is the pressure difference across the crack. They found the average flow exponent to be 0.62.

In the MTLC Toolbox, researchers set envelope leakage for the four exterior walls and the roof at the average leakage rate found by Emmerich et al. for retail buildings. The model assumes a slab construction and does not allow leaks through the floor.

Roof Color

Coloring the roof of buildings in regions with high yearly cooling loads can often increase a roof's reflectivity and lower cooling costs. The MTLC Toolbox had two roof options: standard roof or white roof. For the standard roof, researchers used parameters from the USDOE reference model. For the white roof, they used performance properties from a commercially available white roof coating (see Table 41).[31]

Table 41: White Roof Coating Properties Used in the Multitenant Light Commercial Tool

	Standard Roof (USDOE reference model)	White Roof
Roof Membrane Thickness (m)	0.01	0.02
Thermal Absorption	0.9	0.07
Solar Absorption	0.7	0.14

Source: UC Davis EEC

Awnings

In the MTLC Toolbox, users specified no awnings or awnings on the front façade windows. Researchers optimized awning length for different angles to reduce the effective length of the awning (see Table 42). As shown in Table 43, as the angle of the awning changes, the required awning length was reduced while providing the same hours of shading. The research team plotted the awning lengths (L) at each angle. The Toolbox used an awning sized for a 9 foot tall window, with an 8° awning tilt. The appropriate awning length was 12.8 feet.

31 SureCoat variables provided by: http://www.surecoatsystems.com/white-roof-paint-vs-white-roof-coating-case-study.asp.

Table 42: Sun Angle and Effects on Optimal Awning Length

	South	East	West
Sun profile angle (from zenith) (degrees)	**60**	**60**	**60**
Sun profile angle (radians)	1.0472	1.0472	1.0472
Awning length for 50% WWR (9 ft)	15.6	15.6	15.6

Source: UC Davis EEC

Table 43: Awning Dimensions with Respect to Awning Angle for a Fixed Duration of Daily Shading (assumes 9' tall window)

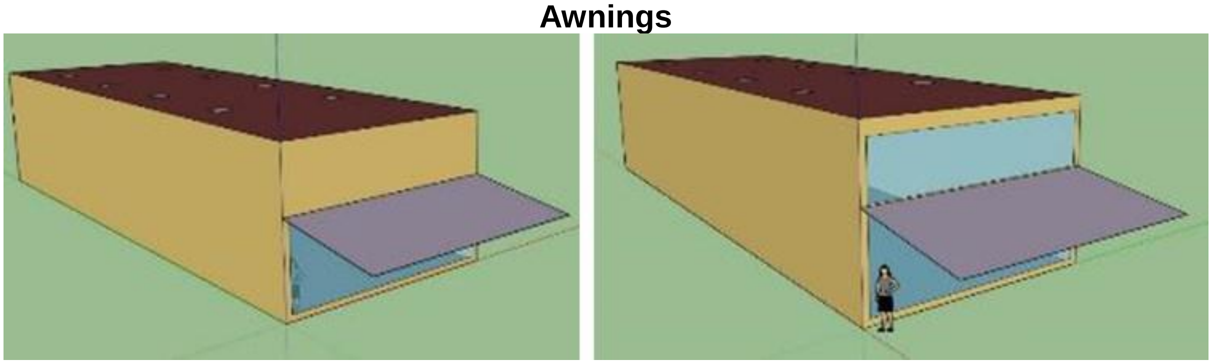
	Length South	Length East	Length West	Height South	Height East	Height West	Depth South	Depth East	Depth West
8 ° (9ft window)	12.8	12.8	12.8	7.2	7.2	7.2	7.2	7.2	7.2
12° (9ft window)	11.8	11.8	11.8	6.6	6.6	6.6	6.6	6.6	6.6
15° (9ft window)	11.2	11.2	11.2	6.1	6.1	6.1	6.1	6.1	6.1

Length is length of awning in feet; height is base of window to awning in feet; depth is horizontal distance from building in feet.

Source: UC Davis EEC

An awning with 8° tilt has a height from base of window to top of window of about 7.2 ft. This gives an overall height of 8 feet from ground to the lowest point on the awning, which is an acceptable clearance for anyone to pass underneath. Figure 73 shows a rendering of the awning used with the MTLC Toolbox.

Figure 73: Rendering of Multitenant Light Commercial Model Tenant Space with Awnings

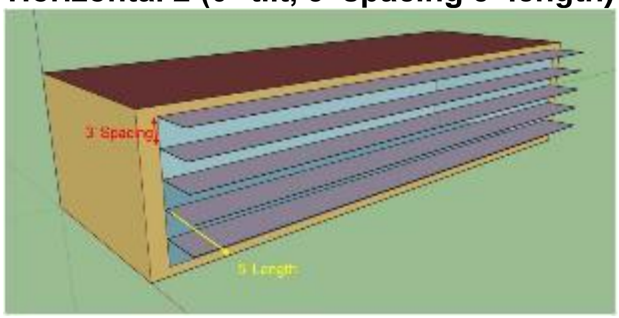


Source: Department of Energy and UC Davis EEC

Horizontal Louvers

Louvers, like awnings, offer many benefits to reduced cooling energy use. Unlike awnings however, louvers reduce the viewing angle and visibility from the outside, which can be a desirable trait for building tenants requiring privacy. The MTLC Toolbox had two options for users to select: no louvers and horizontal window louvers. Figure 74 shows a rendering of the shading option. The louvers were 5' in length with 3' spacing and a 0-degree tilt.

Figure 74: Exterior, Horizontal Window Louvers included in Toolbox, Horizontal 2 (0° tilt, 3' spacing 5' length)



Source: Department of Energy and UC Davis EEC

Heating, Ventilation, and Air Conditioning Equipment

MTLC Toolbox users could consider a variety of HVAC technologies as part of an ECM package. For Toolbox simulations, heating was assumed to be a gas furnace with a fixed efficiency of 0.8. Users could select improvements to the air conditioning and ventilation systems as described below.

Air Conditioning

The cooling capabilities of air conditioners vary to provide adequate cooling to buildings and loads of various sizes. Air conditioners are rated by the amount of cooling that they can provide at specific indoor and outdoor air conditions referred to as "rated conditions."

When selecting an air conditioner for a space, a general rule of thumb is one ton of refrigeration per 350 sq-ft of floor area in the space being conditioned. This nearly always results in oversizing, but is widely practiced. Using this sizing practice, the air conditioner in the USDOE reference model, also used in the MTLC Toolbox, was configured to provide six tons of cooling at rated conditions.

Air Conditioner Efficiency

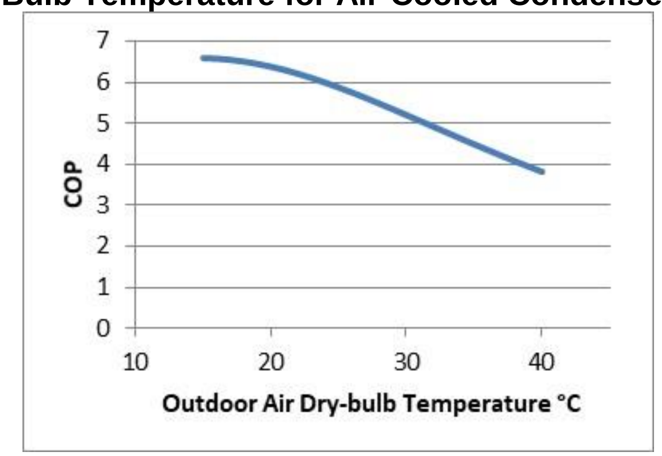
Air conditioner efficiency can vary significantly. Although national standards established and regulated by the USDOE, set minimum requirements for the efficiency of new air conditioners, many old and inefficient systems are still in use. Additionally, even new units can perform at lower than intended efficiencies due to improper refrigerant charge, restricted air flow across the evaporator or condenser, damaged or worn out components and poor duct connections.

EnergyPlus uses the air conditioner's coefficient of performance (COP) at rated conditions to describe efficiency. The COP is the ratio of cooling provided to the work or energy input required. The rated COP of air conditioners can vary from 5 for new, highly efficient, well maintained and properly installed units, to 1.5 for old, poorly maintained units. In the MTLC Toolbox, users selected one of four COP values: 2.9, 4.1, 5, and 6.

Air Conditioner Condenser

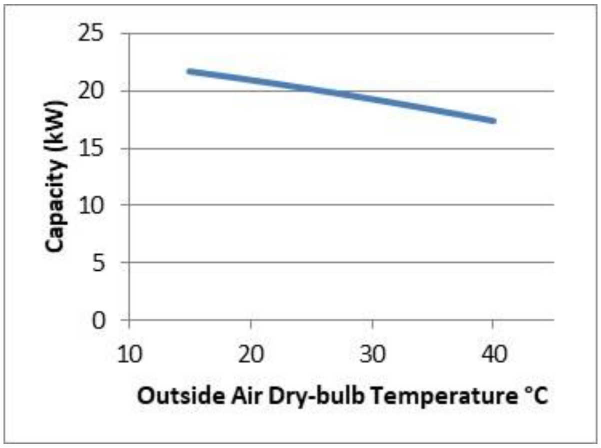
The MTLC Toolbox had two condenser options: standard air-cooled condenser or evaporative precooling condenser. Most air conditioners use an air-cooled condenser coil to reject heat from the building to the ambient air. The cooling capacity and efficiency of these systems are highly dependent on the dry-bulb temperature of the ambient air, as the compressor has to operate at higher pressure to reject heat at a higher temperature. Figure 75 and Figure 76 show the efficiency and capacity of an air-cooled condenser with respect to outdoor-air temperature. As outdoor air temperature increases, the COP and capacity decreases. These curves represent the default values researchers used in the MTLC Toolbox when an air-cooled condenser was selected.

Figure 75: Air Conditioner Coefficient of Performance versus Outside Air Dry-Bulb Temperature for Air-Cooled Condenser



Source: UC Davis WCEC

Figure 76: Air Conditioner Capacity versus Outside Air Dry-Bulb Temperature for Air-Cooled Condenser



Source: UC Davis WCEC

With an evaporative cooled condenser, outdoor air can be evaporatively cooled before it passes over the condenser coil to improve the efficiency of an air conditioner. This evaporative cooling serves to decrease the temperature of the air arriving at the coil, thereby increasing both capacity and efficiency. Thus the capacity and efficiency of an air conditioner can be improved by installing an evaporative cooler on the condenser.

Evaporative effectiveness is defined as the percentage of the wet-bulb depression (the difference between the dry-bulb and wet-bulb temperature of air) that the dry-bulb temperature of the air is reduced through evaporation. WCEC laboratory tests have shown that evaporative pre-coolers typically have an evaporative effectiveness of 70 percent and can range between 40 percent and 75 percent. In MTLC Toolbox, when users selected an evaporative precooled condenser, the evaporative effectiveness was set to 70 percent.

Economizers

To meet building ventilation requirements, most roof top units on California MTLC buildings have an outdoor air intake on the return side of the fan that is used to bring in ventilation air. In multi-tenant buildings, this intake is typically a fixed size opening. The outside air fraction is the fraction of supply air that is ventilation air and is typically 15 percent.

An economizer is a set of motorized dampers used to control the amount of outdoor air the HVAC system brings into the space. Economizers can help reduce the annual energy consumed for cooling, but are most effective during the beginning and end of the cooling season, or during morning operation in California. Economizers generally have no effect on peak cooling demand since the peak virtually always occurs at times when the outdoor air temperature is far greater than the indoor air temperature and thus no “free cooling” is available. Users could configure the MTLC Toolbox to run with an economizer or without an economizer. In the case of an economizer, the Toolbox was configured to control the outside air fraction based on the return air dry-bulb temperature and the outdoor air dry-bulb temperature.

Fan Control

In typical MTLC buildings, HVAC system fans are single speed with a simple thermostat fan control, which is usually labeled "auto" and "on." In "auto" mode the fan operates only when the heating or cooling systems are operating. In this mode, the unit cannot provide ventilation when heating and cooling are off because the fan is off. In "on" mode the fan is operated 100 percent of the time regardless of other HVAC system components. This results in a large amount of energy being spent to circulate air through the system, providing ventilation that is only a fraction of the air that is recirculated. Many buildings operate their fan in "auto" to save energy at the cost of indoor air quality and in conflict with California code requirements. In the MTLC Toolbox, users could set the fan as auto or on.

Ducts

The origin, extent, and impact of duct leaks has been the subject of many research investigations; recorded field measurements show that ductwork in small commercial buildings leaks by approximately 20 percent. In the MTLC Toolbox, users could select leaky or tight ducts. Researchers assumed average duct leakage (leaky) to be 18 percent on the supply side and 18 percent on the return side. Researchers assumed application of duct sealing (tight) to reduce the average duct leakage to 3 percent on each side.

Indoor Lighting Equipment

Electric lighting affects heating and cooling loads. Larger lighting loads produce more heat, as compared to smaller loads, impacting the cooling needs of a space during hot months and heating needs during cold months. Electric lighting energy use can be characterized by lighting power density or LPD (W/sq-ft) and is often correlated to the type of light source installed.

MTLC buildings have a range of installed LPDs. The MTLC Toolbox allowed users to select from several lighting vintages to better simulate the variety of California MTLC building stock. These vintages are based on a combination of USDOE model building reference parameters and California Title 24 allowed LPD reference parameters. In the Toolbox, users select one of seven lighting packages, five taken from the USDOE and Title 24 parameters, and two additional scenarios representing current, best-in-class lighting designs (row 6 and 7, Table 44): pre 1987, 1978-1988, 1989-1997, 1998-2004, post 2004 (T12), post 2004 (T8), and post 2004 (LED). Researchers developed best-in-class scenarios based on the Illuminating Engineering Society's (IES) lowest recommended light levels. To achieve these levels, lighting was assumed to be high performance T8 or LED technology.

Lighting Efficiency

In addition to determining the appropriate LPD, the lighting system was defined by a corresponding source technology available at the time the LPD allowance was in place. For the MTLC Toolbox, three source technologies were considered, each defined by a typical lighting efficacy: T12 lighting technology, T8 lighting technology, and LED lighting technology.

Table 44: Multitenant Light Commercial Toolbox Lighting Power Density by Business Type and Year of Installation

	Mercantile W/m2 (W/ft2)	Food Sales W/m2 (W/ft2)	Food Service W/m2 (W/ft2)	Office W/m2 (W/ft2)	Service W/m2 (W/ft2)
Pre 1978	35.5 (3.30)	29 (2.69)	29 (2.69)	60.3 (5.60)	60.3 (5.60)
1978-1988	33.4 (3.10)	25.8 (2.40)	10.8 (1.00)	53.8 (5.00)	38.8 (3.60)
1989-1997	23.7 (2.20)	21.5 (2.00)	12.9 (1.20)	17.2 (1.60)	23.7 (2.20)
1998-2004	18.3 (1.70)	16.1 (1.50)	12.9 (1.20)	12.9 (1.20)	18.3 (1.70)
Post 2004 (T12)	16.1 (1.50)	16.1 (1.50)	12.9 (1.20)	8.6 (0.80)	18.3 (1.70)
Post 2004 (T8)	12.22 (1.14)	12.22 (1.14)	4.36 (0.41)	6.54 (0.61)	4.36 (0.41)
Post 2004 (LED)	9.4 (0.87)	9.4 (0.87)	3.9 (0.36)	5.9 (0.55)	3.9 (0.36)

Source: UC Davis CLTC

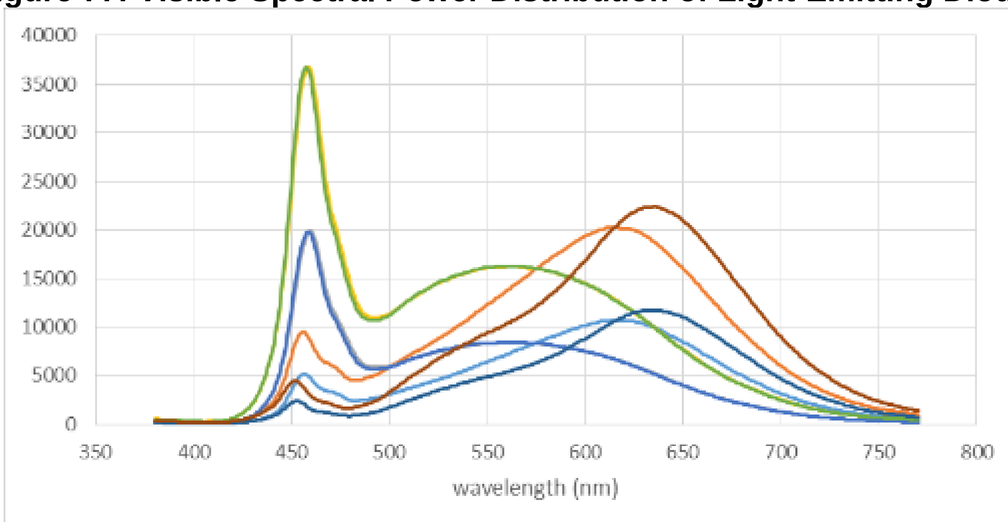
EnergyPlus models lighting efficacy by using three different variables.

- Total light energy (measured in W/sq-ft or W/m2)
- Fraction visible or "FV" (measured from 0 to 1)
- Fraction radiant "FR" (measured from 0 to 1)

Each of the three technologies of choice (T12, T8 and LED) had its own radiant and visible coefficients that had to be included. The research team used the IES's Lighting Handbook 10th edition as the main source for radiant and visible coefficients for the MTLC Toolbox (DiLaura et al., 2011). The values for 'fraction visible' and 'fraction radiant' of LED technology vary based on the LEDs being used in the lamp or light fixture. With the variety of LED lighting technologies that were on the market, the research team selected a blue LED with phosphor coating as the baseline LED type. To calculate the FV and FR coefficients, researchers took the spectral power distributions (SPD) of eight different LED lamps tested at CLTC and measured the output power from each source separately, taking the lowest FV and highest FR calculated as the constants for use in the EnergyPlus model. Figure 77 shows the visible light emitted from each LED measured from 380 nm to 770 nm.

By summing the total lighting power output in the visible spectrum (380 nm to 770 nm) and dividing it by the total power consumed by the LED lamp, researchers determined the ratio FV for each specific lamp. As expected, the visible output of the LED light source (FV) was much higher than the output of older technologies, while the radiant output (FR) was lower (see Table 45).

Figure 77: Visible Spectral Power Distribution of Light-Emitting Diodes



Source: UC Davis CLTC

Table 45: Fraction Visible and Fraction Radiant for Lighting Technologies

	Incandescent	T12	T8	LED
FV	10%	18%	28%	40%
FR	90%	70%	72%	60%

Source: UC Davis CLTC

Indoor Lighting Controls

Occupancy controls and daylight sensing equipment can drastically reduce lighting loads. Adaptive lighting, using sensors, scheduling equipment, and dimmable lighting, is used to tailor building lighting to occupants' actual needs. Reductions may be based on area occupancy, available daylight, or task needs.

Occupancy profiles (tenant-space occupancy by hour during business hours) did not vary in the MTLC Toolbox, therefore the energy savings attributed to using occupancy sensors to control lighting or HVAC loads couldn't be directly estimated. Lighting systems were assumed to be on at full power with light output during all business hours. However, users could easily scale simulation results by an occupancy factor and lighting reduction factor to estimate savings from lighting controls measures.

To simulate daylighting harvesting controls with the MTLC Toolbox, the research team used illuminance set points, calculated by applying the Title 24-compliant LPD to the model building for each MTLC business type (see Table 46).

Table 46: Daylight Harvesting Control Set Points

	Mercantile	Food Sale	Food Service	Office	Salon
Set point (Lux)	538.2	538.2	215.3	322.9	215.3
Height of Set point (m)	0.762	0.762	0.762	0.762	0.000

Source: UC Davis CLTC

Evaluation of Select Packages using Multitenant Light Commercial Toolbox

With the MTLC Toolbox, researchers ran many retrofit simulations to create a database of simulation results. To focus their efforts, researchers ran simulations for one climate zone (Climate Zone 12-Sacramento) and used buildings with and without drop ceilings to demonstrate the power and flexibility of the Toolbox. In the end, the team created two databases: one based on monthly data (without drop ceilings) to explore impacts on energy consumption and another on hourly data (with drop ceilings) to explore impacts on peak electrical demand.

Within the MTLC Toolbox, there were a large number of retrofit opportunities that could be added serially or simultaneously. Thus, the Toolbox could be used to conduct a sensitivity analysis to examine how an individual retrofit measure, or any combination of measures, impacts energy consumption and/or peak electrical demand. Researchers analyzed a few key retrofits and retrofit combinations to understand and illustrate energy savings and peak demand reduction.

Simulation Results, Buildings without Drop Ceilings (Monthly Analysis)

Researchers evaluated the energy performance of a subset of retrofit measures for a variety of tenant space configurations. For the non-drop ceiling case, the team compared monthly simulation results to an MTLC baseline building with parameters described in Table 48. MTLC retrofit packages were limited to one or more of the following:

- Window replacements
    - Improved U-factor
    - Increased SHGC
- Awnings
- Horizontal window louvers

- Skylights paired with dimming controls
- HVAC cooling system improvements – Upgraded RTU
- Economizers
- Evaporative pre-coolers
- Cool roofs
- High performance T8 lighting upgrades
- High performance LED lighting upgrades
- Daylight harvesting controls

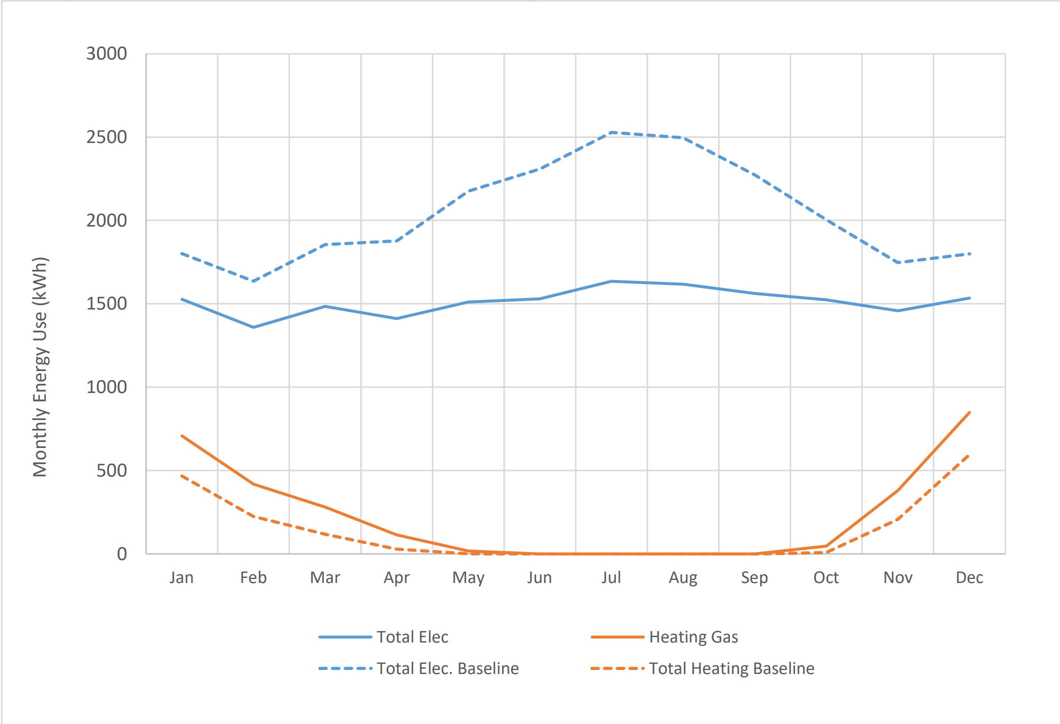
In analyzing their simulations, researchers found that the most energy-efficient package for general retail tenants included an intuitive combination of measures for the building envelope, HVAC, and lighting (see Table 47). As compared to the baseline building, this retrofit package saved 27 percent electricity annually. This package, however, did increase natural gas use during the heating season by 35 therms (1032 kWh), but the low cost of natural gas, combined with the substantial electricity savings of the package, negated any cost impacts on consumers. As shown in Figure 78, there were significant electricity savings during the cooling season, which is due to the package of HVAC improvements, cool roof addition, and reduced lighting power (and heat) generated by the LED lighting and daylight harvesting control system.

Table 47: Optimal Multitenant Light Commercial Retrofit Package for Retail Tenants

Parameter	Variables
Upgraded RTU including evaporative pre-cooler	COP = 6
HVAC Economizer	
Cool Roof	
Upgraded windows	SHGC = 0.25 UFactor = 3.236
Skylights	SHGC = 0.8 UFactor = 3.24
LED Lighting	LPD = 0.87 W/sf
Daylight Harvesting Control System	Continuous dimming

Source: UC Davis EEC

Figure 78: Monthly Energy Savings Attributed to the Best-Performing Technology Package Examined for Multitenant Light Commercial Retail Establishments



Source: UC Davis EEC

Across all simulations, researchers found the top 10 highest performing packages all contained the following technologies:

- High efficiency RTU (COP = 6)
- Evaporative pre-cooling
- LED lighting (LPD 9.36 W/m^2)
- Skylights
- Daylight harvesting control systems

Interestingly, the team found that window upgrades and the addition of a cool roof had minimal impact on overall building energy performance, saving just 2 percent annually between buildings that included these technologies and buildings that did not.

Simulation Results, Buildings with Drop Ceilings (Hourly Analysis)

To evaluate peak demand impacts of retrofit packages, researchers used an hour-by-hour analysis for a model building with drop ceilings and the parameters specified in Table 47. Similar to the monthly simulations, MTLC retrofit packages were limited to one or more of the following:

- Window replacements
  - Improved U-Factor

    - Increased SHGC
- Awnings
- Horizontal window louvers
- Skylights paired with dimming controls
- HVAC cooling system improvements – Upgraded RTU
- Economizers
- Evaporative pre-coolers
- Cool roofs
- High performance T8 lighting upgrades
- High performance LED lighting upgrades
- Daylight harvesting controls

Researchers ran hourly simulations, producing extremely rich data that could have been analyzed in many ways. The team first examined the top-5 performing retrofit packages, contrasting them with the bottom-5 retrofit packages. The hourly analysis enabled researchers to assess annual electricity consumption and peak electricity demand, which was determined based on the hour with the maximum electricity demand for the year.

Table 48 provides a snapshot picture of the analysis results, showing characteristics of the best 5 performing packages versus the worst 5 performing packages. Researchers found that the results varied depending on whether they used annual electricity consumption or peak electricity demand as the primary ranking factor.

- When researchers used annual electricity consumption as the primary ranking factor, the best 5 configurations consumed roughly 8500 kWh of electricity with a peak demand of 2.6 to 2.9 kW. The worst 5 configurations consumed 150,000 kWh of electricity with a peak demand of roughly 32 kW.
- When researchers used peak electricity demand as the primary ranking factor, the best 5 configurations consumed 9300kWh of electricity with a peak demand of 2.5KW. The worst 5 configurations consumed 150,000kWh of electricity with a peak demand of 32kWh.

Table 48: Best and Worst Multitenant Light Commercial Package/Characteristics (per Electricity Consumption and Peak Electricity Demand)

	Electric Energy Best	Electric Energy Worst	Peak Demand Best	Peak Demand Worst
COP	6 (60%) 5	2.9	6	2.9
Duct Leakage	Low (60%)	High	Low (80%)	High
Fan-Control	Auto	On	Auto	On
Ceiling Insulation	None	Insulated	None	Insulated
AC Condenser	Evaporative (80%)	Air	Evaporative	Air
Light Power Density (W/m^2)	9.36	12.9	9.36	12.9
Electric Load (W/m^2)	5.4	146.4	5.4	146.4
People Dens. (m^2/person)	9.8	6.1	9.8	6.1
Orientation	0	0 (40%) 90	90	90
Opening Time	Late	Early	Late	Early
Closing Time	Early	Late	Early	Late
Skylights	Yes	No	Yes	No
Daylight Harvesting Control System	Yes	No	Yes	No
Roof Emissivity	0.07	0.9	0.07	0.9
Roof Absorptivity	0.14	0.7	0.14	0.7
Window U-value	3.2	6.9 (60%) 1.65	3.2(60%) 1.65	6.9

Source: UC Davis EEC

In examining Table 48, researchers made several key observations.

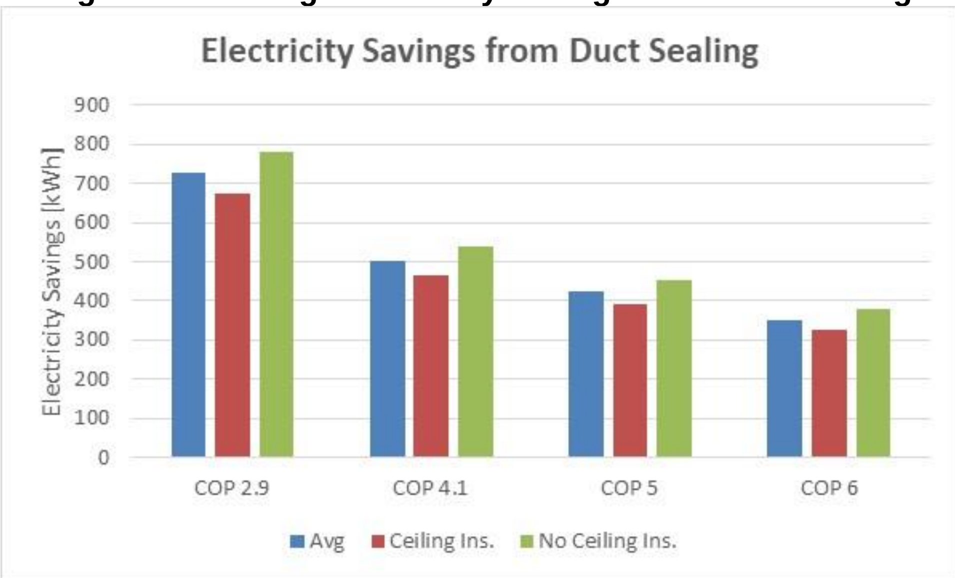
- None of the best 5/worst 5 configurations were exactly the same when comparing peak demand and electricity consumption as the primary ranking factors.
- Certain retrofits appeared consistently in the best 5, however the results were not always obvious.

- One of the best retrofits was changing to Auto Fan Control. Allowing the fan to cycle on and off with the compressor and furnace reduces fan energy consumption and the magnitude of duct losses. Changing from continuous On Fan Control to intermittent operation is not considered a valid retrofit, however, as it goes against building code. One solution might be a retrofit that simultaneously reduced fan speed and changed the outdoor air fraction, supplying enough ventilation to meet code, while also saving electricity.

Although Table 48 identifies the best and worst combinations, it does not identify the relative magnitudes of the electricity and peak demand savings associated with different individual measures/characteristics, or combinations of measures/characteristics. The large hourly-results database, however, allows users to examine these impacts. As an example of this type of analysis, researchers examined the impacts of sealing duct leakage on annual electricity consumption and peak electricity demand, looking at interactions with COP and drop ceiling insulation level (Figure 79 and Figure 80).

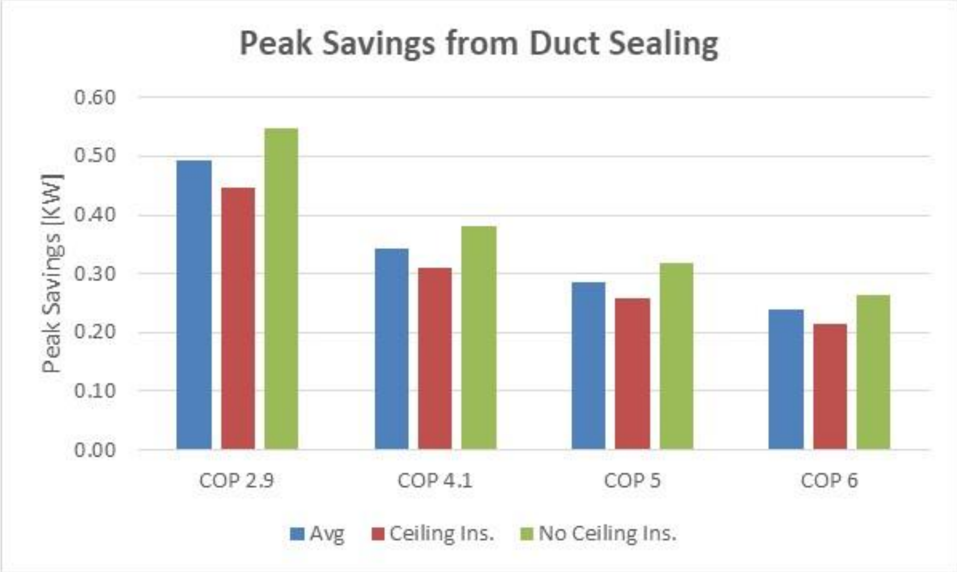
As expected, Figure 79 and Figure 80 show that the lower the COP, the higher the electricity and peak savings. The results also show that savings are larger when there is no ceiling insulation.

Figure 79: Average Electricity Savings from Duct Sealing



Source: UC Davis EEC

Figure 80: Average Peak Demand Savings from Duct Sealing



Source: UC Davis EEC

Retrofit: Cost Effective Deployment of Integrated Packages

In addition to the creation of the MTLC Toolbox, the team examined the potential cost savings of a scaled direct install program that sells HVAC retrofit services to entire MTLC buildings. To achieve this, researchers conducted a cost survey of contractors to understand the impact of scaling with regards to four types of HVAC retrofit jobs: RTU replacements, advanced controller replacements, duct sealing (manual or aerosol), and evaporative pre-cooler installation.

Researchers focused on MTLC buildings with existing HVAC systems in California and limited data collection to California licensed HVAC contractors who offer installation services to MTLC buildings.

Data and Methods

Sampling Methodology and Recruitment

Given the demanding nature of the survey, researchers used a three-pronged recruitment strategy for their cost survey.

1. Draw a random sample of licensed HVAC contractors from the California State Licensing Board's (CSLB) database of individuals who hold current C20 licenses.[32]

32 http://www.cslb.ca.gov.

2. Target a sub-sample of contractors who attended the Institute of Heating and Air Conditioning Industries, Inc. (IHACI) trade show.
3. Reach out to contractors within the team's professional network.

Each strategy is discussed in more detail below.

Random Sample of Licensed Heating, Ventilation, and Air Conditioning Contractors

Team researchers contacted contractors from the C20 sample via telephone to explain the study and the requirements of respondents. In particular, they explained that the purpose of the study was to estimate cost savings from: 1) bundling RTU services across all RTUs on a single MTLC building, as opposed to doing the services one RTU at a time, and 2) eliminating contractor time to engage in the sales process. Researchers asked if contractors would be willing to review a portfolio describing a model MTLC building and develop a hypothetical proposal for providing a range of services.

The team informed respondents that the study was purely for research, but that it would inform utility decision-making about programs to pay for rooftop-wide service packages for MTLC HVAC customers. They offered an incentive payment to complete the survey as a token of appreciation for the respondents' time and effort in compiling the requested data. Respondents received $25 per survey module, up to $100 for completing all four modules. Researchers also explained respondents' rights as a research participant; including anonymity and that consent was implied by the submission of a completed survey.

Researchers asked participating respondents for an email, physical address, or fax number to send the study materials. They were requested to return the completed surveys, ideally within a week, in the most convenient manner, using email, fax, or United States Postal Service (USPS). Researchers asked respondents to provide a convenient time to call in order to check in, confirm receipt of the survey materials, and answer questions.

After the initial recruitment call, researchers sent respondents, who agreed to participate, the survey materials through their preferred means (that is, email, USPS, or fax). After a week or more, respondents received a follow-up call. Those that received the survey via email also received one reminder via email.

The team anticipated significant challenges in recruiting participants to the survey given the survey length. To minimize the burden on respondents, researchers scheduled recruitment and data collection during the months of October and early November, the slowest period for HVAC service providers. However, due to several factors, the start of recruitment was delayed. To compensate, recruitment ran from late October to the end of January.

Researchers used a cleaned version of the C20 contractors list, received from EMI consulting, to randomly select C20 contractors.[33] They selected 2002 contractors to be contacted as part of the study recruitment. Due to budget and time constraints, only 1610 contractors from the list were contacted.

The percentage of contractors who agreed to participate was close to the anticipated 10 percent. However, only 3 percent of those who agreed to participate actually submitted completed surveys. In some cases this was due to ineligibility (for example, contractors who served only the residential market or did not do installation work). In other cases, upon receiving a reminder call, contractors requested the materials be re-sent. Thus, it is likely that many did not note having received the survey when it was sent to them. Researchers also suspected that many, upon reviewing the survey, decided not to complete it as it would take several hours, although this was explained during the recruitment call.

Target Subsample of Contractors

During the trade show, team researchers recruited and implemented several online surveys regarding another project. At the end of the surveys, there was a description of the MTLC cost survey and a question asking permission to contact the respondent with further information about the MTLC survey. Seven contractors volunteered to be contacted and were sent survey materials. Only one completed the survey.

Outreach to Contractors within Team's Professional Network

Researchers contacted six contractors and two submitted a completed survey.

Sampling Results

Across the three recruitment methods, the team received seven completed surveys. Table 49 presents the breakdown by recruitment method.

Table 49: Number of Survey Respondents by Recruitment Method

Recruitment method	Number of respondents
Random selection from C20 list	4
IHACI survey referral	1
Personal contact	2
Total	7

Source: UC Davis EEC

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33 http://www.emiconsulting.com.

Overall, the response rate was extremely low due to the onerousness of the survey itself. Although incentives were relatively generous, they did not appear to be adequate enticement for many to participate. Furthermore, a portion of the recruitment period coincided with the holidays in November and December, which numerous contractors, when called, reported was a very busy time of year. Given the extremely small sample sizes, made smaller by the fact that not every contractor offered each survey, the data collected is not a statistically significant representation of the population. However, it does provide some indicative evidence of the potential savings a direct install program could expect.

Data Specifications for Respondents

Respondents who agreed to participate in the survey were sent (via email, USPS, or fax) a portfolio describing a model MTLC building for which four HVAC-related services were needed, that is, RTU replacement installation, retrofit controller installation, duct sealing (manual or aerosol), and evaporative pre-cooler installation (including bringing water to the RTU).

The portfolio described the number, make, and model of existing RTUs (for simplicity, only two types were included), access to the roof, access to water, crane access, roof dimensions, and pertinent drawings and photographs of the building and existing equipment. The portfolio also provided additional details about each type of service required for clarification (for example, expected month of service, distance from contractor's office, number of RTUs that could be out of service in a single day, and so on).

The survey asked respondents to prepare a series of cost estimates for each of the services they typically offer (among the four included in the survey). The team asked respondents to return the completed survey via email, fax, or telephone within a week. Unless a response was received, researchers called respondents a week or more after the survey was sent to check-in, remind them to respond, and answer questions.

Results

Estimated Costs Attributed to Bundling

The team collected data on two types of discounts from the hypothetical direct install program described in the survey: 1) discounts from bundling services across an MTLC building and 2) discounts from avoiding contractor costs associated with the sales process.

First, the team analyzed and shows the result of bundling services across an MTLC building. The survey asked respondents about costs associated with providing the four services listed, net of equipment costs. Specifically, they were asked to provide an estimate for installing one unit, one day's worth of units (and indicating how many units that would be, ranging from 2-10), and 20 units. The aim was to obtain some insight into where the cost savings lay – that is, in bundling over a single day or several days.

Table 50 through Table 53 show the summary statistics for the cost estimates of each service at different levels of bundling. In each case, the mean per unit cost declined with each level of bundling, that is, from one unit to one day, and from one day to 20 units.

It is also worth noting that the range of cost estimates was substantial, even at a given bundling level. For example, the cost of installing a single RTU replacement ranged from $1,750 to $7,150.

There are several factors to consider when interpreting these cost estimates as related to a direct install program. First, the scenario respondents were given was highly simplified to ease the burden of preparing estimates. In reality, there would be more variation in the equipment type and condition on a real MTLC rooftop. This would create more work and greater uncertainty for the installing contractor. Thus, in some respects the above estimates may represent a lower bound. On the other hand, contractors might be motivated to offer slightly lower bids to a direct install program than they would cite on a survey, given that the former would have real revenue at stake. If this were the case, a direct install program might expect even lower costs than those cited here.

Another factor that may influence cost estimates is the time of year in which the work is completed. The survey specified that the work would take place in October, which is thought to be the slowest time of year for HVAC contractors. To get a sense of how estimates might fluctuate over the course of the year, researchers asked respondents to state the percentage by which their estimates might increase in the summer months, known as the busiest time of year.

Table 50: Summary Statistics of Cost per Unit, by Scale of Project and Service RTU Replacement

	RTU replacement (n=6) Mean	RTU replacement (n=6) SE	RTU replacement (n=6) Min	RTU replacement (n=6) Max
Single unit	$4,652	*$777*	$1,750	$7,150
1 day's worth of units	$4,007	*$739*	$1,500	$6,781
20 units	$3,738	*$772*	$1,200	$6,781

Source: UC Davis EEC

Table 51: Summary Statistics of Cost per Unit, by Scale of Project and Service Controller Replacement

	Controller replacement (n=4) Mean	Controller replacement (n=4) SE	Controller replacement (n=4) Min	Controller replacement (n=4) Max
Single unit	$531	$158	$330	$1,000
1 day's worth of units	$418	$100	$300	$719
20 units	$403	$107	$250	$719

Source: UC Davis EEC

Table 52: Summary Statistics of Cost per Unit, by Scale of Project and Service Duct Sealing

	Duct sealing (n=4) Mean	Duct sealing (n=4) SE	Duct sealing (n=4) Min	Duct sealing (n=4) Max
Single unit	$1,171	$197	$650	$1,600
1 day's worth of units	$1,038	$184	$600	$1,500
20 units	$935	$225	$400	$1,500

Source: UC Davis EEC

Table 53: Summary Statistics of Cost per Unit, by Scale of Project and Service Evaporative Pre-Cooler Installation

	Evaporative pre-cooler installation (n=3) Mean	Evaporative pre-cooler installation (n=3) SE	Evaporative pre-cooler installation (n=3) Min	Evaporative pre-cooler installation (n=3) Max
Single unit	$2,273	$1,357	$550	$4,950
1 day's worth of units	$2,221	$1,380	$500	$4,950
20 units	$1,684	$946	$425	$3,536

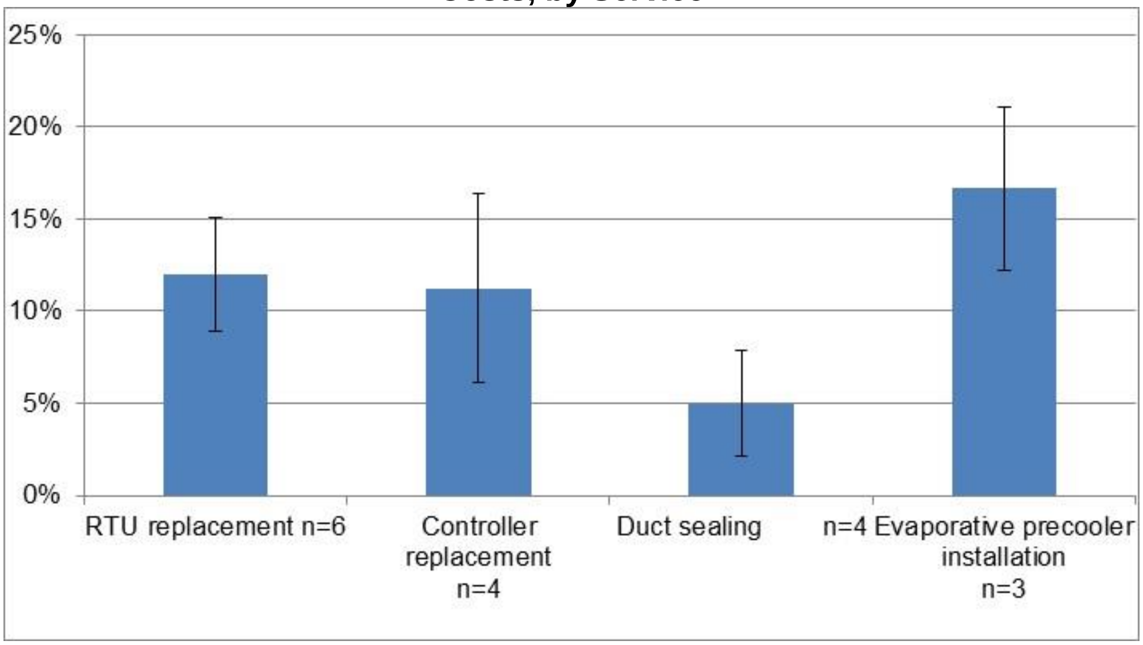
Source: UC Davis EEC

As Figure 81 on the following page shows, the mean inflation rates range from 5 percent for duct sealing to 17 percent for evaporative pre-cooler installation.

Estimated Discount Rates

As mentioned before, the team collected data on discounts from bundling a service across a building compared to discounts associated with lower contractor costs related to the sales process. The former was derived from the cost estimates described above, while the latter was reported directly by respondents in most cases, and derived in others. In the section below, the impact of discounts attributed to lower contractor costs in the sales process are shown, followed by a comparison of the impact of the two different discounts, bundling versus lower contractor costs in the sales transaction.

Figure 81: Mean and Standard Error of Summertime Inflation Rate for Installation Costs, by Service



Source: UC Davis EEC

In the survey, researchers gave respondents three options for how to report cost savings derived from avoiding the sales process. Some quoted a fixed rate, others a fixed amount, and a third group re-calculated the cost estimates applying a sales discount. For respondents who provided a fixed amount or new set of cost estimates, researchers calculated the sales discount rate using the information provided and the original cost estimate.

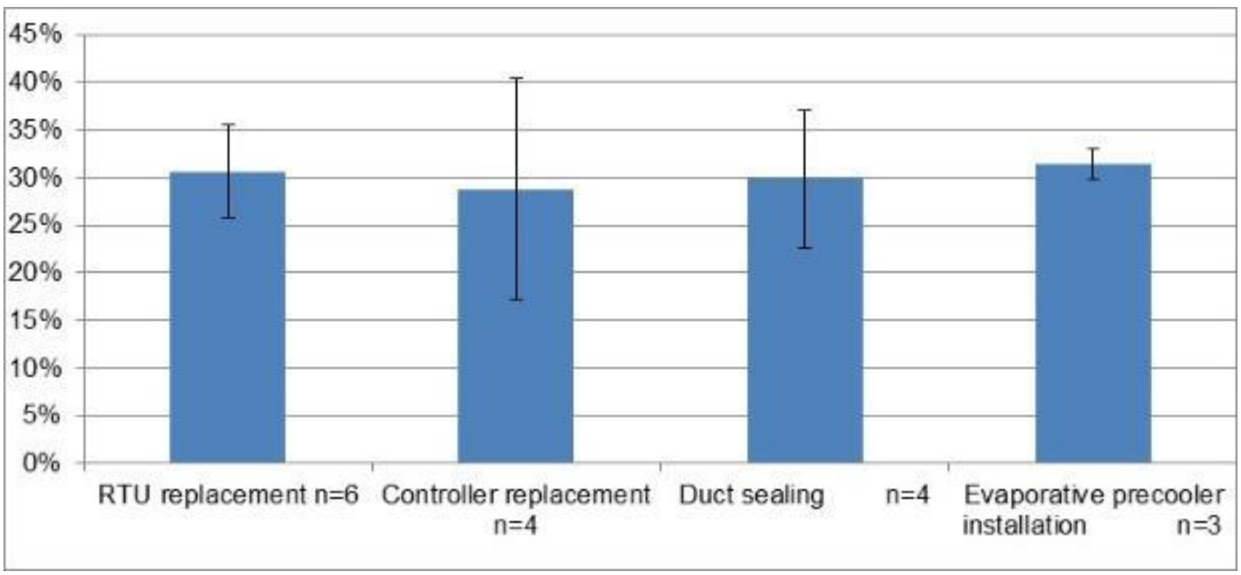
Table 54 and Figure 82 show the estimated discounts associated with a direct install program for the four services listed. These discount rates reflect the aggregate savings derived from avoiding contractor costs associated with the sales process. Note that while the mean discount rates were approximately 30 percent for each of the four services, the distribution around the mean varied substantially from service to service. Furthermore, the maximum and minimum values indicate that there is substantial variation in the estimated cost savings a contractor could offer a direct install program. Despite the wide variation and small sample size, this research found some encouraging evidence that a number of contractors would be willing and able to offer substantial discounts to a direct install program in which they were approved contractors.

Table 54: Summary Statistics of Estimated Discount Rate for Direct Install Program

	RTU replacement	Controller replacement	Duct sealing	Evaporative pre-cooler installation
Mean	31%	29%	30%	31%
Standard Error	5%	12%	7%	2%
Minimum	15%	0%	11%	29%
Maximum	44%	56%	46%	34%
n (sample size)	6	4	4	3

Source: UC Davis EEC

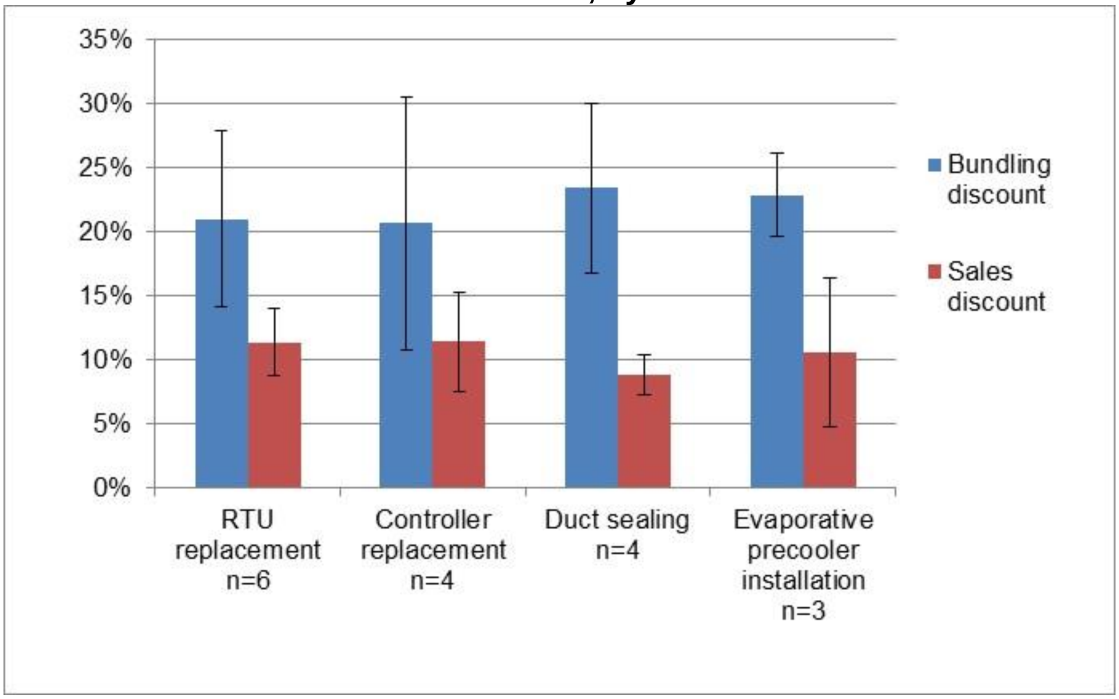
Figure 82: Mean and Standard Error of Estimated Discount Rates for Direct Install Program, by Service



Source: UC Davis EEC

As Figure 83 indicates, researchers found a larger share of the aggregate discount was derived from the bundling of services. The discount rates from bundling ranged from 21 percent to 23 percent, whereas the sales discounts ranged from 9 percent to 11 percent.

Figure 83: Mean and Standard Error of Disaggregated Bundling and Sales Discount Rates, by Service



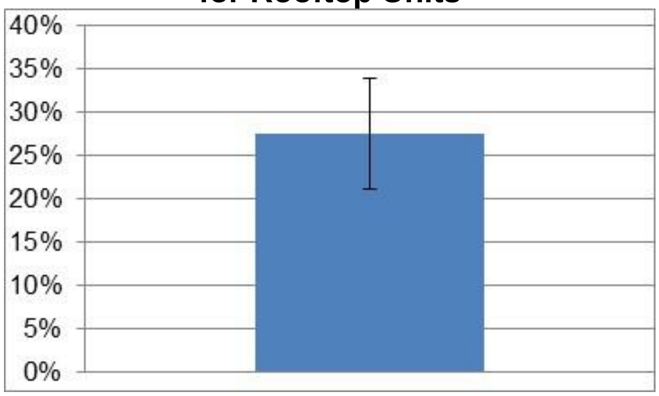
Source: UC Davis EEC

Much of the discount associated with bundling services across many RTUs comes from the ability to leverage cost savings by spreading set-up costs over a greater number of units (for example, crane rental and establishing water access for evaporative pre-coolers). To the extent that a typical job for a direct install program might involve providing all four services for more than 20 RTUs, the estimated savings yielded from bundling services may represent a lower bound.

As noted above, some contractors quoted the estimated cost savings derived from avoiding the sales process as a fixed cost and others as a fixed rate. In reality, engaging a customer and developing a bid has fixed and variable costs associated with it, and those may not be consistent across projects. For example, some customers may take longer to engage than others. Furthermore, the time required to develop a bid is positively associated with the amount of variation across the existing RTUs. The team's survey simplified the list of existing equipment to just two RTU models, but in reality contractors would encounter much more variation. Contractors who reflect this in their cost estimate of the sales process would likely offer a higher discount than is reported here for jobs with more than 20 RTUs (the number provided in this example), and with more varied equipment on the roof. Thus, the sales discount cited here may represent a lower bound.

Finally, another benefit contractors would derive from a direct install program is the ability to sell maintenance and service contracts associated with the RTUs replaced. Although it would not affect the costs associated with a direct install program, any discount contractors could offer on bundled service contracts would be an additional customer benefit. To get a rough estimate of this benefit, researchers asked respondents to report the percentage by which they could reduce the cost of their maintenance and service contracts for 20-unit bundles of RTUs (see Figure 84).

Figure 84: Mean and Standard Error of Discount on Maintenance and Service Contracts for Rooftop Units



Source: UC Davis EEC

Given the small sample sizes, the data collected is not generalizable to the population of contractors at large. However, even in its limited form, the results indicate that there is room for discounts on the order of 30 percent for a direct install program supporting duct sealing and the installation of RTU replacements, advanced controller replacements, and evaporative pre-coolers, mostly due to the bundling of service.

Conclusion

The current state of implementing deep energy savings in the MTLC space is broken, but feasible solutions exist. The use of the CCC to conduct audits allows for both extensive understanding of available conservation measures as well as audits at lower than current market rates. In addition, the team's MTLC Toolbox helped to complete auditing analysis, allowing for examination of on-site ECM measures without using costly engineers. Furthermore, although there is limited data available, researchers found evidence that HVAC costs can be reduced through implementing ECMs at the building level instead of at the tenant level.

CHAPTER 5: Retrofit Demonstrations

Introduction

The team's overarching vision was to achieve deep energy and demand savings in California's existing MTLC buildings by developing tailored retrofit programs. Technology demonstrations are a key research component because they provide real-world performance data. Demonstrations help determine the effectiveness of research outcomes in real-world environments and provide stakeholders with improved confidence to deploy solutions in California's MTLC building stock.

Researchers collected field measurements and analyzed data from three demonstration sites in California to understand the effectiveness of chosen retrofit designs and their associated implementation process. The results provide a starting point for understanding why actual savings may differ from anticipated savings. The three demonstration projects also highlight best practices, which can help inform effective engagement strategies for the MTLC market.

Site Selection Process

Site Selection Criteria

The team selected demonstration sites based on whether or not the site had lighting and HVAC systems that were representative of the MTLC market as a whole. Characteristics researchers used to select sites are described below.

Interior Lighting

Researchers selected demonstration sites with standard linear fluorescent, compact fluorescent, incandescent, or metal halide light sources. If sites used more advanced, energy-efficient source technologies such as T5 fluorescent or LED, or custom luminaires, researchers did not select the site because it was atypical of the California MTLC market.

Outdoor Lighting

The team selected MTLC demonstration sites that used outdoor high-intensity discharge (HID) area and parking lot lighting, fluorescent illuminated cabinets, and HID or incandescent spot lighting for signs. They did not address internally illuminated channel letters on individual tenant spaces. If the site used more advanced light sources, such as LED or induction area lighting, researchers did not select the site because it was atypical of the MTLC market as a whole.

Lighting Controls

Researchers selected MTLC sites with basic types of lighting controls, including manual wall switches, mechanical time clocks, and bathroom occupancy sensors. If more advanced controls were present, they did not select the site, as it was atypical of the California MTLC market.

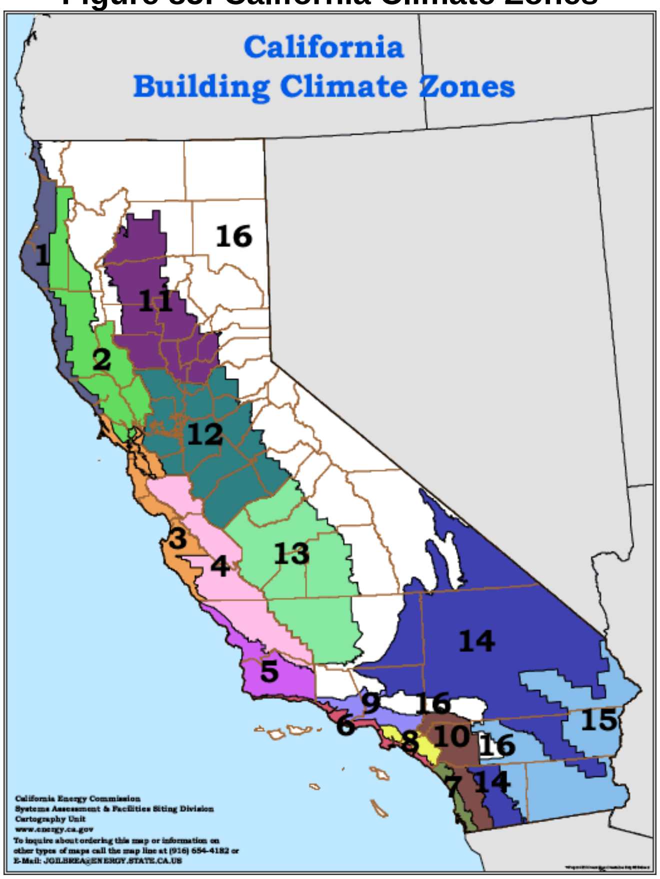
Heating, Ventilation, and Air Conditioning

The team selected MTLC buildings with "typical" HVAC systems: older, packaged, roof top units with low efficiency and basic controls.

Climate Zones

California has an extremely varied topology and climate with sixteen recognized climate zones (see Figure 85). Each zone represents a geographical area with similar weather patterns and climate conditions. To accurately understand the energy benefits of building technologies when installed in such a variety of environments, researchers, to the extent possible, selected demonstration sites in different climate zones.

Figure 85: California Climate Zones



Source: California Energy Commission,
http://www.energy.ca.gov/maps/renewable/building_climate_zones.html

Level of Interest and Financial Assistance

Researchers selected sites where tenants showed interest in becoming a demonstration site and where they could provide financial assistance for the demonstration.

Selected Sites

The team selected three MTLC shopping center demonstration sites: Davis, California; Upland, California; and Sacramento, California.

Unfortunately, not all tenants within each MTLC building elected to participate in the demonstration. Therefore, retrofit package demonstrations only provide findings for a portion of tenants at each site. In their analyses, researchers focused on understanding retrofit package savings, package implementation, and customer engagement within the MTLC market.

Retrofit Overview

Demonstration site retrofits focused on indoor lighting, outdoor lighting, and/or HVAC improvements.

- Indoor lighting retrofits consisted primarily of replacing linear fluorescent lighting and incandescent directional lamps with LED alternatives and adding occupancy and dimming controls. In addition, at some locations, adding simple skylights improved daylight penetration into the building and reduced dependence on electric lighting.
- Outdoor lighting retrofits consisted primarily of replacing HID luminaires with LED alternatives.
- HVAC retrofits consisted primarily of replacing existing air conditioners and heat pumps with high efficiency units, thermostat replacement, painting of exposed ductwork with reflective paint, and variable speed fan control.

Across all sites, researchers estimated retrofits to save between 30 and 70 percent of baseline electricity consumption, based on tenant space and the selected measure(s).

Davis, California Site

The first demonstration site was a shopping center in Davis, California (see Figure 86). Two tenants participated in the project: a sports retailer and a dry cleaner. The sports retailer occupies about 6,000 sq-ft of the 20,000 sq-ft building. The retailer sells and repairs, bike, ski, and snowboard equipment. The store contains a large open retail area, an adjacent bike repair area, as well as several support spaces such as storage, offices, and restrooms. The research team selected the main retail floor and adjoined bike repair area for the demonstration, as well as an adjacent dry cleaner tenant.

Figure 86: Aerial Map of Building in Davis, California

Source: Google Maps

Davis is located in climate zone 12 which experiences warm summers and cold winters. Rain falls between November and April. Ground fog can be common and some areas experience winter frost. There are often more heating degree days (HDD) than cooling degree days (CDD) for this climate zone. Davis is based in the PG&E utility territory.

Retrofit Selection and Implementation

The sports retail store implemented indoor lighting and HVAC retrofits. The dry cleaner implemented HVAC retrofits.

Pre-Retrofit Technology - Lighting

The sports retail store used linear fluorescent luminaires for the general merchandise and track lights along the perimeter to add extra illumination on vertical displays. The building did not have skylights, awnings, or other fenestration technology beyond standard front façade windows. General lighting was provided by surface mounted, linear fluorescent luminaries operating with standard 4′ or 8′ T8 lamps (Figure 87). In addition, the main retail area contained recessed down lights near the front of the store. Track lighting was also used, mainly around the sales floor perimeter, consisting of mixed stock track heads with incandescent PAR-30 or GU-12 lamps. Lighting was controlled by manual toggle switches.

Figure 87: Pre-Retrofit Lighting at Sports Retailer

Source: UC Davis

Pre-Retrofit Technology – Heating, Ventilation, and Air Conditioing

The sports retail store was served by two package RTUs. The first unit was a 12.5-ton air conditioner and natural gas heating unit that served the main sales space. This unit was multi-stage, but of older vintage and did not incorporate advanced demand control ventilation, an economizer, or other advanced energy efficiency features. The second unit was a smaller 3 1/3-ton air conditioner that served a back office area.

The dry cleaner was served by a mid-size RTU, estimated to be around 5-tons in size. This unit was installed in such a way that long sections of rooftop ductwork were used to deliver supply air to the space. The return air duct was somewhat shorter. Total exposed ductwork was about 100 ft.

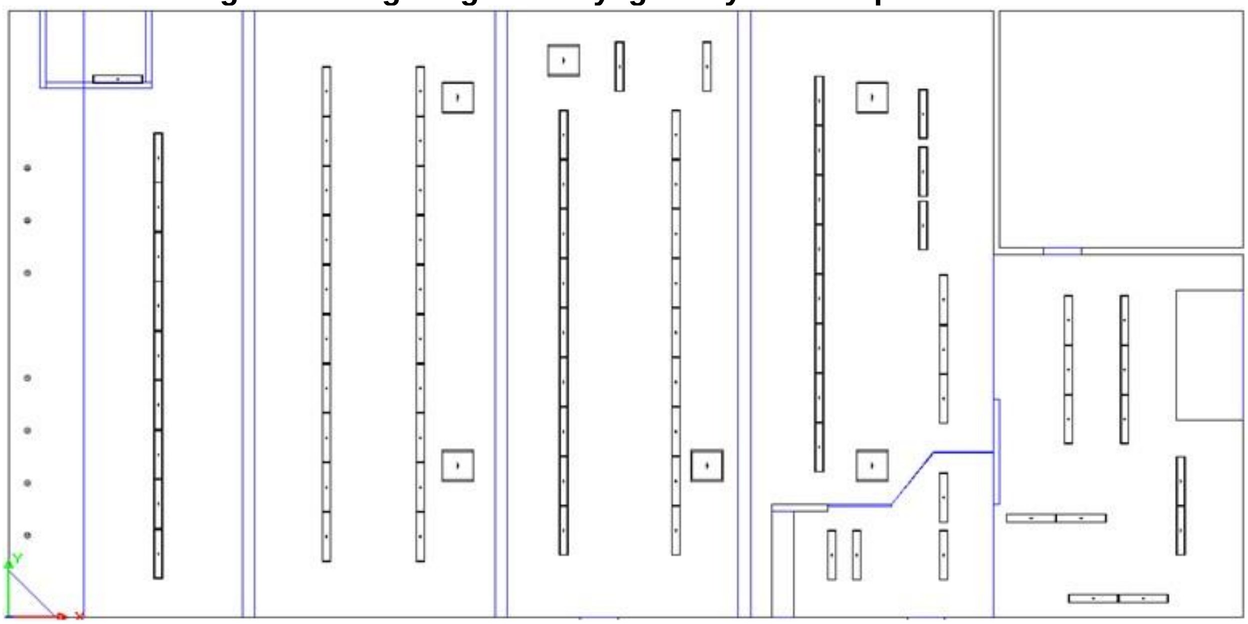
Retrofit and Installation Details - Lighting

The sports retail store's retrofit package included skylights, LED area lighting, and networked lighting controls. The system was designed and specified to meet IES recommended light levels for retail applications. Existing luminaire mounting locations were maintained in most areas of the store.

For general retail areas, IES recommends horizontal illuminance of 40 fc at 2.5 ft from the finished floor. Existing fluorescent luminaires were retrofit with dimmable, LED alternatives, which were expected to deliver light levels exceeding IES recommendations (42 fc estimated). IES recommended light levels for general service areas is 50 fc. New luminaires for this area were expected to deliver light levels exceeding this value for much of their useful life (67 fc estimated).

Figure 88 shows the skylight and luminaire layout. Installation occurred over the course of three weeks. First the luminaires and controls systems were installed, followed by the skylights. Figure 89 shows the incumbent lighting system and Figure 90 shows the skylight details for both the exterior work and the finished interior.

Figure 88: Lighting and Skylight Layout for Sport Retailer



Luminaire Schedule			
Symbol	Qty	Label	Description
	10	C_2_32	Cree T8 Replacement
	40	XSM80XX-1300-B_with_XSA-	Green Creative Lamps with
	77	30455	Philips DuaLED 1DLG36L840
	23	MNSL_MV_M6	Lithionia Strip MNSL MV M
	7	CR6-800L LED Downlight I	Cree Downlight
	10	Skylight	30x30 in Splayed Skylight

Source: Davis Retailer

Figure 89: Post-Retrofit Lighting

Source: UC Davis

Figure 90: Finished Skylights Exterior (Left) Interior (Right)

Source: UC Davis

Researchers verified lighting designs for compliance with LPD and controls requirements contained in California's 2013 Building Energy Efficiency Standards (CBSC, 2011). The allowed LPD for the main retail area and the bike repair area was 1.7 W/ft^2 and 0.9 W/ft^2, respectively.[34] Total allowed lighting power was 6913 W. Total power of the new systems was 3320 watts, approximately 52 percent less than that allowed by code.

The retrofits required area controls, multi-level lighting controls, and shut-off controls to meet code requirements. Controls requirements were met through inclusion of a digital lighting management control system. Area and multi-level controls were achieved

34 Based on the Area category method. Includes an additional 0.3 W/sf allowance for accents/displays and an additional 0.2 W/sf for decorative lighting in retail spaces as allowed by code.

through two separate dimming switches, one for the retail space and another for the shop area. Additionally, manual dimming did not override other controls measures such as daylighting and high-end tuning; however, switches did override scheduled dimming or OFF periods for up to two hours. Automatic shutoff control was achieved through the use of zonal occupancy sensors and a scheduling feature included with the digital control system. Daylighting controls were also included, however, they were not required by code.

Retrofit & Installation Details – Heating, Ventilation, and Air Conditioning

At the sports retailer, the large 12.5 ton HVAC unit was retrofitted with an RTU controller. This controller relies on modulating supply air flow to reduce energy consumption by indexing the fan to one of three speeds (40, 75, or 90 percent of full speed) based on whether the RTU is in ventilation, stage 1, or stage 2 cooling mode. Heating stage 1 and stage 2 are set to 75 and 90 percent of the full fan speed, respectively. The RTU retrofit controller also incorporates demand control ventilation based on CO_2 sensor feedback, advanced differential economizer control, and monitoring and failure diagnostics through its web-enabled eIQ Platform.

The installed RTU retrofit controller has many energy saving features, however, it does not have an economizer. Researchers quantified savings with the RTU retrofit controller due to modulating the air flow supply because economizer integration was not possible.

Retrofit controller installation was straightforward and was completed by one technician in less than one day. The technician installed a variable frequency drive (VFD) on the supply fan motor, the RTU retrofit controller in a weather-proof enclosure, and the required sensors needed to modulate the supply air flow (see Figure 91and Figure 92).

Figure 91: RTU Retrofit Control Box on Exterior of Rooftop Unit

Source: UC Davis

Figure 92: Retrofit Controller Variable Frequency Drive on Interior of Rooftop Unit

Source: UC Davis

For the dry cleaning tenant, the selected retrofit was a solar reflective treatment, which was applied to 100 feet of exposed rooftop ductwork (see Figure 93). This measure was selected based on cost effectiveness and anticipated widespread applicability to California MTLC buildings. Researchers selected an acrylic-based, solar reflective paint primarily used for rooftop applications. The manufacturer claimed large reductions in surface temperature of exposed surfaces due to reduction in solar heat gain, resulting in a reduced cooling load for the space. The contractor applied the product to the cleaned surface of the exposed ducts in accordance with the manufacturers recommended procedures (see Figure 94).

Figure 93: Pre-Retrofit of Exposed Supply Ductwork at Dry Cleaning Tenant

Source: UC Davis

Figure 94: Post-Retrofit of Exposed Supply Ductwork at Dry Cleaning Tenant

Source: UC Davis

Commissioning Details - Lighting

The primary goal of commissioning is to ensure retrofits operate as intended. The manufacturer's commissioning agent completed controls commissioning at the sports retailer. The main control strategies used in this space were schedule-based dimming and daylight harvesting. Schedule-based dimming uses the scheduling abilities of the control system segment manager to provide different high-occupied (high-end trim) and low-unoccupied light levels for both open and closed hours. Daylight harvesting uses the daylight entering the space to reduce the electric light level while still maintaining an average, overall desired illuminance.

Before the high end trim was selected, researchers took preliminary illuminance measurements throughout the spaces. The retail space had an average of 69.3 fc and the bike shop had an average of 79.2 fc. Both of these levels were approximately 30 percent higher than IES recommended levels. As such, researchers found that the high end of the lighting system (maximum light output) could be reduced by approximately 30 percent to yield immediate energy savings.

Business hours at this site were Monday through Friday 9am to 8pm, Saturday 9am to 7pm, and Sunday 12pm to 5pm.

Table 55 shows the lighting schedule, based on these hours of operation. During open hours, the bike shop's lighting was trimmed to 65 percent for the high level and 20 percent for any periods of inactivity greater than 20 min. For closed hours, the occupied light level was still 65 percent and when unoccupied lights turned off after 5 min of inactivity. The retail area high occupied light level was 70 percent during open hours and 35 percent during unoccupied periods. Higher light levels in the main retail area were selected to ensure the store still looked inviting from the outside, even while unoccupied. For closed hours, security lighting was left on at 70 percent, while the rest of the lights were dimmed down to 55 percent.

Table 55: Light Level set Level High and Low for Open and Closed Hours

	Business Hours High	Business Hours Low	Non-Business Hours High	Non-Business Hours Low
Bike Shop	65%	20%	65%	off
Retail Area	70%	35%	35%	off
Retail Security	70%	35%	70%	55%

Source: UC Davis CLTC

Commissioning Details – Heating, Ventilation, and Air Conditioning

Painting of the exposed duct at the dry cleaner required no comissioning or interfacing with the building tenant. For the RTU retrofit controller at the sport retailer, the installer tested the controller in all modes. In this testing, none of the factory equipment protection features were overridden and the package unit continued to interface with the building through the same thermostat control wiring that existed before (no new thermostat controller was required). The theromstat settings were not adjusted and the technician did not need to go in the building.

Performance Monitoring and Results

To determine actual energy savings of retrofit measures, researchers created a performance monitoring plan to compare pre-retrofit and post-retrofit energy use.

Performance Monitoring – Lighting

To confirm occupancy and lighting use, researchers used a single data logger capable of recording both measurements. They installed loggers strategically around the retail sales floor and bike repair area to capture a majority of the space. Researchers set loggers with a 5-minute timeout period to align with the occupancy sensor timeout period for the new control system. They collected three months of pre-retrofit data.

Researchers also collected circuit-level energy data. Monitoring equipment included current transducers (CT), a WattNode Pulse device, and a HOBO data logger. The WattNode Pulse is a device that measures energy use by way of CTs and voltage inputs. Energy consumption is converted by the WattNode into pulses, which are recorded by the HOBO data logger and used to calculate energy use.

The team monitored energy use of the new system in phases to attribute energy savings to each of the control layers applied to the space. During phase 1, researchers only enabled tuning, scheduling, and occupancy control. During phase 2, they added task-specific tuning. Both monitoring periods lasted approximately 14 days.

Researchers collected light level readings for both pre and post-retrofit conditions. They took horizontal illuminance measurements at the task level (2.5 ft.) along an 8 ft by 8 ft grid throughout the store. The team aligned the grid so that measurement locations alternated between a point directly under a luminaire and a point between two adjacent luminaires.

Performance Monitoring – Heating, Ventilation, and Air Conditioning

The team monitored HVAC units pre-retrofit for multiple periods starting in July of 2014 until the retrofits occurred in April and July of 2015. Pre-retrofit monitoring spanned the summer cooling season as well as winter heating season, however analyses focused on the cooling season. The team monitored HVAC units post-retrofit starting in April and July 2015 through August 2015, which included spring and summer data only. For the RTU retrofit controller installation, researchers separated the pre-monitoring period into two periods: one before the lighting retrofits were installed and one after the lighting retrofits were installed. Analyzing these two data sets separately allowed the team to investigate the impact of lighting on the HVAC system load.

The team conducted an energy analysis based on kWh usage, mean outdoor air temperature, and peak values to compare equipment efficiency before and after the retrofits. They used HOBO brand current measurement to monitor and log the current on each leg of the power input into the HVAC unit (both units retrofitted used 3-phase power).

Results - Lighting

Researchers evaluated system performance along three vectors: energy, light level and building occupancy. The team compared energy savings of the retrofit lighting system to: 1) the site baseline and 2) a 2013 Title24-compliant design.

Building Occupancy

Table 56 shows the results of the light and occupancy logging. Researchers found that the lighting systems were used continuously during business hours (98 percent in the bike repair area and 85 percent in the main area).

Table 56: Occupancy Rates and Lighting System Operation at Retail Demonstration Site

Area and Logger ID#	Total Time On	Total Occupancy	Average Occupancy Rate	Occupancy – Business Hours	Occupancy – Non-business hours
Bike Repair – 6	54%	38%	48%	98%	13%
Bike Repair – 7	97%	0%	48%	98%	13%
Bike Repair – 67	19%	24%	48%	98%	13%
Main Area – 20	28%	5%	41%	85%	10%
Main Area – 23	49%	24%	41%	85%	10%
Main Area – 49	6%	25%	41%	85%	10%
Main Area – 56	24%	6%	41%	85%	10%
Main Area – 59	20%	9%	41%	85%	10%
Main Area – 71	34%	6%	41%	85%	10%
Main Area – 73	54%	7%	41%	85%	10%

Main Area – 75	38%	21%	41%	85%	10%
Main Area – 86	22%	6%	41%	85%	10%
Main Area – 94	63%	3%	41%	85%	10%

Occupancy rate for timeout period set at 5 minutes

Source: UC Davis CLTC

Light Level and Energy

The new luminaires, excluding application of control measures, saved 36 percent annually as compared to baseline and 52 percent annually as compared to a Title 24 compliant lighting system (see Table 57). Researchers found that the addition of bi-level, occupancy based control resulted in an additional 5 percent energy savings, or 57 percent total savings annually. Finally, the team found that the application of a 20 percent high-end trim to tune the system, delivering light levels consistent with industry recommendations, resulted in a final system savings of approximately 65 percent (as compared to a Title 24 compliant lighting system).

Table 57: Annual Energy Savings – Retail Demonstration Site

Technology	LPD (W/sf)	Lighting system power (W)	Annual Energy Consumption (kWh)* No Controls	Annual Energy Consumption (kWh)* Bi-level occupancy control	Annual Energy Consumption (kWh)* Add Tuning
Title 24-compliant Baseline	1.6**	6,900	25,116	-	-
Demonstration site - baseline	1.2	5,175	18,837	-	-
New System	0.77	3,320	12,084	10,875	8,700
Savings – demonstrated	36%	36%	36%	42%	53%
Savings compared to Title 24 baseline	52%	52%	52%	57%	65%

***Based on 3,640 annual hours of use (actual business operating hours).**

****Weighted average of 1.7 W/sf in main retail space and 0.9 W/sf in bike repair area.**

Source: UC Davis CLTC

Overall, researchers found that this system performed as designed. There have been some issues with the dual loop photocell calibrations, which are part of the daylighting controls. Occasionally, the device re-calibrates itself incorrectly making the store dim, however with one click of a switch it can be recalibrated, bringing the light levels up to the correct value. Additionally, while the skylights provide some light for the space that greatly enhances the visual environment in the store, they would be more effective if there were more of them.

Researchers took illuminance measurements of the space both before and after the installation of the adaptive lighting system. Table 58 shows the illuminance results before (pre-illuminance) and after (post trimmed) the retrofit, as well as compared to the IES standard. In analyzing the data, the team found that the space has a high lighting uniformity. The horizontal illuminance of the space is slightly higher than is needed for this space type; however the staff is very happy with the current levels.

Table 58: Illuminance Measurements at Sports Retailer

	Horizontal Illuminance Average	Horizontal Illuminance Maximum/ Average	Vertical Illuminance-Perimeter Average	Vertical Illuminance-Perimeter Maximum/ Average
IES Standard	40	3:1	75	4.1
Pre-illuminance	43.5	1.5:1	35	1.8:1
Post Trimmed	45+		35+	

Source: UC Davis CLTC

Results – Heating, Ventilation, and Air Conditioning

The team analyzed the impact of the two HVAC measures: duct painting and the RTU retrofit controller. For the installation of the RTU retrofit controller, researchers also investigated the impact of the lighting retrofit on the HVAC system's energy consumption.

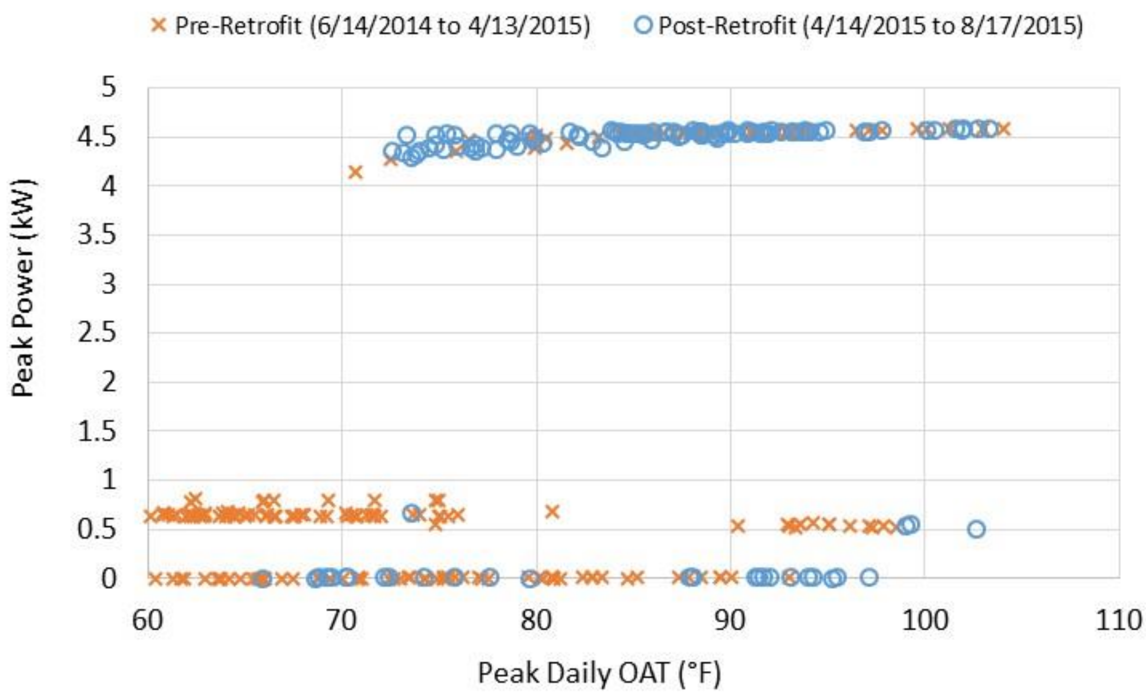
Duct Painting

Researchers predicted that painting the exterior duct work with paint that reflects radiation would reduce the heat load on the duct work, decrease the supply air temperature to the space, and reduce the required run-time for the air conditioner to satisfy the set-point. They expected the peak demand of the air conditioner, however, to be the same, meaning that when the air conditioner is running, it would draw the same power before and after the retrofit.

Key findings include:

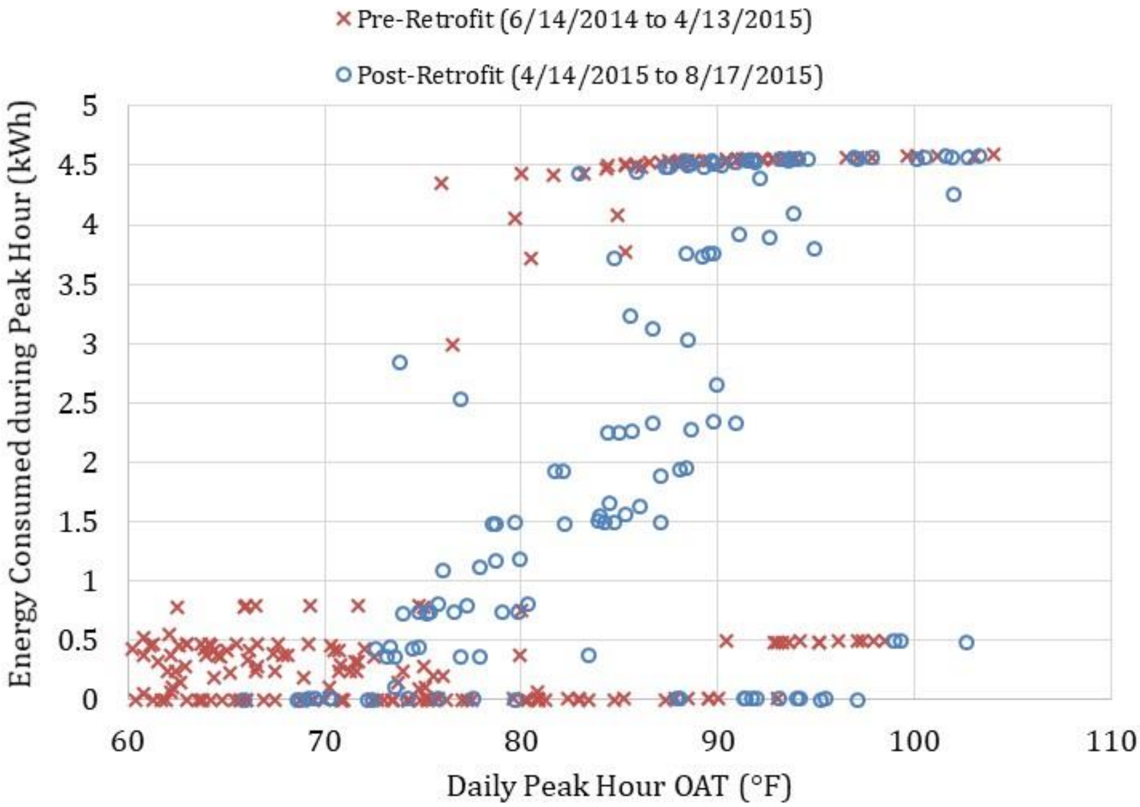
- Peak power (kW) versus peak daily outdoor air temperature (OAT): Researchers found that the daily peak power of the air conditioner increased as daily peak outdoor air temperature increased, regardless of the retrofit (see Figure 95). The effect of the retrofit is apparent, however, when reviewing the results of energy consumed during peak hour (kWh) versus peak daily outdoor air temperature (°F) (see Figure 96). This figure shows that during the peak hour of the day, the pre-retrofit air conditioner was frequently running for the entire hour, whereas with the retrofit the unit was cycling and only running for a partial hour.

Figure 95: Peak Power versus Peak Daily Outdoor Air Temperature



Source: UC Davis WCEC

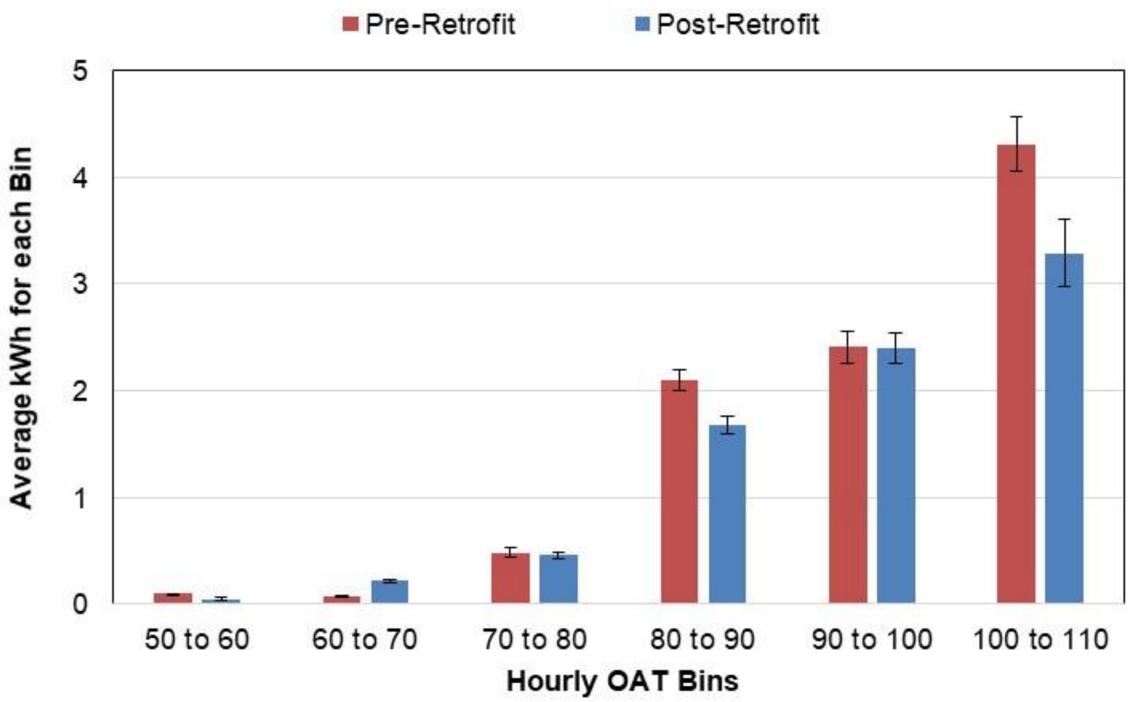
Figure 96: Energy Consumed during Peak Hour versus Peak Daily Outdoor Air Temperature



Source: UC Davis WCEC

Averaged hourly energy consumption (kWh), grouped by ten degree outdoor air temperature bins (see Figure 97): Researchers found a 25 percent savings when outdoor air temperatures were 100-110°F, no savings when temperatures were 90-100°F, a 20 percent savings when outdoor temperatures were 80-90°F, and no savings when outdoor air temperatures were below 80°F. When outdoor air temperatures were below 70°F, energy consumption was due to the fan running for ventilation or heating and not due to cooling. In examining the results, researchers noted that the sample size for the 100-110°F bin was small; researchers measured only 10 hours at this condition pre-retrofit and 25 hours post-retrofit. A greater sample size could change this result significantly. For the 90-100°F bin, the sample size was larger, with 173 hours measured pre-retrofit and 190 hours post-retrofit. Therefore, the absence of energy savings in this temperature range suggests that retrofit benefits are not evident at high outdoor air temperatures, and that the results above 100°F are an anomaly due to the small sample size. During these temperatures, the air conditioner may need to run continuously to meet the load on the building, regardless of the benefit provided by the reflective coating. For the 80-90°F bin, the sample size was excellent with 446 hours pre-retrofit and 472 hours post-retrofit. The savings during this period were very clear, with 20 percent estimated savings.

Figure 97: Average Hourly Energy Consumption with Standard Error Grouped by Ten Degree Outdoor Air Temperature Bins



Source: UC Davis WCEC

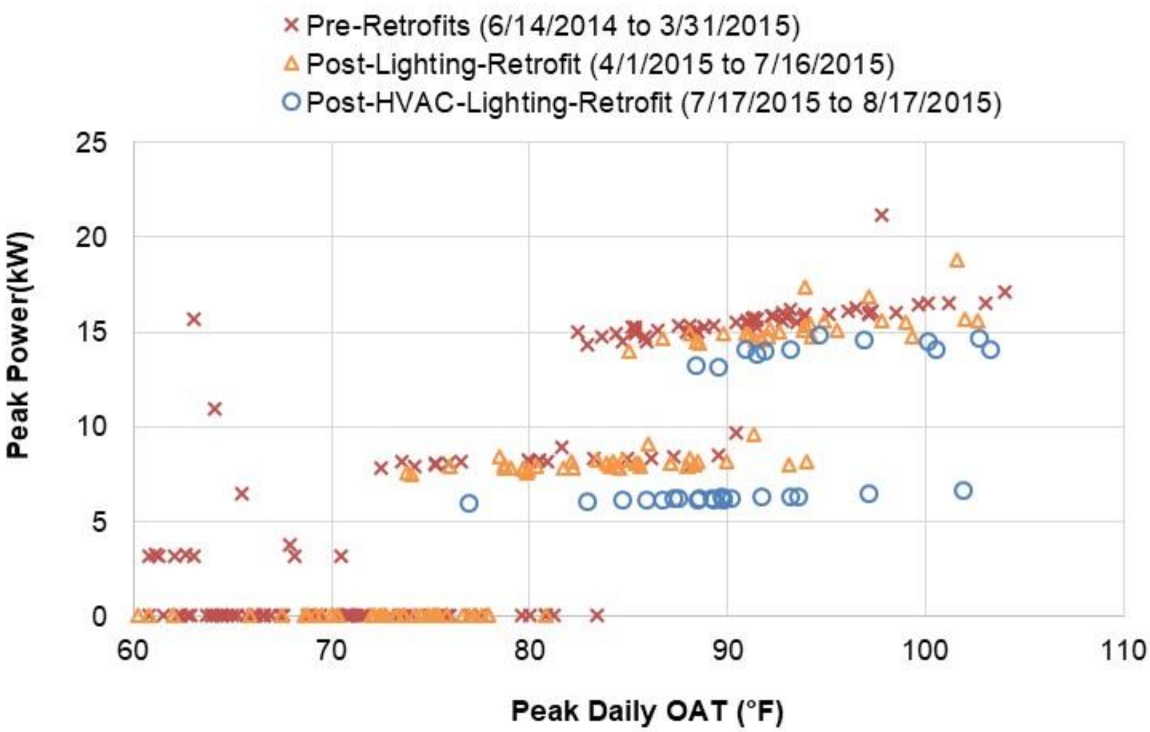
- Annual electricity use: The team determined that the baseline cooling system used an estimated 2540 kWh annually and the retrofit resulted in electricity savings of 330 kWh, or an annual cost savings of $53 a year (assuming an average commercial electricity cost of $0.16 per kWh). The duct paint cost approximately $150 for material (retail cost) and a few hours of labor, with an estimated value of $100. Researchers projected the simple payback for this retrofit to be approximately 5 years. In larger quantities, the cost of materials and labor may be reduced to achieve a faster payback.

Reduced Lighting Load and RTU Retrofit Controller

Key findings include:

- Peak power (kW) versus peak daily outdoor air temperature: Researchers found that the pre-retrofit and the post-lighting retrofit had a similar peak power draw (see Figure 98). This was excepted because the lighting retrofit did not change the performance characteristics of the RTU, but rather reduced the building load, which would impact the run-time of the equipment and not the peak power. Researchers found that the installation of the RTU retrofit controller reduced the peak power draw by about 20 percent in stage 1 cooling and by about 10 percent in stage 2 cooling (see Figure 98). This is likely due to a reduction in the speed of the blower (from 100 percent to 75 percent speed for stage 1 cooling and from 100 percent to 90 percent for stage 2 cooling).

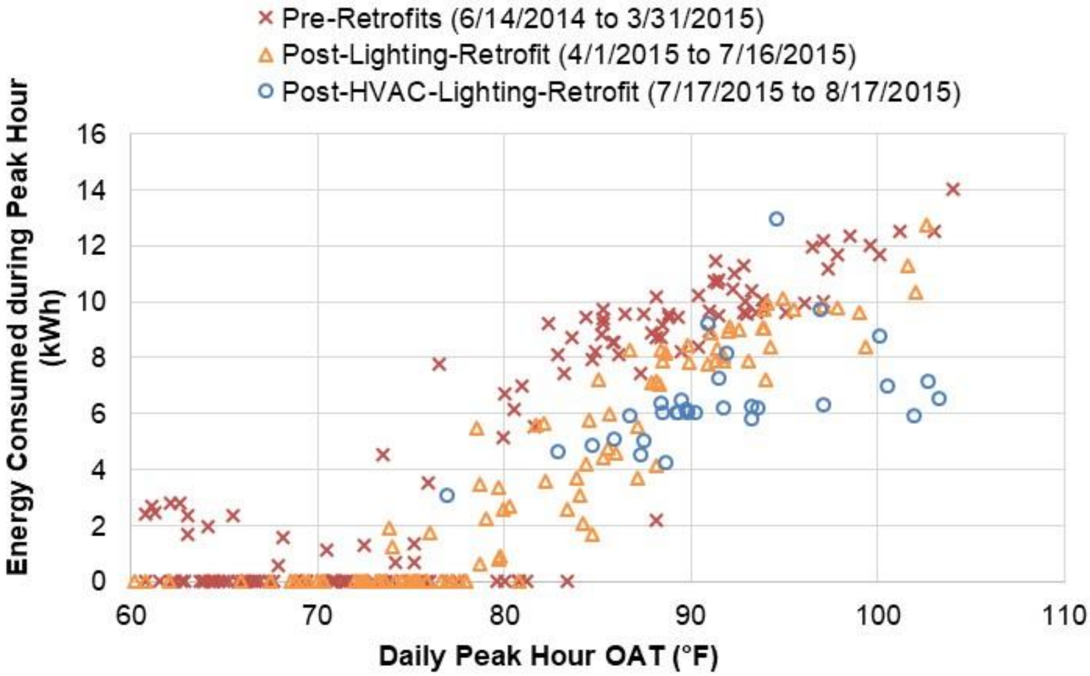
Figure 98: Peak Power versus Peak Daily Outdoor Air Temperature



Source: UC Davis WCEC

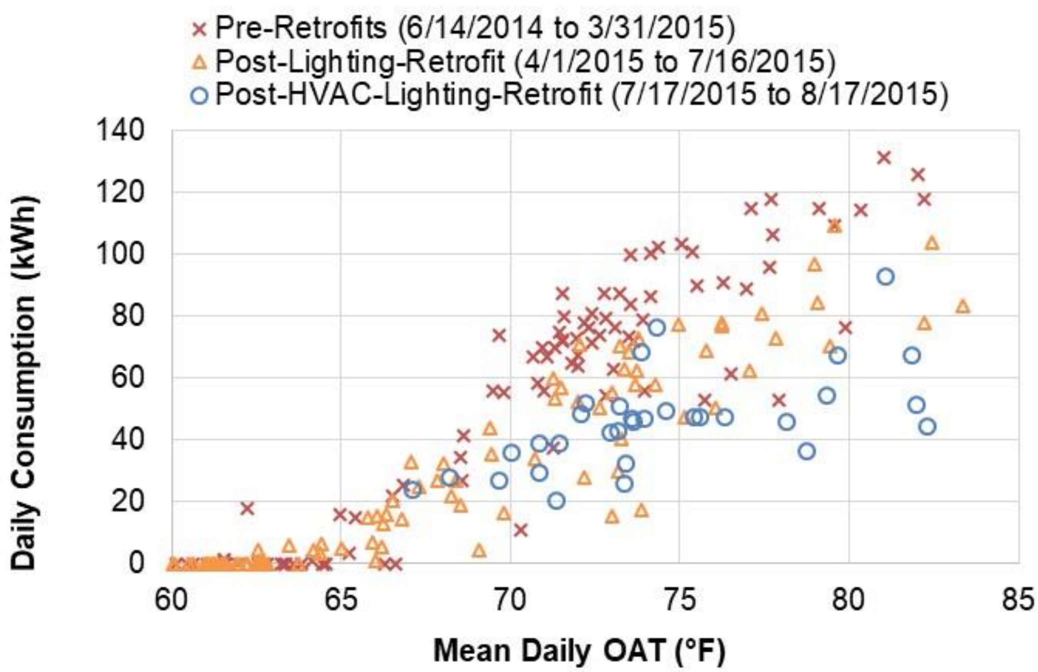
- Energy consumed during the daily peak hour versus the daily peak outdoor air temperature: The team found that the energy consumed during the peak hour was reduced substantially with the lighting retrofit and further reduced with the RTU controller retrofit (see Figure 99). The team clearly saw this effect when they examined daily energy consumption versus the mean daily outdoor air temperature (see Figure 100).

Figure 99: Energy Consumed during Peak Hour versus Peak Daily Outdoor Air Temperature



Source: UC Davis WCEC

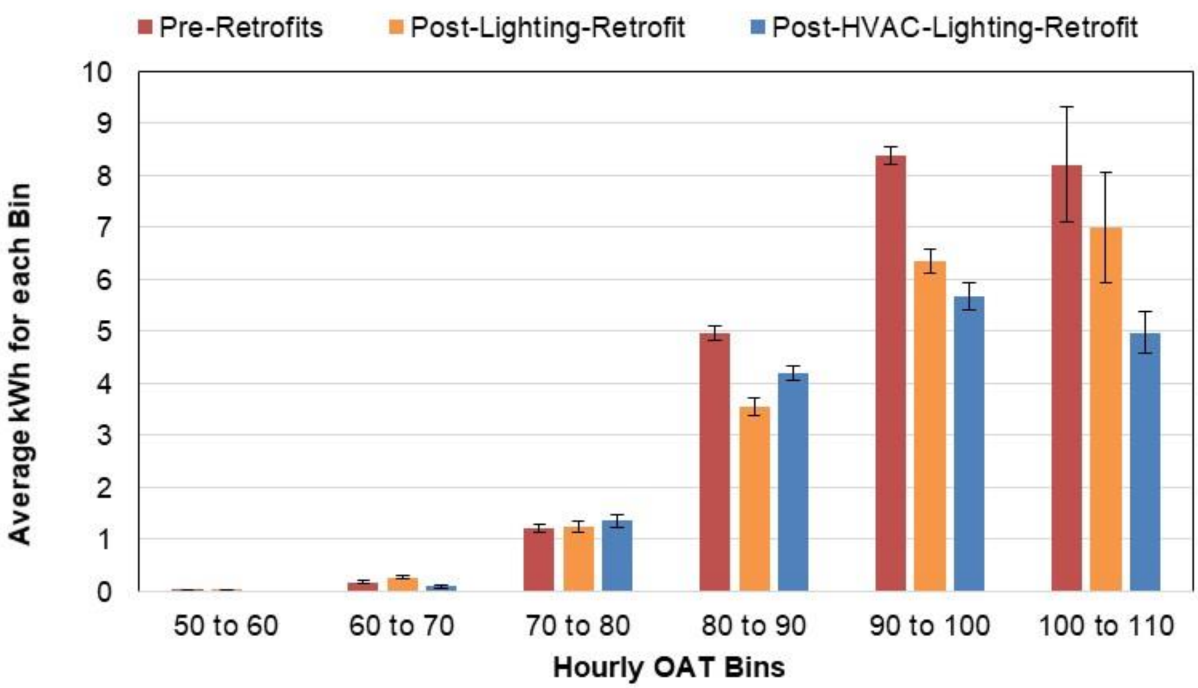
Figure 100: Daily Energy Consumption versus Mean Daily Outdoor Air Temperature



Source: UC Davis WCEC

- Averaged hourly energy consumption (kWh), grouped by ten degree outdoor air temperature bins (see Figure 101). Researchers found:
  - 15 percent savings due to the lighting retrofit and an additional 28 percent savings due to the RTU retrofit controller when outdoor air temperatures were 100-110°F
  - 25 percent savings due to the lighting retrofit and additional 10 percent savings due to the RTU controller when temperatures were 90-100°F
  - 30 percent savings due to the lighting retrofit and no additional savings due to the RTU controller when outdoor temperatures were 80-90°F
  - No savings when outdoor air temperatures were below 80°F, because the cooling load was minimal.

Figure 101: Hourly Energy Consumption versus Hourly Outdoor Air Temperature (°F)



Source: UC Davis WCEC

- The sample size for the 100-110°F bin was small; researchers only measured 15 hours pre-retrofit, 11 post lighting retrofit, and 14 hours post RTU-controller retrofit. A greater sample size could change these results significantly. For the 90-100°F bin, the sample size was larger, with 192 hours pre-retrofit, 116 hours post-lighting retrofit, and 68 post RTU-controller retrofit. Although the data at high temperatures are compelling, the RTU-controller's savings of 10 percent in the 90-100°F bin is better supported by the data. Researchers are unclear why the controller showed no savings in the 80-90°F temperature range. Even though the peak power was clearly reduced, it appears that longer equipment run times negated this savings.

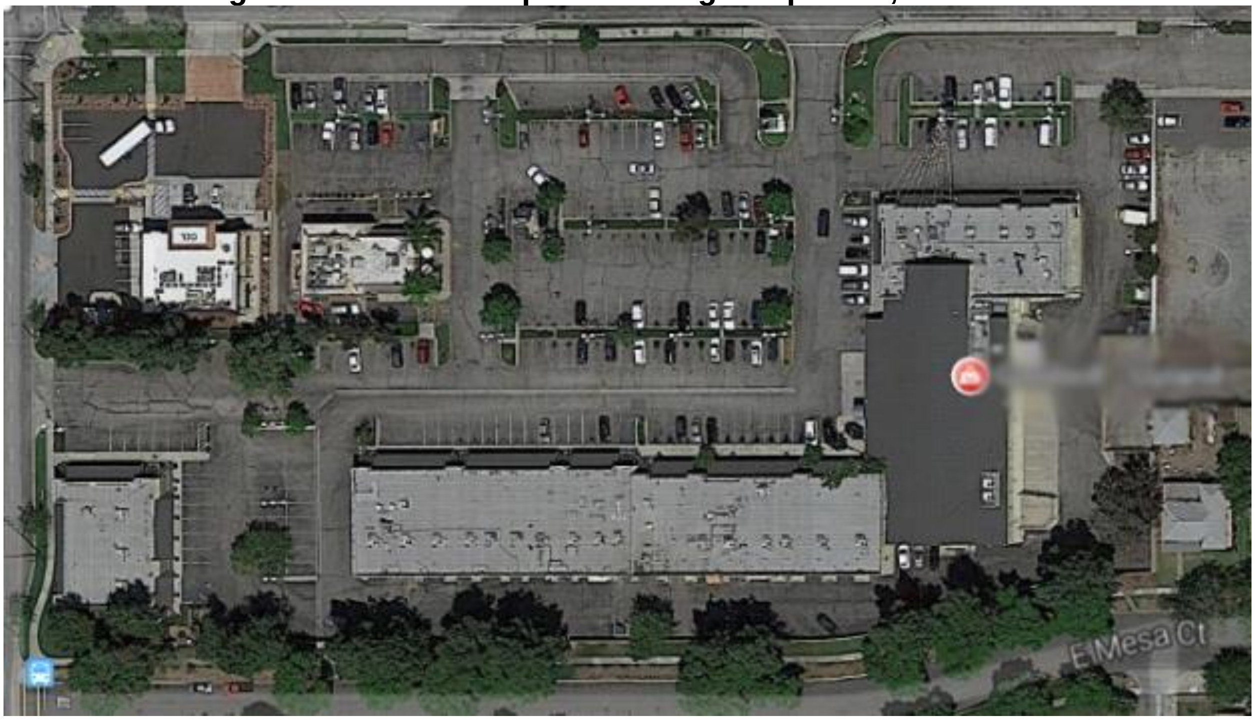
- Fan use: Researchers found that the building occupant ran the fan only when cooling was needed and not for ventilation only. The RTU-controller would save additional energy if the fan was used for ventilation purposes and would have even greater benefits with installation of an economizer.
- Annual electricity use: The team determined that the baseline HVAC system used 5600 kWh annually and the retrofit demonstrated electricity savings of 1800 kWh annually due to the reduced lighting load, or an annual cost savings of $288 a year (assuming an average commercial electricity cost of $0.16 per kWh). Additionally, the retrofit controller demonstrated an additional savings of ~100 kWh annually, or $16 a year. The retrofit controller and installation cost approximately $1380 for materials and labor, resulting in an undesirable payback. Researchers expect the payback for the technology to be more favorable in installations where the controller can reduce energy use during ventilation hours and include economizer integration.

Upland, California Site

The second demonstration site was a shopping center in Uplands, California (see Figure 102). One tenant, a large retail store, participated in the project (see Figure 103). The tenant occupies a space on the east side of the complex that is approximately 12,000 sq-ft and is used as a donation and retail store. The store includes a main sales floor, unused second floor mezzanine, and a rear unloading and storage area. The main sales floor on the first floor is surrounded by office and inventory space that is separated by a one story half wall. The second floor is an unoccupied mezzanine that has no physical barrier between it and the open retail area below.

Upland is located in climate zone 10, which is in Southern California's interior valley. The area experiences many sunny days with rainfall contained mostly to winter months. For most areas of this climate zone, HDDs exceed CDDs. Upland is based in the SCE utility territory.

Figure 102: Aerial Map of Building in Uplands, California



Source: Google Maps

Figure 103: Large Retail Store in Upland, California

Source: Southern California Edison

Retrofit Selection and Implementation

Researchers developed general recommendations for lighting, fenestration, and HVAC retrofits based on site visits and communication with the utility project manager.

Pre-Retrofit Technology - Lighting

Parking area lighting consisted of 48 pole-mounted luminaires equipped with 400W metal halide lamps. Total input power to each luminaire was rated at 458W for a total combined load of approximately 22 kW. All outdoor common area lighting operated on 120-V service. Luminaires were arranged in single, double and triple unit configurations depending on the pole location. More details on mounting location and configuration is shown in Figure 104. Lighting was controlled by a photocell with typical dusk to dawn operation. Average annual operating hours were estimated at approximately 4,380 hours resulting in an estimated annual consumption of 96,200 kWh. Comparison to pre-retrofit site data collected by the local utility for common area lighting circuits, shows annual consumption slightly above this estimate at 98,700 kWh. The difference can be attributed to somewhat longer operating hours and/or higher nominal input power for each luminaire due to variances in ballast type and age.

Pre-Retrofit Technology – Heating, Ventilation, and Air Conditioning

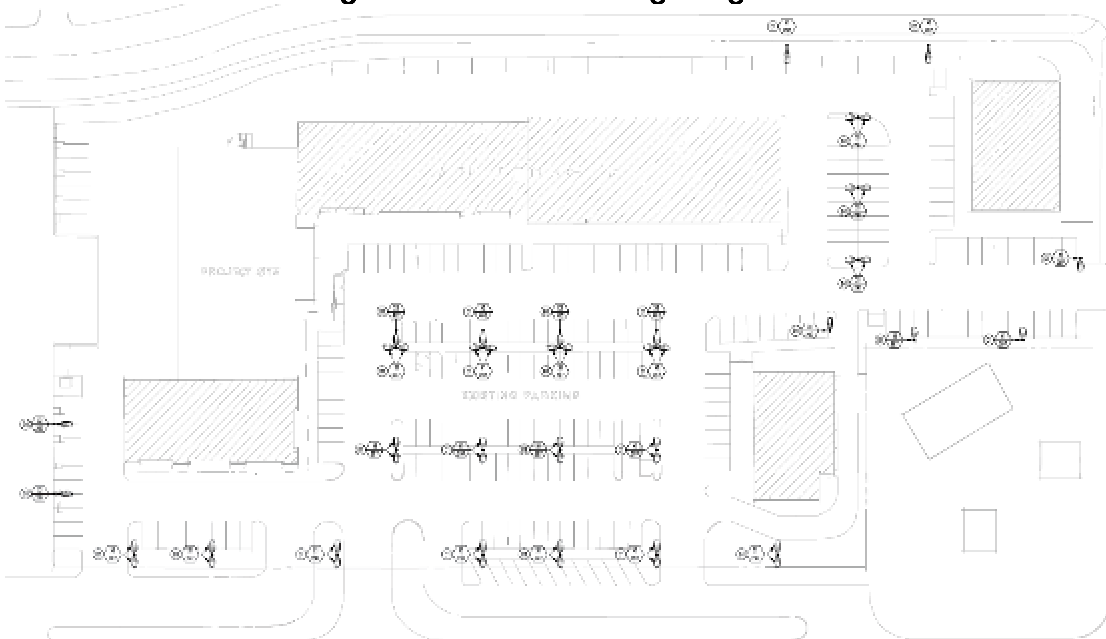
The building space was primarily served by a single 20 ton split system which had the condenser unit and air handler located on the roof, immediately adjacent to one another. The building also featured a 4-ton heat pump serving the mezzanine and five, 1.5 ton split systems (only two were operable) serving the office and inventory space. The main system was controlled by a single thermostat located within the retail space, but was inaccessible in a location behind merchandise.

Retrofit and Installation Details – Lighting

The property owner, in collaboration with their local utility, chose to complete a package of building-level improvements including updated parking area lighting. Outdoor common area lighting was retrofit with energy-efficient LED luminaires. Existing parking area luminaires were replaced with 209W, 4000 K LED luminaries equipped with dimming drivers and occupancy sensors. During vacant periods, lighting ramps down over several minutes to minimum levels. When occupants are detected, dimmed lighting ramps up to full output over several seconds.

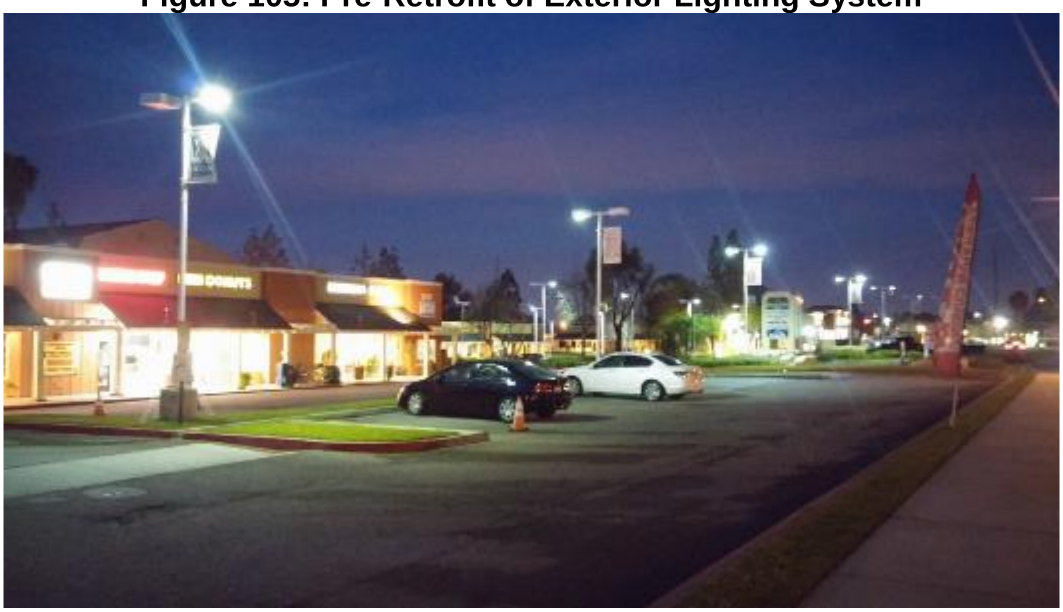
Figure 104 shows the common area exterior lighting site plan. Figure 105, Figure 106, and Figure 107 detail the exterior lighting retrofit installation. Table 59 provides the luminaire schedule for the site.

Figure 104: Exterior Lighting Site



Source: Southern California Edison

Figure 105: Pre-Retrofit of Exterior Lighting System



Source: Southern California Edison

Figure 106: Installation of the LED Lighting Measure

Source: Southern California Edison

Figure 107: Post-Retrofit of Exterior Lighting System

Source: UC Davis

Table 59: Exterior Common Area Lighting Schedule

LUMINAIRE SCHEDULE									
Symbol	Label	Qty	Catalog Number	Description	Lamp	File	Lumens	LLF	Watts
	A	15	Lithonia – DSX1 LED 60C 1000 40K TFTM MVOLT Mt @ 23' AFG	DSX1 LED WITH (2) 30 LED LIGHT ENGINES, TYPE TFTM OPTIC, 4000K, @ 1050mA	LED	DSX1_LED_60C_1000_40K_TFTM_MVOLT_MA.ies	Absolute	0.90	209
	AL	3	Lithonia – DSX1 LED 60C 1000 40K TFTM MVOLT L90 Mt @ 23' AFG	DSX1 LED WITH (2) 30 LED LIGHT ENGINES, LEFT ROTATED TYPE TFTM OPTIC, 4000K, @ 1050mA	LED	DSX1_LED_60C_1000_40K_TFTM_MVOLT_L90.ies	Absolute	0.90	209
	AR	3	Lithonia – DSX1 LED 60C 1000 40K TFTM MVOLT R90 Mt @ 23' AFG	DSX1 LED WITH (2) 30 LED LIGHT ENGINES, RIGHT ROTATED TYPE TFTM OPTIC, 4000K, @ 1050mA	LED	DSX1_LED_60C_1000_40K_TFTM_MVOLT_R90.ies	Absolute	0.90	209
	B	23	Lithonia – DSX1 LED 60C 1000 40K T3M MVOLT Mt @ 23' AFG	DSX1 LED WITH (2) 30 LED LIGHT ENGINES, TYPE T3M OPTIC, 4000K, @ 1050mA	LED	DSX1_LED_60C_1000_40K_T3M_MVOLT_MA.ies	Absolute	0.90	209
	BH	4	Lithonia – DSX1 LED 60C 1000 40K T3M MVOLT HS Mt @ 23' AFG	DSX1 LED WITH (2) 30 LED LIGHT ENGINES, TYPE T3M OPTIC, 4000K, @ 1050mA WITH HOUSE SIDE SHIELD	LED	DSX1_LED_60C_1000_40K_T3M_MVOLT_MA_HS.ies	Absolute	0.90	209

Source: Southern California Edison

Retrofit and Installation Details – Heating, Ventilation, and Air Conditioning

Researchers and tenants undertook a major upgrade to the HVAC equipment at the large retail store. The retail store space was the largest of the tenants at the shopping mall, and the equipment that served this space was among the most outdated. The team selected a heat pump to replace an existing 20-ton electric air conditioner and furnace. The retrofit also included installation of new, programmable thermostats in locations that were easily accessible by staff.

This demonstration site was ideally suited for electric heat pump technology, based on the mild winter climate and the need to provide heating only during daytime business hours. This is a characteristic of many MTLC buildings and this demonstration could promote greater adoption of heat pump technology. Statewide policy trends towards electrification, for reasons including safety concerns over natural gas and increased availability of renewable electricity generation, create additional interest in heat pump technology.

Site retrofits were not completed at the time of this report, however, the retrofit plan is detailed below.

Table 60 and Table 61 outline the retrofit plan to replace the heat pump system and the air conditioning systems with higher efficiency equipment, evidenced by the increased energy efficiency ratio (EER) and seasonal energy efficiency ratio (SEER). The primary 20 ton split system will be replaced by a newer 20 ton split system heat pump, along with moving the entire air handling portion from outside into an indoor equipment room. The new system will have an improved efficiency rating and will eliminate the loss associated with having air pass through an outdoor air handler, taking full advantage of the split system. This will reduce duct losses and required fan power for air distribution.

Table 60: Pre-Retrofit Equipment Information for Large Retail Store in Upland, California

Description	Make	Model	Cool Size (tons)	Cooling Efficiency EER	Cooling Efficiency SEER
Main Unit	Ruud	RAWD - 200CAS	20	9	
Secondary Unit	Carrier	50YQ048400	4	7.9	
Small Split	Carrier	38YH018300	1.5 (QTY:2)		8.4-9.5[1]

[1]SEER rating is affected by air handler model, which is unknown

Source: UC Davis WCEC

Table 61: Post-Retrofit Equipment Information for Large Retail Store in Upland, California

Description	Make	Model	Cool Size (tons)	Cooling Efficiency EER	Cooling Efficiency SEER
Main Unit	York	PD240/ ND240	20	10.6	
Secondary Unit	York	ZYG08	7.5	12	
Small Split	York	YHJD48/AHE 48D	4		15

Source: UC Davis WCEC

The 4-ton heat pump, serving the mezzanine area, will be replaced with a 7.5-ton RTU, along with a better distribution system located along the boundary between the mezzanine and retail area. The replacement RTU has a much higher efficiency rating, but due to the increase in capacity, it is unclear what effect it will have on energy savings.

The five 1.5 ton units, of which only two are still in operation, will be removed and replaced by a single 4 ton split system to serve the office area and other enclosed floor level spaces. This replacement has a much higher efficiency rating and the duct work will be balanced to better serve spaces efficiently. Researchers expect the slight increase in capacity to have little effect on the energy savings potential of this retrofit.

Commissioning Details - Lighting

Occupancy and photocontrols were commissioned at the factory prior to installation. Occupancy sensors were set with 5-minute timeout periods and a 5-minute ramp down period during vacant periods for connected luminaires. Photocells were set with a target relative illuminance of 200 fc. When sufficient daylight is detected, levels above 200 fc, photocells are programmed to wait five minutes before turning off connected luminaires. When daylight levels drop below the 200-fc threshold, lighting is turned on within 45 seconds.

Commissioning Details – Heating, Ventilation, and Air Conditioning

Site retrofits were not completed at the time of this report.

Performance Monitoring and Results

Performance Monitoring – Lighting

SCE provided circuit-level, utility grade, energy use data. Exterior lighting measures were contained on 'Common Area' circuits. Researchers compiled pre-retrofit billing data for 12 months and post-retrofit billing data for 1 month. For each monitored area, they determined average monthly load (kW) energy use (kWh) and extrapolated to calculate the annual energy use for both pre- and post-retrofit lighting systems.

Results – Lighting

The team found that outdoor lighting retrofits resulted in approximately 52 percent electricity savings, as compared to baseline systems (see Table 62). Based on extrapolation of actual savings, researchers calculated annual electricity savings to be 51,799 kWh. In addition, they found that each luminaire consumed approximately 203W, as compared to the 209W listed on manufacturer's specification sheets.

Table 62: Pre- and Post-Retrofit Lighting Systems - Monitoring Data at Upland Demonstration Site

Load	Number of Months Analyzed	Average Monthly Energy Use (kWh)	Projected Annual Energy Use (kWh)
Common Area – Pre-retrofit	12	8,233	98,791
Common Area – Post-retrofit	1	3,916	46,992
Energy Savings		4,317 (52%)	51,799 (52%)

Source: UC Davis CLTC

Researchers also completed illuminance measurements to quantify light levels provided by the new LED luminaries (see Table 63).

Table 63: Contrast Ratios Provided by New LED Lighting at Upland Demonstration Site

Contrast Ratio by Zone (based on illuminance measurements)	Post-Retrofit Max-Min (ratio x:1)	Post-Retrofit Avg-Min (ratio x:1)	Post-Retrofit Average Illuminance (fc)
IES recommended	15	4	
A	11.1	4.4	4.2
B	42.8	18.1	5.1
C	9.4	3.9	3.0
D	20.9	7.9	3.8
F	7.4	3.8	4.5

Source: UC Davis CLTC

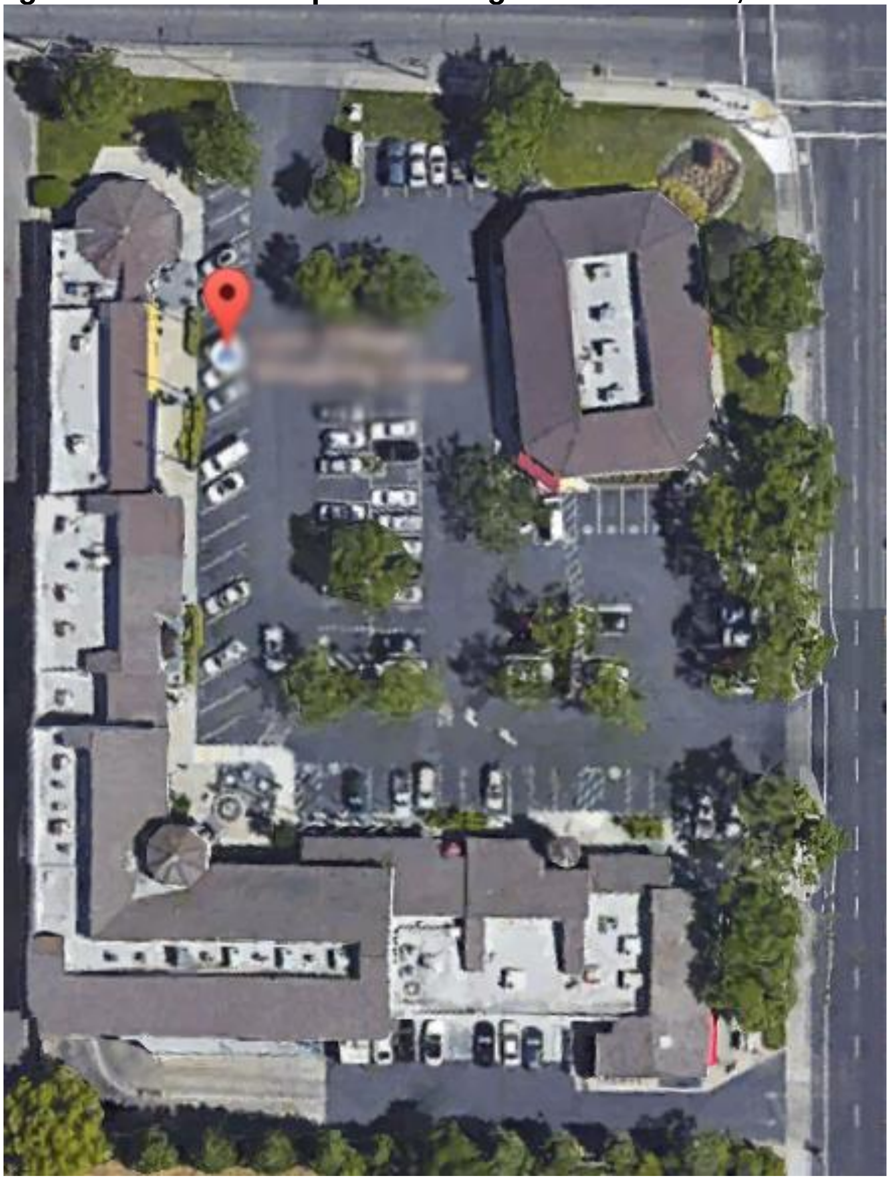
Researchers identified and took measurements in five outdoor lighting zones (A, B, C, D, and E) along a 10' x 10' grid. In analyzing the data, the team found approximately 3 of the 5 outdoor zones (60 percent) had contrast ratios that met or exceeded IES recommendations for the site. They also found that the average illuminance at grade ranged from 3 to 5.1 fc, well in excess of IES minimum recommendations. Given that existing pole spacing for the outdoor lighting was maintained for the retrofit, this represents a good result for a 1-1 replacement scenario.

Sacramento, California

The third demonstration site was a shopping center in Sacramento, California (see Figure 108). Eight tenants participated in the project. The center's main L-shaped building is approximately 26,000 sq-ft. The largest tenant in the building is a medium-sized office complex that spans two building floors and has multiple open office spaces, private offices, support spaces, and restrooms.

Like the first demonstration site, Sacramento is located in climate zone 12, which experiences warm summers and cold winters. Rain falls between November and April. Ground fog can be common and some areas experience winter frost. There are often more HDD than CDD for this climate zone. Sacramento is based in the Sacramento Municipal Utility District (SMUD) territory.

Figure 108: Aerial Map of Building in Sacramento, California



Source: Google Maps

Retrofit Selection and Implementation

Researchers developed general recommendations for the shopping center lighting, fenestration, and HVAC retrofits based on site visits and communication with the utility project manager at SMUD. The utility required prioritization of technologies and spaces that best fit within their existing incentive and rebate programs.

Pre-Retrofit Technology – Lighting

Figure 109 shows the pre-retrofit conditions in the medium-sized office complex.

Figure 109: Pre-Retrofit Open Office

Source: UC Davis

Pre-Retrofit Technology – Heating, Ventilation, and Air Conditioning

Figure 110 shows a typical pre-retrofit HVAC unit for the tenants.

Figure 110: Pre-Retrofit of Rooftop

Source: UC Davis

Retrofit and Installation Details – Lighting

A utility subcontractor replaced existing recessed fluorescent troffers with LED solutions. They also added passive infrared (PIR) wall-switch occupancy sensors to the open office, private offices, and common areas. Figure 111 shows the final installation.

Figure 111: Post-Retrofit Open Office

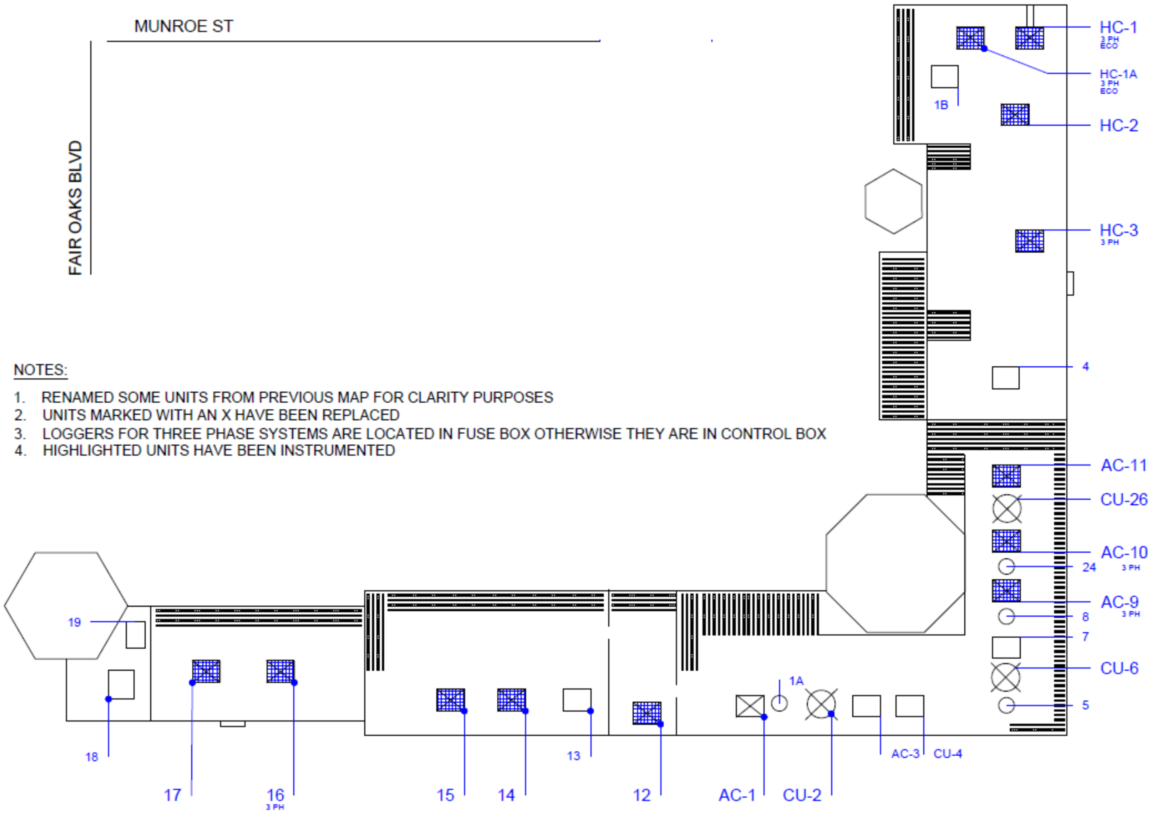
Source: UC Davis

For some large open office areas, installers eliminated wall switch occupancy sensor switches because the sensor did not have a direct line of site to the occupants and therefore would not have functioned as intended. In private offices with two luminaires and traditional A/B switching, two wall-switch sensors were installed, one for each luminaire.

Retrofit and Installation Details – Heating, Ventilation, and Air Conditioning

Shopping center retrofits included a mass replacement of outdated rooftop package units with modern high efficiency units (see Figure 112). The team selected units to be replaced based on age. The units removed were estimated to be approximately 27 years old with an existing SEER of 9.5. In total, 16 outdated and low efficiency rooftop units were replaced with new high efficiency units (see Figure 113). All new units were 16 SEER units, well exceeding the current federal requirement of 13 SEER. By projecting the expected efficiency increase over a normalized year of operation, researchers found that the new equipment would save 38-44 percent of HVAC energy consumption.

Figure 112: Shopping Center in Sacramento, California Heating, Ventilation, and Air Conditioning Retrofit Plan



Source: UC Davis WCEC

Figure 113: Post-Retrofit of Rooftop Unit

Source: UC Davis

In addition to the new high efficiency rooftop package units, many shopping center tenants received and installed new advanced thermostat controls from Pelican Wireless Systems. These thermostats incorporated features such as advanced scheduling features, internet programming, and the ability to disable HVAC function based on a door open switch.

Commissioning Details – Lighting

The wall-switch sensors had three different settings that could be tuned to meet space needs: light dim level, time delay to off, and sensor sensitivity (see Figure 114). Installers commissioned sensors for maximum light output, a maximum time delay of 30 min, and the maximum sensor sensitivity.

Figure 114: Wall Switch Occupancy Sensors (Left) and Exposed Programming Interface (Right)

Source: UC Davis

Commissioning Details – Heating, Ventilation, and Air Conditioning

The new HVAC units were installed over about a week’s time by removing the old equipment from the existing equipment curbs and installing the new equipment in its place. Researchers checked the thermostats to make sure that the proper schedule was implemented during the retrofit period of data monitoring.

Performance Monitoring and Results

The utility provider, SMUD, provided circuit level, utility grade, and energy use data for each tenant and the common areas. For the medium office space, researchers identified circuits as ‘non-HVAC,’ ‘HVAC,’ ‘Unknown,’ and ‘Common Area’. ‘Non-HVAC’ and ‘Unknown’ circuits contained interior lighting measures; ‘Common Area’ circuits contained exterior lighting measures; and ‘HVAC’ systems were connected to the HVAC circuit.

Performance Monitoring – Lighting

HVAC equipment was separately metered from other loads, allowing researchers to easily compare pre and post-retrofit meter data to determine lighting energy savings. In addition, no other equipment retrofits or replacements were conducted during the monitoring period so changes between pre and post-retrofit electricity consumption were directly attributable to the lighting and HVAC retrofit measures.

Researchers analyzed 913 days of pre-retrofit data to determine the electricity use of existing lighting systems. Lighting retrofit measures were installed in December 2014. Researchers compared 49 days of post-retrofit meter data.

Performance Monitoring – Heating, Ventilation, and Air Conditioning

Retrofit measures for the site included upgrading the existing vintage package units with new hi-efficiency package units. To evaluate the actual energy savings from this retrofit measure, the team analyzed utility meter data for each tenant from January-December 2013 (pre-retrofit) and compared it to utility meter data from January-July 2015 (post-retrofit). For each tenant, other than the medium office space, the HVAC energy consumption was included in the utility meter for the entire space. No other equipment retrofits or replacements were conducted during the monitoring period, however, so changes between pre and post-retrofit electricity consumption were directly attributable to HVAC retrofit measures. For the medium office space, HVAC electricity use was sub-metered.

For each month, researchers calculated the average electricity consumption (kWh/day) for each tenant. Because HVAC energy consumption is highly weather dependent, the team accounted for average monthly outdoor air temperatures. Researchers downloaded the average monthly dry temperature from a National Oceanic and Atmospheric Administration weather station in downtown Sacramento. Researchers plotted the result of average monthly dry bulb temperature and average monthly electricity costs, and fit a polynomial curve to relate the average monthly temperature to energy consumption.

In addition to monitoring the lighting retrofit, the team briefly surveyed the occupants of the space to see how they felt about their new lighting.

Results – Lighting

For each circuit, researchers determined the average daily energy use (kWh) and extrapolated to calculate the annual energy use for both pre- and post-retrofit lighting systems (see Table 64 and Table 65). For the lighting retrofit measures, annual energy savings was 63,680 kWh or a 28 percent energy use reduction (see Table 66).

In analyzing data from the lighting survey, researchers found that employees:

- Valued lighting and felt that general lighting was incredibly important for a workspace;

- Felt that the open office space and the private office lighting had greatly improved and that object appearance and light level uniformity had also greatly improved; and
- Would recommend the new LED light and occupancy control system.

Table 64: Pre-Retrofit Monitoring Data

Load	Total Monitored Energy Use (kWh)	Number of Days	Average Daily Use (kWh)	Calculated Annual Energy Use (kWh)
Non-HVAC	310,578	913	340	124,163
Unknown	26,934	913	30	10,768
Common Area	218,497	913	239	87,351

Source: UC Davis CLTC

Table 65: Post-Retrofit Monitoring Data

Load	Total Monitored Energy Use (kWh)	Number of Days	Average Daily Use (kWh)	Calculated Annual Energy Use (kWh)
Non-HVAC	9,122	49	186	67,947
Unknown	1,115	49	23	8,303
Common Area	11,190	49	228	83,351

Source: UC Davis CLTC

Table 66: Savings Summary

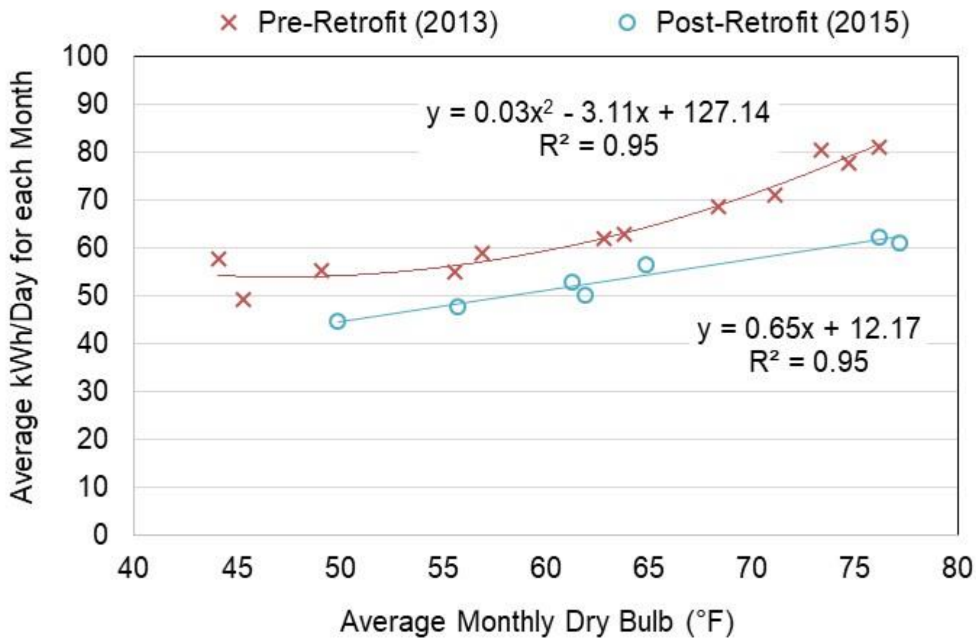
Load	Pre-Retrofit	Post-Retrofit	Annual Savings (kWh)	Savings (%)
Non-HVAC	124,163	67,947	56,216	45%
Unknown	10,768	8,303	2,464	23%
Common Area	87,351	83,351	4,000	5%
Total	222,281	159,601	62,680	28%

Source: UC Davis CLTC

Results – Heating, Ventilation, and Air Conditioning

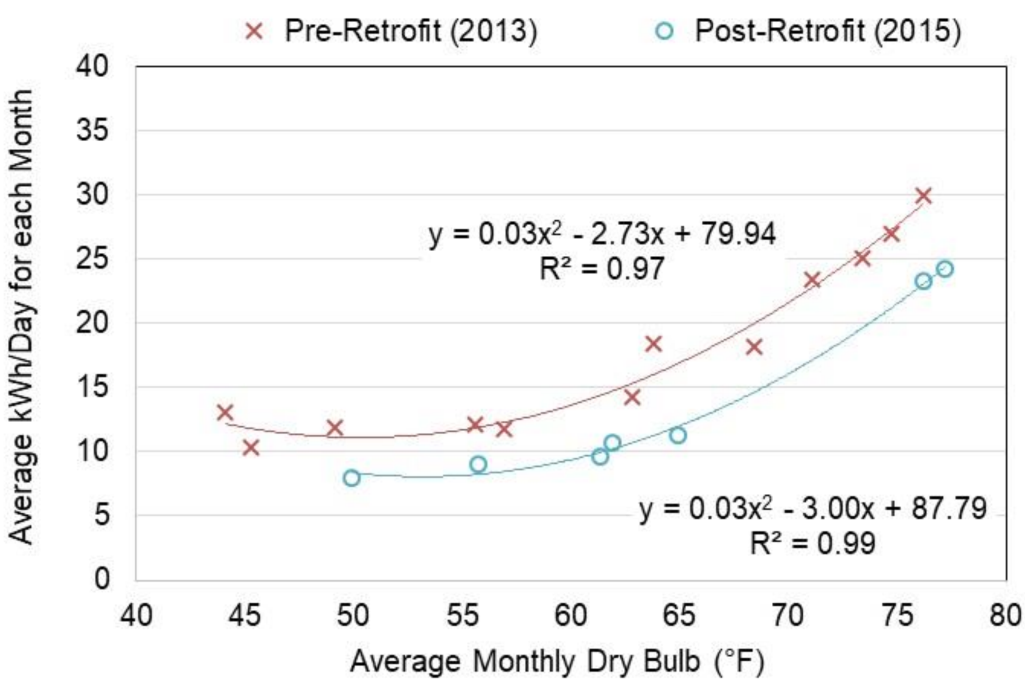
Researchers analyzed five of the eight tenant spaces retrofitted with HVAC replacements. They excluded two tenant spaces from the analysis due to a change of tenancy over the monitoring period and one tenant space due to erroneous pre-retrofit monitoring data. For each tenant space, researchers fit a polynomial curve for both the "pre-retrofit" and the "post-retrofit" data set. Results are plotted in Figure 115 through Figure 119 for tenant spaces A, B, C, D, and E. Of the five spaces, only tenant "D" received lighting retrofits.

Figure 115: Tenant "A" Utility Meter Data Before and After Retrofit



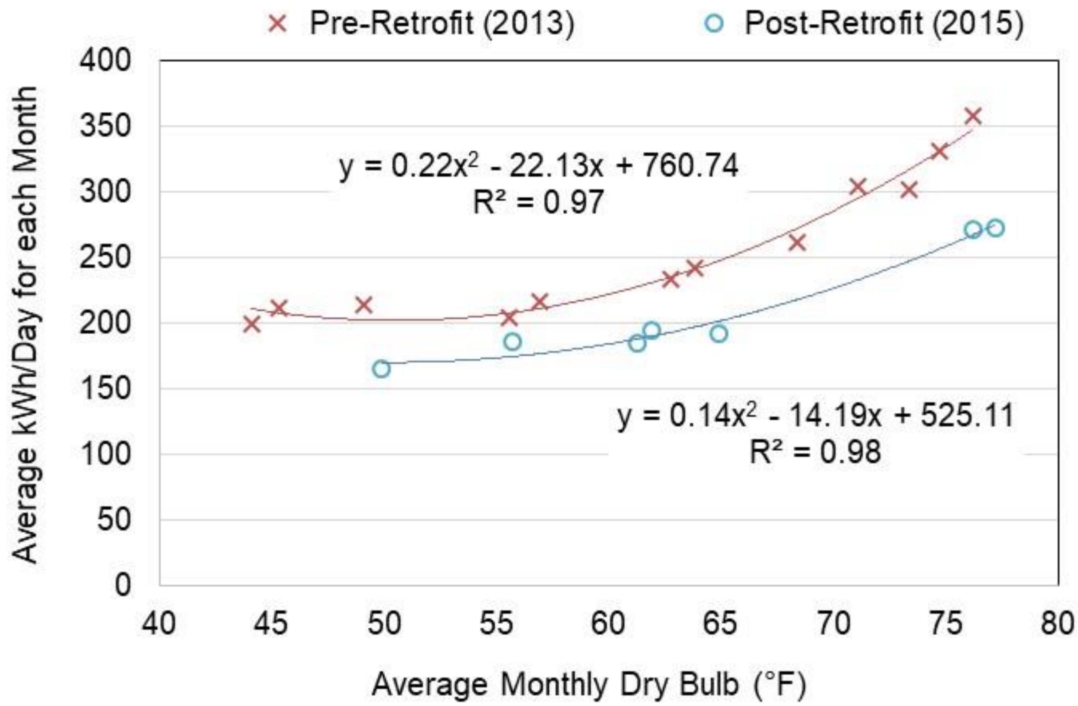
Source: UC Davis WCEC

Figure 116: Tenant "B" Utility Meter Data Before and After Retrofit



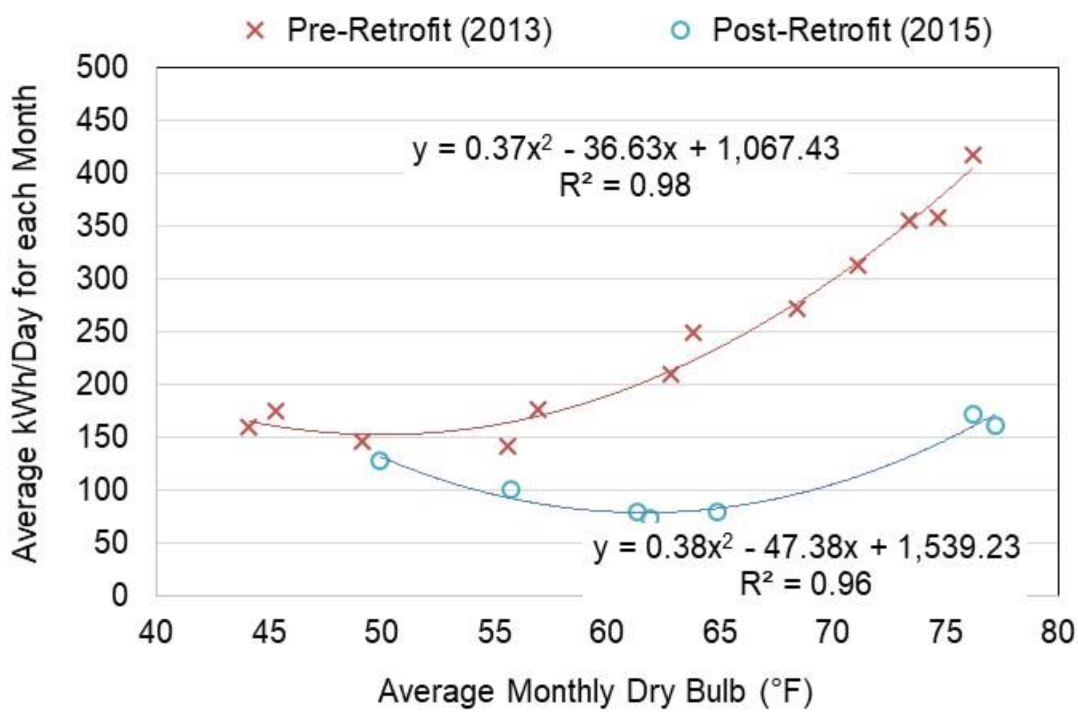
Source: UC Davis WCEC

Figure 117: Tenant "C" Utility Meter Data Before and After Retrofit



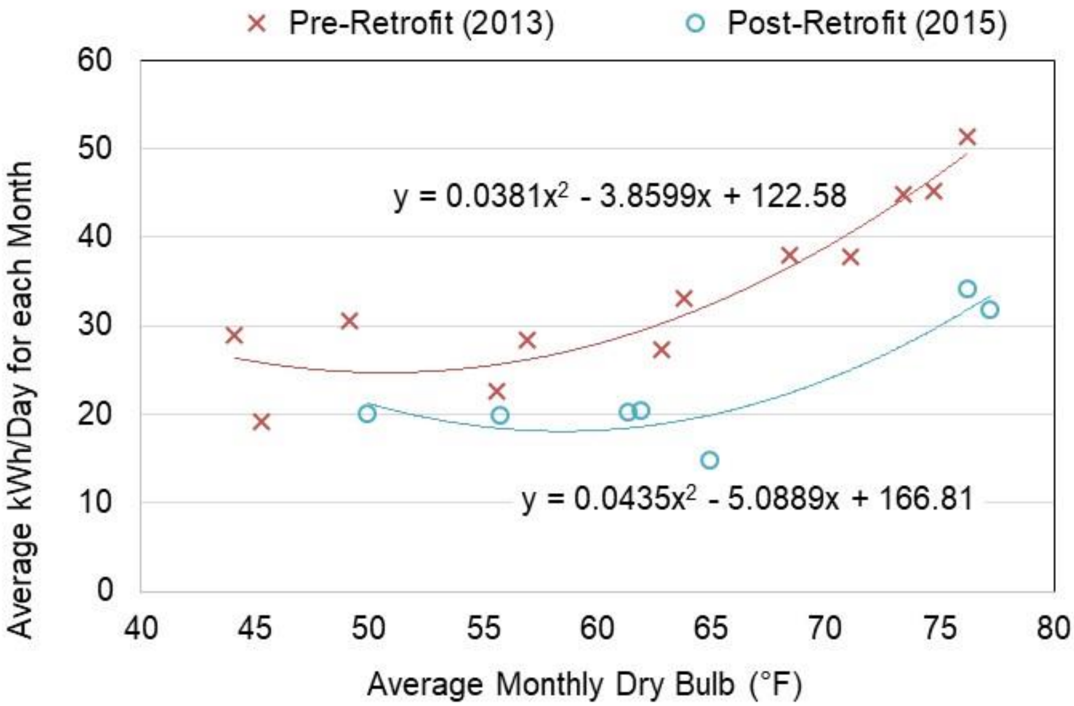
Source: UC Davis WCEC

Figure 118: Tenant "D" Utility Meter Data Before and After Retrofit (HVAC only, does not include Lighting Retrofit)



Source: UC Davis WCEC

Figure 119: Tenant "E" Utility Meter Data Before and After Retrofit



Source: UC Davis WCEC

Based on the polynomial curves, the team projected annual HVAC savings using typical metrological year (TMY) data. For tenant "D," in which lighting retrofits occurred, researchers estimated savings due to the lighting retrofits. In analyzing the data, the team found annual HVAC electricity savings of 62,736 kWh, annual HVAC electricity savings due to the lighting retrofits of 13,336 kWh, and annual HVAC electricity savings due to HVAC retrofits of 47,685 kWh (Table 67).

Electricity savings from HVAC equipment replacement were significant. The team found that payback time ranged from 7-23 years, with an average of nine years (Table 67). This wide range is likely due to variation in required cooling loads of the various tenants. The cost metrics are based on retrofitting all 10 tenants simultaneously, however some tenants will benefit more than others.

Table 67: Projected Annual Heating, Ventilation, and Air Conditioning Savings and Payback

Tenant	Estimated annual HVAC savings (kWh)	Est. annual HVAC savings from lighting load reduction (kWh)	Est. annual HVAC savings from HVAC equipment (kWh)	Total tons of cooling	Total Cost	Simple Payback (years)
A	4,131	-	3,787	3	$5,500	8.3
B	1,576	-	1,504	3	$5,500	23.2
C	16,078	-	14,779	12.5	$23,000	8.9
D	37,572	13,336	23,458	14.6	$27,000	7.0
E	3,379	-	3,379	4	$7,400	13.7
TOTAL	62,736	13,336	47,685	33	$68,400	9.0

Source: UC Davis WCEC

Conclusions

Real-world retrofit demonstrations play a critical role in advancing deep energy and demand savings in California's existing MTLC buildings. This research project collected and analyzed data from lighting and HVAC retrofits at three field sites in Davis, Upland, and Sacramento. Although not all tenants within each MTLC building elected to participate in the demonstration, researchers were able to implement lighting and HVAC retrofits with specific tenants and monitor and understand retrofit package savings. Overall, the team found significant energy savings from implemented retrofits. Cost savings and payback for retrofits varied depending on the specific retrofit and tenant characteristics.

CHAPTER 6: Conclusions and Future Research

This multi-year, programmatic research leveraged an interdisciplinary team to conduct primary and secondary market research, analyze appropriate technologies and implementation strategies, develop tools for large, integrated ECM retrofit packages, and establish field demonstrations—all targeted at MTLC buildings, specifically small and medium-sized shopping centers. This research provides insight into a market that has largely been ignored and unaddressed. In addition, software tools like the MTLC Toolbox, and implementing demonstrations on more buildings would help advance cost-effective ECM installations in the MTLC market.

The MTLC market is large, in square footage and energy consumption. It is also extremely diverse in size, business type, equipment, owner-tenant relationships, and leasing structures. Through its market research and the process of acquiring demonstration sites, the research team encountered real world challenges associated with approaching MTLC businesses with retrofit packages. The most critical challenge was the need to avoid any inconvenience to tenant businesses. Other impediments to launching the demonstrations, and more generally to widespread implementation of energy efficiency in the MTLC market, include:

- Difficulty in reaching 100 percent participation of all building tenants;
- Building-owner and tenant dynamics, including lease structure (split incentives and complex ownership structures);
- Challenges with regards to financing and information gaps;
- Relatively low project costs and profits from the perspective of ESCOs;
- Time constraints and complexity of retrofit implementation;
- Purchase price and installation costs of retrofits; and
- Utility programs that are not designed for deep energy retrofits in the MTLC market.

The existing utility approach for the MTLC market is neither customized nor integrated; rather, utilities' direct install programs focus on deploying only a few standard ECMs across the broader non-residential market. Utilities typically do not target MTLC facilities, nor do they prioritize a comprehensive audit methodology to gather data on a multitude of retrofit opportunities.

While the current state of implementing deep energy savings in the MTLC space is non-functional, feasible solutions exist. As a result of its research, the team identified three programmatic tools to achieve targeted retrofit packages for MTLC shopping centers.

These tools would enable deeper energy savings than DI programs, but will do so in a cost-effective manner, with technologies that are designed and targeted for the MTLC market. The three programmatic tools are related to the audit, analysis, and retrofit processes:

1. Audit—Use the California Conservation Corps (CCC) to conduct on-site audits.
2. Analysis—Use of software like the MTLC Toolbox to conduct energy efficiency analyses.
3. Retrofit—Implement retrofit installations at the building level.

Using the CCC to conduct audits allows for extensive understanding of available conservation measures and audits at lower than current market rates. In addition, the team's MTLC Toolbox helps to complete auditing analysis, allowing for examination of on-site energy efficiency measures without using costly engineers. Furthermore, although there is limited data available, researchers found evidence that HVAC costs can be reduced through implementing measures at the building level instead of at the tenant level. Additional research, with larger sample sizes, is needed in this area.

Data from the field demonstration sites, while limited, validated many of the researchers' findings. Overall, the team found significant energy savings from implemented retrofits. Cost savings and payback for retrofits varied depending on the specific retrofit and tenant characteristics. More work is required to understand the energy impacts of window upgrades, the addition of thin films, and the dependence of these measures with respect to climate zone, business type, building orientation, and general building construction.

Retrofits of existing buildings are necessary for California to realize greenhouse gas reduction and energy efficiency goals. California requires wide-scale energy efficiency retrofits in every sector of the economy, including MTLC buildings. Based on the market research and direct experience of the research team, regulators may want to consider encouraging green leasing structures and policies to impact MTLC buildings. Likewise, utilities may want to design custom MTLC programs, in particular ones that outreach to customers at the proper times during the building lifecycle, such as during remodeling, tenant changeover, and equipment failure/exchange.

LIST OF ACRONYMS

Term	Definition
3Ps	Third Parties
AB32	Global Warming Solutions Act of 2006
AB758	The Comprehensive Energy Efficiency in Existing Buildings Law
AC	Air conditioning
AEE	Association of Energy Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEAP	Building Energy Assessment Professional
Btu	British Thermal Unit. There are 3412 Btu's per kWh
CALiPER	United States Department of Energy's Commercially Available LED Product Evaluation and Reporting Program
CAM	Common Area Maintenance agreements in leases specify net charges belled to tenants of a commercial property and generally are composed of maintenance fees for worked performed on the common area of a property.
CBECS	Commercial Buildings Energy Consumption Survey
CCC	California Conservation Corps is a state agency that places young men and women in positions where they work outdoors for a year to improve California's natural resources.
CCT	Correlated Color Temperature specifies the color appearance of the light emitted from a lamp, measured in degrees Kelvin (K).
CDD	Cooling Degree Days specifies the demand for energy needed to cool a building.
CBECS	Commercial Building Energy Consumption Survey
CEA	Certified Energy Auditor
CEUS	California Commercial End-Use Survey
CFL	Compact Fluorescent Lamp
CLTC	California Lighting Technology Center at the University of California, Davis.

Term	Definition
COP	Coefficient of Performance is the ratio of cooling provided by an air conditioner to the work or energy input required.
CPUC	California Public Utilities Commission
CRI	Color Rendering Index
CSLB	California State Licensing Board
CSS	California Commercial Saturation Survey
DEC	Direct Evaporative Cooling is a device that cools air through the evaporation of water.
DER	Deep Energy Retrofit uses a whole-building analysis and integrative approach to achieve larger energy savings than traditional energy retrofits.
DEER	Database for Energy Efficient Resources
DI	Direct Install programs are administered by utilities to lower peak demand and meet utility energy efficiency goals.
DLC	Design Lights Consortium
USDOE	Department of Energy
DX	Direct Expansion technologies pass the air used for cooling a building directly over the cooling coil.
EC	Evaporative Cooling combines the natural process of water evaporation with an air-moving system.
ECI	Energy Cost Intensities
ECM	Energy Conservation Measure is a project or technology that reduces the consumption of energy in a building.
EE	Energy efficiency
EEC	Energy Efficiency Center at the University of California, Davis.
EER	Energy Efficiency Ratio
EIA	United States Energy Information Agency
EnergyPlus	EnergyPlus is a whole building energy simulation program that models energy consumption for heating, cooling, ventilation, lighting and plug and process loads, as well as water use in buildings.

Term	Definition
EMS	Energy Management Systems uses computer-aided tools to improve energy efficiency.
ESCO	Energy Service Companies
EUI	Energy Use Intensity
ft	feet
GHG	Greenhouse Gas Emissions
GSM	Graduate School of Management at the University of California, Davis.
GWh	Gigawatt-hours, the energy of 10^9 watts for an hour
HDD	Heating Degree Days specifies the demand for energy needed to heat a building.
HID	High-Intensity Discharge lamps
HMG	Heschong-Mahone Group, an energy consultancy
HPS	High-Pressure Sodium lamps
HVAC	Heating, Ventilation, and Air-Conditioning
HYB	Hybrid Cooling
ICSC	International Council of Shopping Centers
IDEC	Indirect-Direct Evaporative Cooling
IEC	Indirect Evaporative Cooling
IES	Illuminating Engineering Society
IHACI	Institute of Heating and Air Conditioning Industries
IOU	Investor Owned Utility is a private business that provides a utility service.
Itron	A technology and services company dedicated to the resourceful use of energy and water.
kW	kW is an international system of units designation for power equal to one thousand watts.
kWh	Kilowatt hour. The energy of one kW for an hour. $3.6 * 10^6$ Joules
LADWP	Los Angeles Department of Water and Power

Term	Definition
LBNL	Lawrence Berkeley National Laboratory
LED	Light-Emitting Diode
Low-E	Low emissivity windows, which transmit less heat than ordinary glass
LPD	Lighting Power Density
LADWP	Los Angeles Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory
LED	Light-Emitting Diode
Low-E	Low emissivity windows, which transmit less heat than ordinary glass
LPD	Lighting Power Density
MH	Metal Halide lighting
MTLC	Multitenant Light Commercial Buildings include single and multi-story buildings that are typically mixed-use, low-rise developments with offices, retail shops, and other spaces on various floors.
MUSH	Municipalities, Universities, Schools, and Hospitals
M&V	Measurement and Verification
NIST	National Institute for Standards and Technology
OAT	Outdoor Air Temperature
OBF	On-Bill Financing allows utility customers to access third-party financing for energy efficiency retrofits and repay them back on their utility bills.
OBR	On-Bill Repayment is a CPUC On-Bill financing program.
PAC	Program advisory committee for the Integrated Retrofit Solutions for the MTLC Market project.
PACE	Property Assessed Clean Energy programs allow local governments to create financing districts to allow residential and non-residential owners to finance energy efficiency retrofits to their buildings and on-site generation and repay through a voluntary assessment on their property taxes.

Term	Definition
PEA	Preliminary Energy-Use Analysis is the most basic energy audit and involves an analysis of historic energy use and costs. Energy use is typically benchmarked or compared against similar buildings.
PG&E	Pacific Gas and Electric
PGL	Preservation Green Lab
PIR	Passive Infrared, a method for occupancy sensing
PRE	Condenser Air Pre-coolers are used to improve the efficiency of existing vapor-compression equipment.
ProspectNow	A real estate database that lists property data associated with assessor parcel information.
R&D	Research and development
R&S	Retail and service
REIT	Real Estate Investment Trust is a company that owns or finances income-producing real estate.
RILA	Retail Industry Leaders Association
ROI	Return On Investment
RTU	Roof-Top Unit is a commercial air handling unit that heats and cools air.
R-value	R-value is a metric used to represent the thermodynamic conduction properties of a building's wall, ceiling, and floor construction.
SBA	Small Business Administration loans are very low interest rate loans.
SEER	Seasonal Energy Efficiency Ratio
Smart Grid	Smart Grid is the thoughtful integration of intelligent technologies and innovative services that produce a more efficient, sustainable, economic, and secure electrical supply for California communities.
SCE	Southern California Edison
SCGC	Southern California Gas Company
SDG&E	San Diego Gas & Electric
SHGC	Solar Heat Gain Coefficient is the fraction of solar radiation admitted through a window, door, or skylight—either transmitted directly and/or absorbed—and subsequently released as heat inside a

Term	Definition
	building. It is expressed as a number between 0 and 1, with lower values indicating less solar heat transmittance.
SMUD	Sacramento Municipal Utility District
SPD	Spectral Power Distributions
sq-ft	square feet
SUPPP	Stanford University Public Policy Practicum
SWEEP	Southwest Energy Efficiency Project
TATI	Technical Assistance and Technology Incentives Program
TDD	Tubular Daylighting Devices
TLED	Tubular LED
TMY	Typical Metrological Year is a collection of selected weather data for a specific location that represents the range of weather phenomena for a location, while still being consistent with long-term averages.
TRC	Total Resource Cost is a test that compares the benefits of a retrofit measure to society with the cost of installing the identified measure.
TSS	Target Stakeholder Survey conducted as part of this research project to gather information on perceptions of energy-efficient solutions from utility representatives who serve the MTLC market and stakeholders who own, manage or lease the properties.
UC	University of California
USPS	United States Postal Service
U-Value	U-Factor measures heat loss of a window assembly. The lower the U-factor, the greater a window's resistance to heat flow and the better its insulating properties.
VFD	Variable Frequency Drive
VT	Visible Transmittance measures the amount of light a window lets through. It is measured on a scale of 0 to 1, with higher values indicating more visible light.
WCEC	Western Cooling Efficiency Center at the University of California, Davis.
W	Watt

Term	Definition
WWR	Window to Wall Ratio is a ratio of window (glazing) area to wall area.
ZNE	Zero Net Energy is where the net amount of energy produced by on-site renewable energy sources is equal to the value of the energy consumed by a building.

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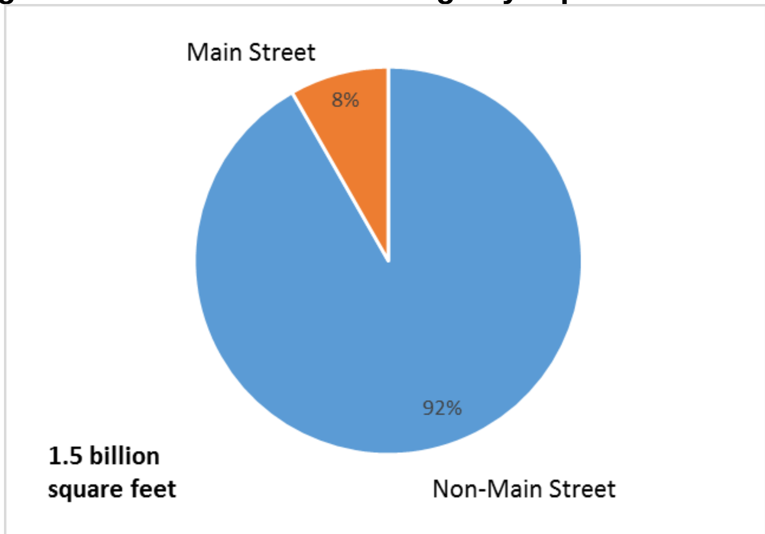
APPENDIX A: Segmentation Process

Segmentation Step 1: "Main Street" Buildings

The first step in the team's segmentation process was to identify "Main Street" buildings or buildings with historical significance. "Historical Significance" is not a common category for energy analyses; however, research conducted by Preservation Green Lab (PGL) demonstrated its widespread applicability for small commercial buildings (Huppert, 2013). PGL found that buildings located in historical downtown districts were typically constructed before WWII and built next to each other. PGL noted that "Buildings typical of Main Street style commercial districts are especially noteworthy because they are energy intensive and offer significant potential for deep energy savings due to their unique physical features. The close relationships between owners and occupants also help to alleviate a significant barrier to entry in this market (Huppert, 2013)." UC Davis auditors, gathering research data on MTLC buildings as part of this project, also found this observation to be true (see Section 2.4.1). For these reasons, the team used Main Street/non-Main Street buildings as a factor to segment the MTLC market.

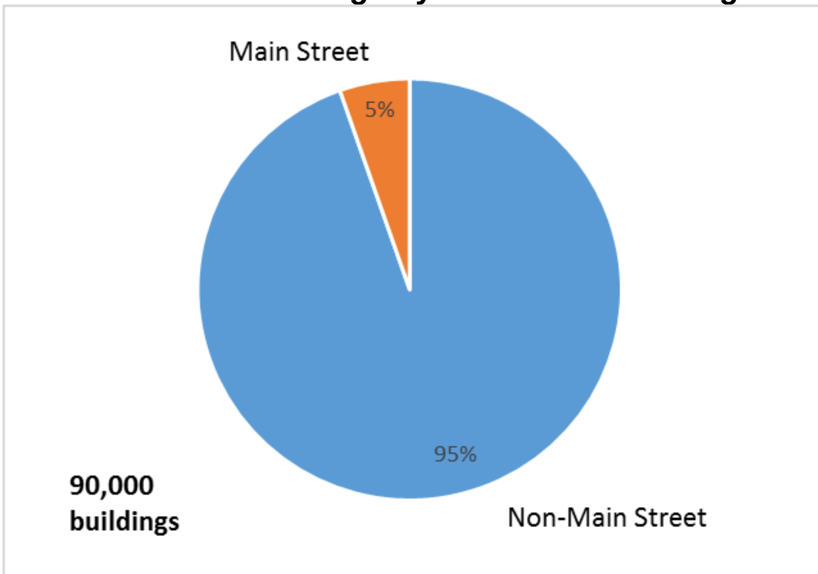
Using the federal 2003 Commercial Buildings Energy Consumption Survey (CBECS) data, the team found that Main Street buildings comprise roughly 8 percent, and non-Main Street buildings 92 percent, of all commercial buildings in California in terms of square feet (sq-ft) (see Figure A-1). The team also found that Main Street buildings comprise 5 percent, and non-Main Street buildings 95 percent, of commercial buildings in terms of number of buildings (see Figure A-2).

Figure A-1: Main Street Buildings by Sq-Ft in California



Source: UC Davis EEC

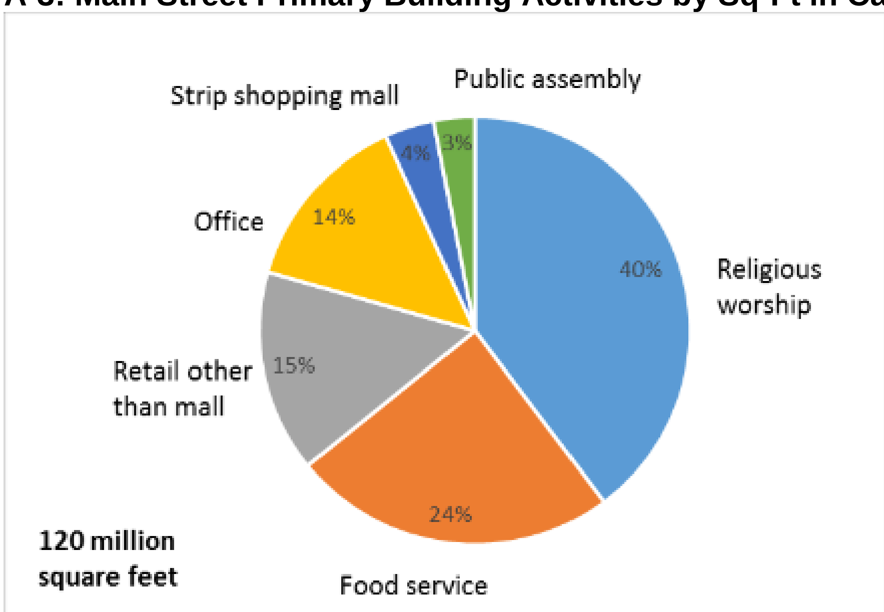
Figure A-2: Main Street Buildings by Number of Buildings in California



Source: UC Davis EEC

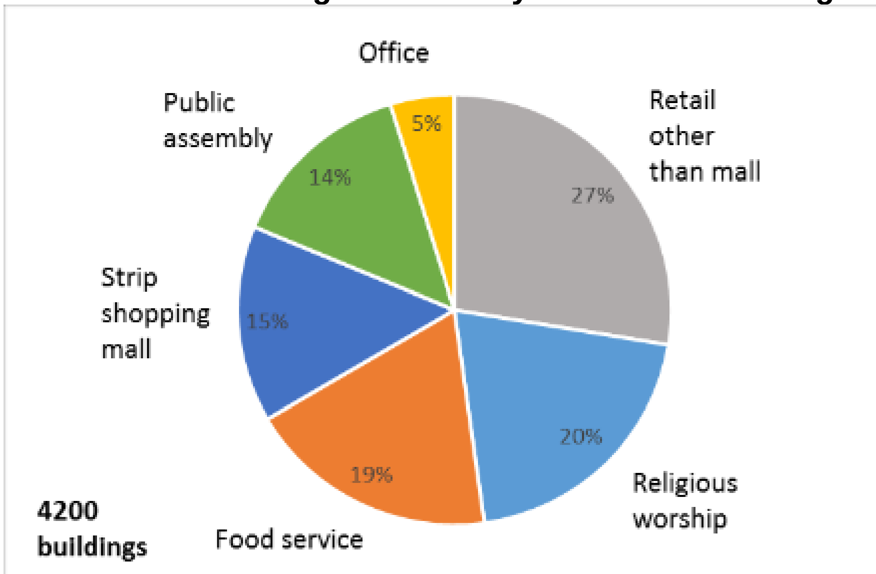
In addition, researchers found that Main Street buildings in California are diverse, making the segment complex to address in terms of energy efficiency without highly specific, expensive solutions (see Figure A-3 and Figure A-4). Because Main Street buildings comprise a small portion of the market and are diverse, the team focused its work on non-Main Street buildings in California.

Figure A-3: Main Street Primary Building Activities by Sq-Ft in California



Source: UC Davis EEC

Figure A-4: Main Street Building Activities by Number of Buildings in California



Source: UC Davis EEC

Segmentation Step 2: Sub-Segmenting non-Main Street buildings

The team divided non-Main Street buildings into four sub-segments:

- Office buildings (often multiple establishments operating as a single unit, such as an office park or large corporate campuses).
- Municipalities, Universities, Schools, and Hospitals (MUSH) buildings (often multiple buildings operating as a single unit, such as university or medical campuses).
- Retail and Service buildings.
- Miscellaneous buildings (all others).

The team chose to divide buildings into these sub-segments due to key differences in terms of application and success of energy efficiency retrofits. For example, while there are many market-based service solutions addressing energy efficiency in Office and MUSH sectors, researchers found that retrofits in retail and service buildings are primarily driven by utilities through third-party and direct install (DI) programs. The team also found that much of the success in terms of energy efficiency in the Office and MUSH sectors is due to the homogeneity in installed equipment and energy end-uses, as well as scale. Many Office and MUSH buildings operate as a single unit with a designated energy manager. Researchers found that the scale of these commercial units, as well as the fact that the majority of these buildings are owner-occupied, make energy efficiency investments more attractive.

Using 2003 CBECS data, the team divided non-Main Street buildings into the four sub-segments based on their primary activity (see Table A-1).

Table A-1: CBECS Primary Building Activity Descriptions and Corresponding Sub-segments

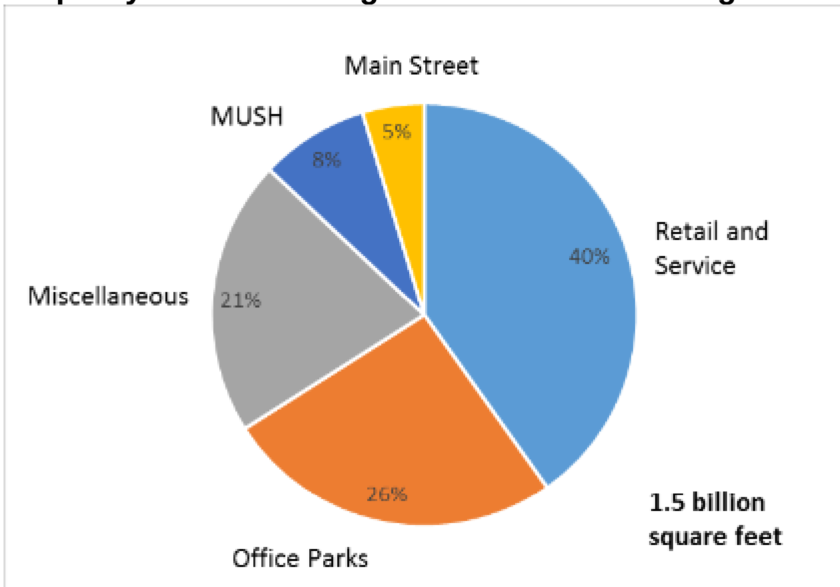
Primary Building Activity	Description	Segmentation Label
Education	Buildings used for academic or technical classroom instruction, such as elementary, middle, or high schools; and classroom buildings on college or university campuses. Career and vocational training buildings are included as well.	MUSH
Nursing	Nursing homes.	MUSH
Outpatient health care	Buildings used as diagnostic and treatment facilities for outpatient care. Medical offices are included if they use any type of diagnostic medical equipment. Veterinarian facilities are included as well.	MUSH
Public order and safety	Buildings used for the preservation of law and order or public safety; examples include police stations, fire stations, jails, and courthouses.	MUSH
Office	Buildings used for general office space, professional office, or administrative offices; examples include corporate offices, government offices, banks, non-profits, and religious offices.	Office
Laboratory	Buildings used for laboratory spaces.	Miscellaneous
Lodging	Buildings used to offer multiple accommodations for short-term or long-term residents; examples include hotels, convents, shelters, and orphanages.	Miscellaneous
Non-refrigerated warehouse	Buildings used to store goods, manufactured products, merchantdise, raw materials, or personal belongings that are non-refrigerated.	Miscellaneous
Other	Buildings that are industrial or agricultural with some retail space. Buildings having several different commercial activities that, together, comprise 50 percent or more of the floorspace, but whose largest single activity is agricultural, industrial/ manufacturing, or residential. All other miscellaneous buildings that do not fit into any other category.	Miscellaneous
Public assembly	Buildings in which people gather for social or recreational activities, whether in private or non-private meeting halls; examples include community	Miscellaneous

Primary Building Activity	Description	Segmentation Label
	centers, gymnasiums, bowling alleys, libraries, and exhibition halls.	
Religious worship	Buildings in which people gather for religious activities, such as chapels, churches, mosques, synagogues, and temples.	Miscellaneous
Vacant	Buildings in which more floorspace was vacant than was used for any single commercial activity. A vacant building may have some occupied floorspace.	Miscellaneous
Enclosed mall	Shopping malls comprised of multiple connected establishments, which are enclosed.	Retail and service
Food service	Buildings used for preparation and sale of food and beverages for consumption; examples include fast food establishments and restaurants.	Retail and service
Retail other than mall	Buildings used for the sale and display of goods other than food; examples include retail stores, liquor stores, studios, and car dealerships.	Retail and service
Service	Buildings in which some type of service is provided, other than food service or retail sales of goods; examples include mechanic shops, car barns, repair shops, dry cleaners, post offices, beauty parlors, and gas stations.	Retail and service
Strip shopping mall	Shopping malls comprised of multiple connected establishments, which are open-air.	Retail and service

Source: CBECS

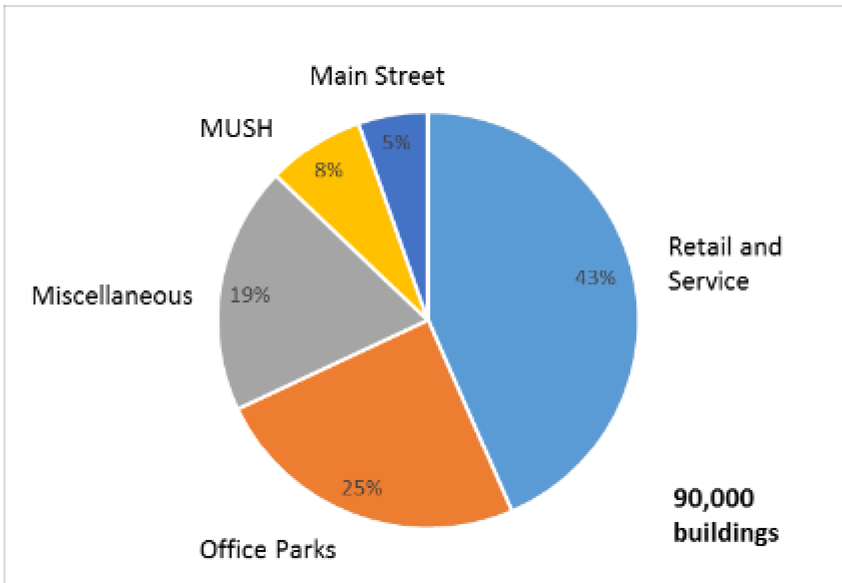
In analyzing the data, researchers found retail and service buildings comprise the largest portion of MTLC buildings in terms of sq-ft (40 percent), followed by office buildings (26 percent), miscellaneous buildings (21 percent), MUSH buildings (8 percent), and Main Street buildings (5 percent) (see Figure A-5). The team found similar results in terms of number of MTLC buildings: retail and service buildings comprise 43 percent of the market, followed by office buildings at 25 percent, miscellaneous buildings at 19 percent, MUSH buildings at 8 percent, and Main Street buildings at 5 percent (see Figure A-6).

Figure A-5: Sq-ft by Multitenant Light Commercial Sub-segment in California



Source: UC Davis EEC

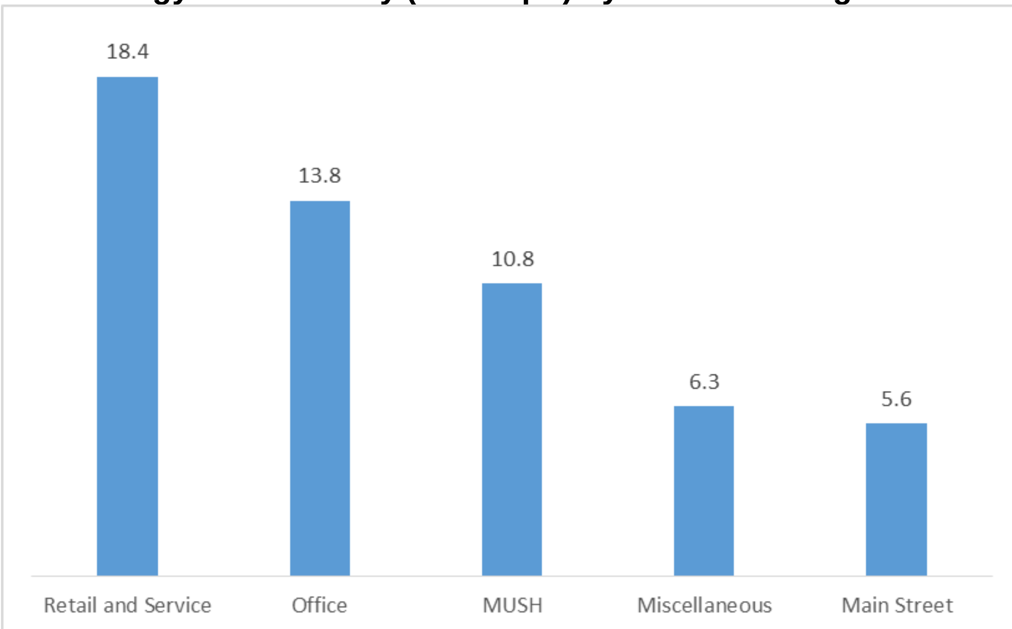
Figure A-6: Number of Buildings by Multitenant Light Commercial Sub-segment in California



Source: UC Davis EEC

Researchers also analyzed energy use intensity by sub-segment (see Figure A-7). They found retail and service buildings have the largest energy use intensity (18.4 kWh/sq-ft), followed by office buildings (13.8 kWh/sq-ft), MUSH buildings (10.8 kWh/sq-ft), miscellaneous buildings (6.3 kWh/sq-ft), and Main Street buildings (5.6 kWh/sq-ft). Because retail and service buildings comprise the largest portion of the MTLC market in terms of sq-ft, number of buildings, and energy use intensity, the team focused its work on retail and service buildings in California.

Figure A-7: Energy Use Intensity (kWh/sq-ft) by MTLC Sub-segment in California

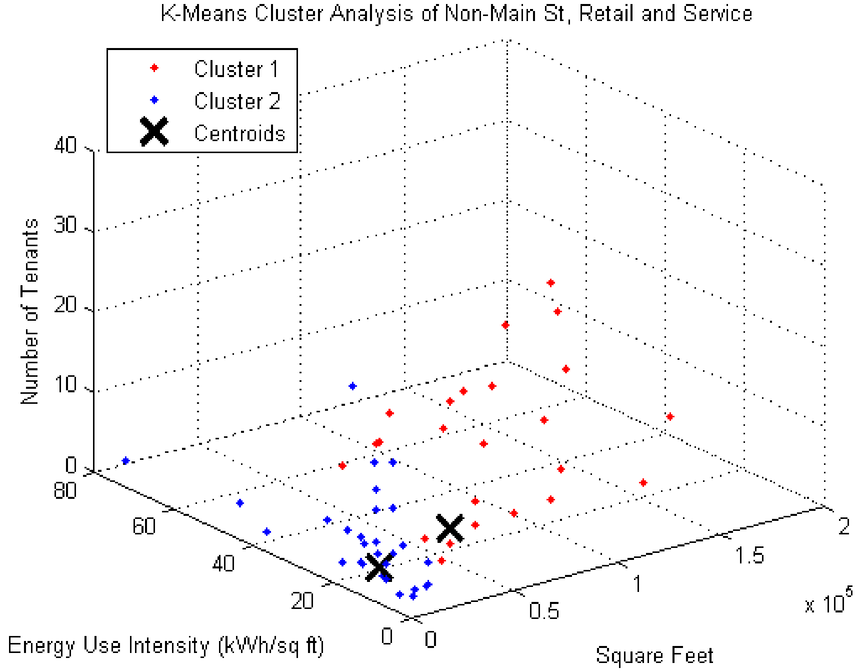


Source: UC Davis EEC

Segmentation Step 3: Sub-Segmenting Retail and Service Buildings

With a focus on retail and service buildings, the team further segmented this building stock because of its broad range of attributes. Based on input from industry experts (Appendix B), as well as previous research in this area, the team identified three attributes—building sq-ft, number of building tenants, and EUI—to partition retail and service buildings into "types" or "clusters" of buildings that have similar characteristics. Based on these attributes, the team preformed K-means clustering analysis to partition retail and services buildings into two clusters. Figure A-8 shows the grouping of buildings into two clusters, where each color represents a different cluster of buildings. Table A-2 outlines the key characteristics of each cluster. Based on these characteristics, the team characterized cluster 1 as "small retail and service" and cluster 2 as "medium retail and service."

Figure A-8: K-Means Clustering Output



Source: UC Davis EEC

Table A-2: Cluster Analysis Results (Sq-Ft, EUI, Number of Tenants)

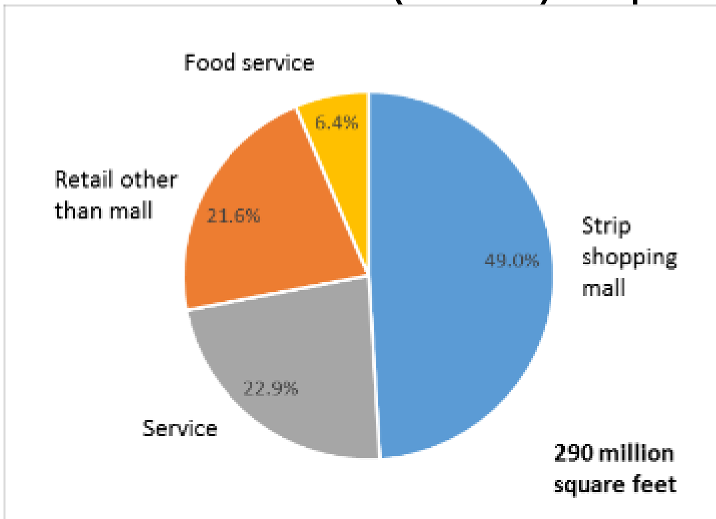
Cluster	Avg Sq-Ft	Min Sq-Ft	Max Sq-Ft	Avg EUI	Min EUI	Max EUI	Avg Ten-ants	Min Ten-ants	Max Ten-ants
1	8,768	1800	26,000	20.3	1.6	75.9	4.3	2	23
2	51,608	31,500	160,000	16.9	4.8	45.4	7.4	2	31

Source: UC Davis EEC

Segmentation Step 4: Adopting the International Council of Shopping Centers Definitions

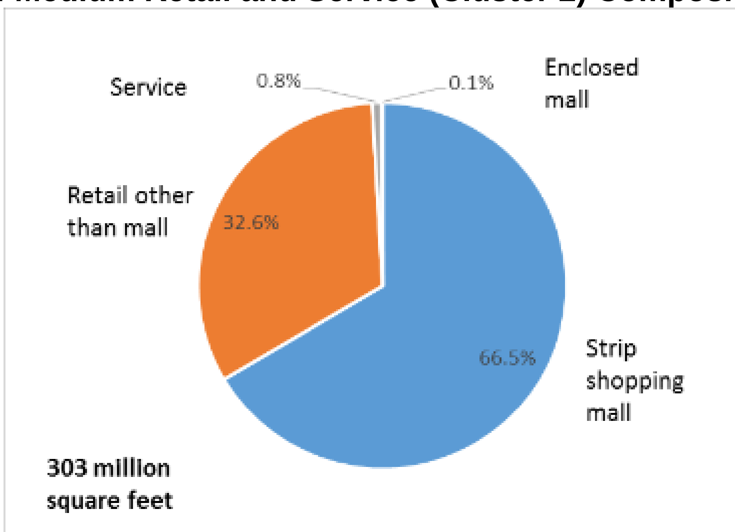
The two groups identified in Step 3 could serve as key archetypes of the MTLC sector, however, the team observed that a high percentage of retail and services buildings were located together as part of a commercial establishment, mostly in open air shopping centers (see Figure A-9 and Figure A-10).

Figure A-9: Small Retail and Service (Cluster 1) Composition by Sq-Ft



Source: UC Davis EEC

Figure A-10: Medium Retail and Service (Cluster 2) Composition by Sq-Ft



Source: UC Davis EEC

The International Council for Shopping Centers (ICSC) defines shopping centers as "a group of commercial establishments planned, developed, owned and managed as a single unit related in location, size and type of shops to the trade area it serves. It provides on-site parking relating to the types and sizes of stores" (ICSC & ULI, 2006). ICSC divides the 114,900 shopping centers in the United States into five general-purpose types based on square-footage: 1) Super-Regional Mall, 2) Regional Mall, 3) Community Center, 4) Neighborhood Center, and 5) Strip/Convenience Center.[35]

35 http://www.icsc.org/uploads/research/general/US_CENTER_CLASSIFICATION.pdf

Taking into account the definitions of the five different types of shopping centers, the team evaluated how buildings in the two groups (small and medium retail and service buildings) were related to three of the five most relevant types of shopping centers: Convenience Shopping Centers, Neighborhood Shopping Centers, and Community Shopping Centers. To evaluate this relationship, researchers randomly selected a sub-sample of 30 shopping centers from the CBECS micro data. The team then used Google square footage calculating tools to estimate the total gross leasing area (GLA) and the square-footage of each building within each shopping center. Based on the GLA estimates, researchers classified shopping centers as "Convenience," "Neighborhood," or "Community" shopping centers as per the respective ICSC definitions. In addition, researchers classified each building in each shopping center as "small" or "medium," as per the definitions established by the team's cluster analysis. Based on these analyses, the team found that the typical "Convenience" shopping center consisted of 1.5 buildings, composed of 100 percent "small" buildings; the typical "Neighborhood" shopping center consisted of 2.5 buildings, composed of 80 percent "small" and 20 percent "medium" buildings; and the typical "Community" shopping center consisted of 3 buildings, composed of 65 percent "small," 22 percent "medium," and 13 percent "other (large)" buildings (see Table A-3). Given the strong correspondence between the team's clusters and the ICSC definitions, the team decided to use the ICSC definitions as key archetypes for the MTLC market.

Table A-3: Composition of Shopping Centers

Shopping Center Type	Small	Medium	Large
Convenience	100%	0%	0%
Neighborhood	80%	20%	0%
Community	65%	22%	13%

Source: UC Davis EEC

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Appendix B: Program Advisory Committee Members

Last Name	First Name	Organization
Adams	Josiah	Ecology Action
Ahmed	A. Y.	Southern California Gas Company
Aldridge	Mahlon	Ecology Action
Ander	Gregg	Energy Foundation
Delaney	Paul	Southern California Edison
Finlay	James	Wells Fargo Bank - RETECHS
Frankel	Paul	CalCEF
Harris	Daniel	New Building Institute
Hunt	Marshall	Pacific Gas and Electric Company
Jackson	Bill	Tennessee Valley Authority
Jacot	David	Los Angeles Department of Water and Power
Penafiel	Karen	Building Owners and Managers Association
Siegel	Adam	Retail Industry Leaders Association
Teichman	Will	Kimco Realty Corporation
Weightman	David	California Energy Commission
Ander	Gregg	Southern California Edison
Kruse	Jane	Pacific Gas and Electric Company

APPENDIX C:
Energy Audits

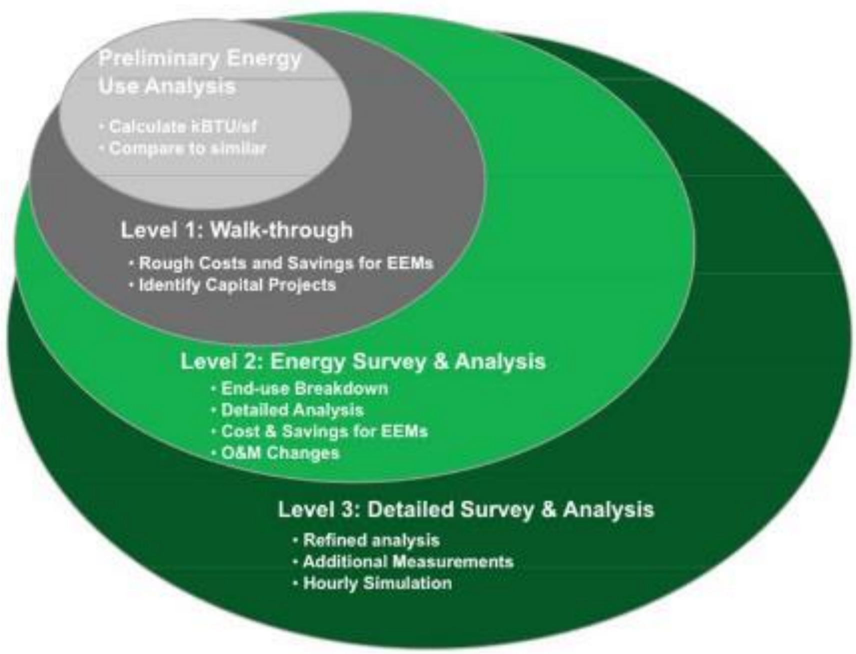
ASHRAE Level of Effort

Introduction

The goals of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) procedure are to define the level of effort for an energy audit and present the best practices in audit procedures. Detailed information about data gathering, energy analysis, and reporting are also provided.

There are three codified levels of effort for an energy audit. In addition, the ASHRAE manual defines the characteristics of the preliminary energy-use analysis and it defines the targeted audit (ASHRAE, 2011). Figure C-1 shows the main characteristics of the different levels of audits.

Figure C-1: Main Characteristics of Level 1, 2, 3 Energy Audits



Source: ASHRAE, 2011

Preliminary Energy-Use Analysis

Before visiting the site, the energy auditor should perform a Preliminary Energy-Use Analysis (PEA). In this phase, the energy use, peak demand, and energy cost are measured (using interval meter data if possible) and metrics such as energy use intensities (EUI) and energy cost intensities (ECI) are calculated. The building is then benchmarked against similar buildings using EPA Portfolio Manager[36], Lawrence Berkeley National Laboratory (LBNL) Energy IQ[37], or other databases. A target energy use is then defined.

Level 1: Walk-Through

The level 1 energy audit is a walk-through audit. The building is quickly inspected and no-cost/low-cost measures are identified. Maintenance issues should also be collected. Savings are estimated with low accuracy and systems that deserve a deeper investigation are listed. The auditor should match this list with the planned capital improvements described by the customer. The auditor should also suggest utility rate changes when appropriate.

Level 2: Energy Survey and Analysis

Level 2 audits consist of a more thorough survey of the building energy systems, including spot or short-time measurements. The main goal is to break down energy consumption by end-use (such as lighting, cooling, heating, and so on) and provide accurate estimates of energy and cost savings. Savings might come from implementation of energy efficiency measures and changes in operations and maintenance procedures. The auditor should also provide a list of capital intensive retrofits that need further analysis (for example a longer period of data collection or more detailed modeling).

Level 3: Detailed Analysis of Capital Intensive Modifications

A level 3 audit is needed for capital intensive projects. It entails detailed field-data gathering and more rigorous engineering and economic analysis. It also frequently includes hourly simulations and a supplier request for offer (RFO) for expensive equipment. Life-cycle cost tools are used to analyze the economics of potential projects.

Targeted Audit

A targeted audit is an investigation of a single specific system or part of the building (for example lighting only or an individual chiller). It allows for more in-depth analysis than the other audit levels.

Table C-1 and Table C-2 detail the process and report requirements for the three audit levels according to ASHRAE procedure.

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36 http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager

37 http://energyiq.lbl.gov/

Table C-1: Required Tasks for Level 1, 2, 3 Energy Audits

Process	Level 1	Level 2	Level 3
Conduct PEA	•	•	•
Conduct walk-through survey	•	•	•
Identify low-cost/no-cost recommendations	•	•	•
Identify capital improvements	•	•	•
Review mechanical and electrical design and condition and O&M practices		•	•
Measure key parameters		•	•
Analyze capital measures (savings and costs, including interactions)		•	•
Meet with owner/operators to review recommendations		•	•
Conduct additional testing/monitoring			•
Perform detailed system modeling			•
Provide schematic layouts for recommendations			•

Source: ASHRAE, 2011

Table C-2: Required Report Items for Level 1, 2, 3 Energy Audits

Process	Level 1	Level 2	Level 3
Estimate savings from utility rate change	•	•	•
Compare EUI to EUIs of similar sites	•	•	•
Summarize utility data	•	•	•
Estimate savings if EUI were to meet target	•	•	•
Estimate low-cost/no-cost savings		•	•
Calculate detailed end-use breakdown		•	•
Estimate capital project costs and savings		•	•
Complete building description and equipment inventory		•	•
Document general description of considered measures		•	•
Recommend measurement and verification method		•	•
Perform financial analysis of recommended EEMs		•	•
Write detailed description of recommended measures			•
Compile detailed EEM cost estimates			•

Source: ASHRAE, 2011

ASHRAE Data Collection by Energy Audit Level

Preliminary Energy Analysis

One or more years of energy bills should be collected. For each billing period (month) the following information should be extracted and calculated (Table C-3):

- Electric demand peak (kW)
- Electricity Use (kWh)
- Number of days in the billing period
- Electricity Use/Day (kWh/day)
- Electricity cost ($)
- Electricity average cost ($/kWh)
- Load Factor
- Gas Use (therms)
- Gas cost ($)

Table C-3: Bill Information Collected and Calculated During Preliminary Energy Analysis

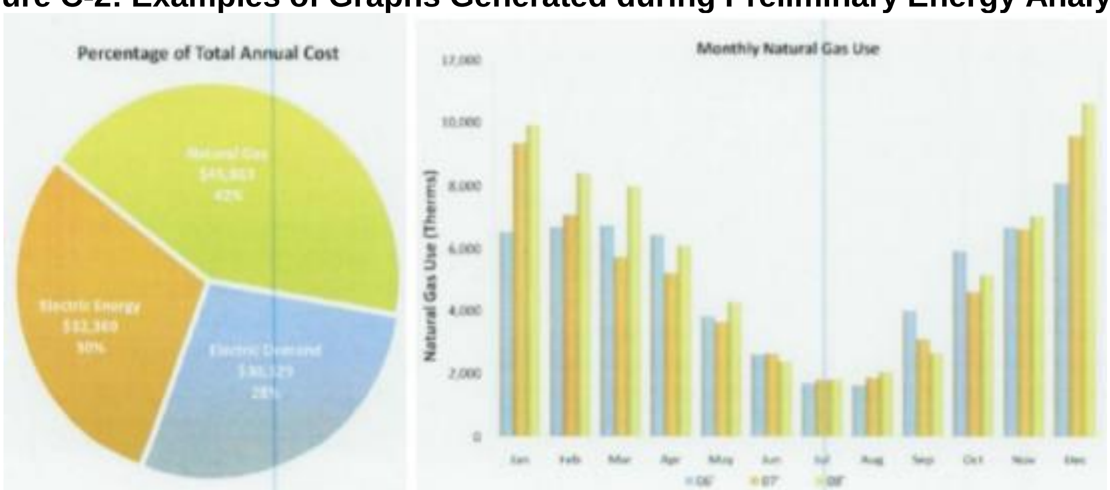
Bill #	Month	Year	Days	Electric Demand Peak kW	Electric Use kWh	Electric Use kWh/day	Electric Cost $	Load Factor
8	Jan	2006	34	163	87,680	2,579	$5,923	66%
9	Feb	2006	29	165	80,480	2,775	$5,483	70%
10	Mar	2006	29	165	79,360	2,737	$5,462	69%
11	Apr	2006	28	163	74,720	2,669	$5,249	68%
12	May	2006	29	165	79,520	2,742	$4,986	69%
13	Jun	2006	32	168	94,240	2,945	$5,368	73%
14	Jul	2006	31	173	91,840	2,963	$5,434	71%
15	Aug	2006	28	165	82,080	2,931	$5,013	74%
16	Sep	2006	32	163	88,000	2,750	$5,019	70%
17	Oct	2006	29	179	80,320	2,770	$4,880	64%
18	Nov	2006	29	173	76,800	2,648	$4,617	64%

Bill #	Month	Year	Days	Electric Demand Peak kW	Electric Use kWh	Electric Use kWh/day	Electric Cost $	Load Factor
19	Dec	2006	33	184	91,360	2,768	$5,206	63%
20	Jan	2007	36	179	95,680	2,658	$5,652	62%
21	Feb	2007	29	165	79,680	2,748	$5,096	69%
22	Mar	2007	29	173	77,440	2,670	$5,132	64%
23	Apr	2007	31	173	80,640	2,601	$5,107	63%

Source: ASHRAE, 2011

This information is graphed in Figure C-2 to show how energy cost is distributed among utility type (gas, energy use, energy peak, and so on), as well as trends in energy use in different years and in relationship to average outdoor temperature. The current utility rate structure should also be analyzed to understand if the customer should change energy tariffs.

Figure C-2: Examples of Graphs Generated during Preliminary Energy Analysis



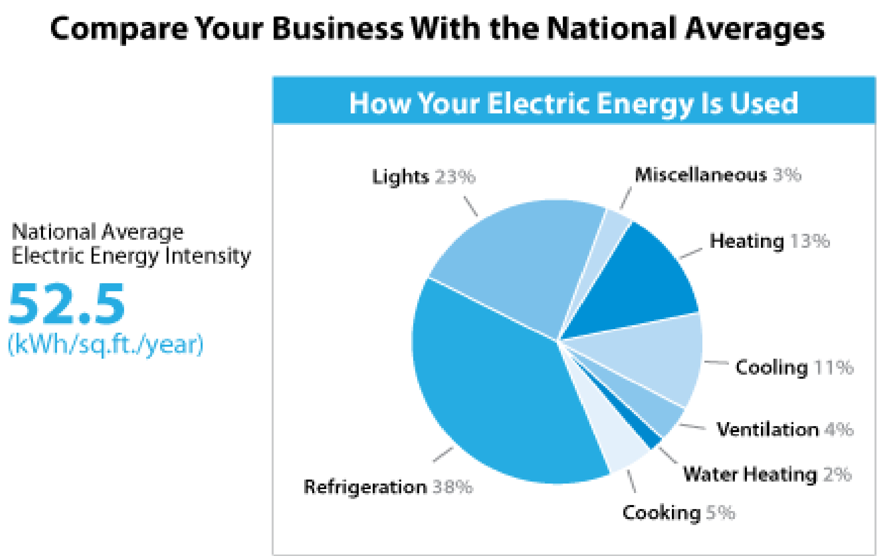
Source: ASHRAE, 2011

Level 1 Analysis

Level 1 analysis consists of using benchmarking tools to compare the facility with similar buildings. If the building uses significantly more energy than its peers after normalization by floor area, weather, and occupancy, then opportunities to save energy may exist. Common tools used for this purpose are Energy Star Portfolio manager (Figure C-3) or LBNL Energy IQ (Figure C-4). In order to perform this comparison, it is necessary to collect additional information:

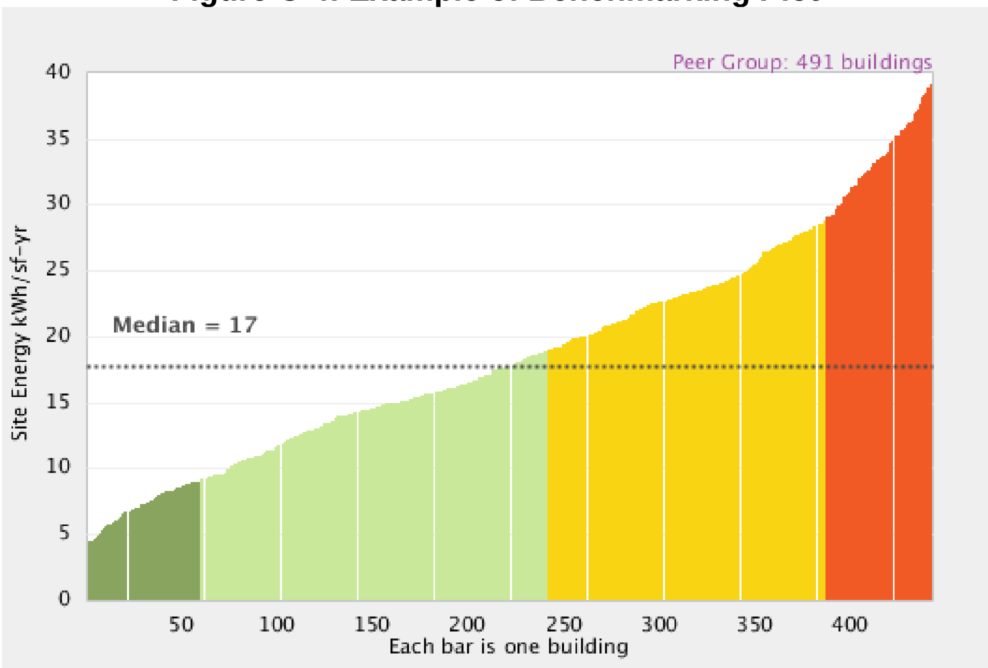
- Building space types (restaurant, retail, and so on)
- Year of construction
- Location (zip code, city, climate zone, weather)
- Occupancy (hours of operation, holidays)
- Gross floor area (since the comparison is usually normalized by area)

Figure C-3: Example of Benchmarking and End-Use Disaggregation



Source: Energy Star

Figure C-4: Example of Benchmarking Plot



Source: Lawrence Berkeley National Laboratory Energy IQ

If smart meter data is available, the energy analysis can be more sophisticated. Several researchers and private companies are developing advanced tools for analytics and diagnostics. Some of them claim to be able to recommend a retrofit without visiting the site.[38] These tools are in their infancy and still have to prove their efficacy and reliability. With more traditional tools, limited retrofits options can be recommended without a site survey since technologies currently installed (lighting, HVAC) are unknown.

Level 2 Audit

When a level 2 audit is performed, the following documentation should be collected in order to identify the major loads, and to understand equipment efficiency and control strategies:[39]

- As-built drawings
- Equipment inventory
- Test reports
- Controls schedule
- Maintenance logs
- Satellite view of the building

The ASHRAE procedure book includes several Excel templates that can be used to fill data during the site visit or afterwards (ASHRAE, 2011). The Washington State University (WSU) also developed a checklist/spreadsheet for energy audits that can be used to conduct the energy analysis.[40] Energy consultants usually use their own spreadsheets to collect and analyze data, but it is not uncommon to write notes on paper and then transcribe them in electronic form. Since this process is time consuming, some companies are developing productivity tools that allow auditors to record data during the site visit with tablets/mobiles in a form that is ready for further analysis, such as savings calculation, hourly simulations, or application for rebates.[41,]

Below we describe the tasks that should be performed during a site visit in a level 2 energy audit and the tools that should be used. This list is limited to general information, lighting, HVAC, and building envelope because these systems are of primary interest for the MTLC project. Additional information can be found in the ASHRAE procedure.

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38 http://firstfuel.com/home.

39 http://www.energy.wsu.edu/Documents/OMchecklists.pdf

40 See footnote 55

41 http://www.empoweredenergysolutions.com

Gather General Building Information

The tasks for this step are to verify drawings, identify tenants and facility staff, and observe use patterns (such as occupancy, services, and customers in retail). Tools to properly investigate include:

- ID/business card
- Digital camera
- Calculator/phone
- Notepad (survey form)
- Clipboard
- Personal protection equipment
- Rags
- Flashlight
- Multi-tool
- Spreadsheet (optional)

ASHRAE or WSU spreadsheets could be used from the beginning to collect data if a computer or tablet is available. Drawings should show the year of construction, orientation, and size (number of floors and square footage) for each building. Location of utility meters and mechanical and electrical rooms should also be indicated, as well as a profile of glazing in each room. When possible, it is useful to schedule a site visit at night to identify phantom loads and areas and systems in use, interview the custodial crew, and test the operation of economizers, occupancy sensors, and so on. Interviews should focus on understanding building schedule, age of the equipment, known performance and maintenance issues, and comfort requirements.

Lighting

The tasks for this component of the site visit are to conduct a lighting inventory, record existing light levels, identify control systems (manual switches, occupancy sensors, timers), and gather control strategies (schedules, control sequences). Tools to properly assess lighting include:

- Illuminance meter
- Flicker checker (Sylvania: 800.544.4828)
- Occupancy sensors (logger)
- Light logger

Conducting a lighting inventory is a time-consuming, but relatively simple process. The auditor should also collect existing lighting levels to assess the opportunity for de-lamping.

Heating, Ventilation, and Air Conditioning

The tasks for assessing HVAC equipment during a site visit are:

- Understand system configuration
- Identify equipment location
- Gather equipment information (nameplate data, sample of actual operation performances)
- Identify control systems information (thermostats, building automation system, other controls)
- Gather control strategies (setpoints, schedules, control sequence)
- Identify thermal zones (zone-equipment-control relationship)
- Identify installation problems (such as exposed ducts)

The requisite tools for the HVAC assessment include:

- Simple toolkit
- Building floor plans
- Satellite map of the building to identify location of RTUs
- Digital camera
- Notepad (audit forms) and clipboard
- Thermometer and humidity meter
- Infrared temperature meter (optional)
- Infrared camera (optional)
- Temperature sensor (logger)
- Runtime sensors (logger for compressors and fans)
- Occupancy sensor (logger)
- Spreadsheet (optional)

During Level 2 audits a combination of spot and short-term measurements are conducted for HVAC equipment. Spot measurements include room and surface temperatures, while short-term measurements include runtime of equipment and motors. Usually at least 2 weeks of data are collected.

Envelope

The tasks for assessing the building envelope during a site visit are to understand structure types; measure U-factor of walls, roof, and floors; document window and door types, area, and orientation; document wall infiltrations; and measure reflectance of the roof. It is easier to retrieve characteristics of windows and walls directly from the drawings, while infiltration rates require a blower-door test. These tests can be difficult to perform during opening hours in commercial buildings.

Energy Calculations

End-use energy data collected during the site visit should be calibrated with the real energy use from the bills. Different tools are available to match up the two. The most accurate would be an hourly simulation tool such as Energy Plus. However, creating a calibrated model of a specific building may be too expensive. On the other hand, the interaction between retrofits must be taken into account. For instance, improving efficiency of the lighting system usually decreases the cooling load and increases the heating load. This would impact the efficacy of a HVAC retrofit deployed at the same time. A simplified method to deal with this issue is under study.

Level 3 Audits

Level 3 audits are investment grade audits for large scale projects and are outside the scope of this project.

Energy Audit Programs

Investor-Owned Utility Audit Programs

Pacific Gas and Electric

The audit programs offered by PG&E for small and medium commercial customers focus on interactive energy management tools that are administered through the company website. The most basic tool is called the "Business Energy Checkup," which requires answering a 5-question survey and offers users ways to observe monthly spending, compare spending to similar sized businesses, track estimated energy usage by type of equipment, receive customized energy saving recommendations (with estimated savings), and create a customized energy savings plan. This quick, do-it-yourself assessment can also be completed over the phone with the help of a PG&E representative.

The next level of analysis available is a benchmarking tool that interfaces with EPA's ENERGY STAR Portfolio Manager tool, if the building qualifies for comparison. This tool allows users to track and assess energy and water consumption for individual buildings. It generates weather-normalized energy intensity (kBtu/sq-ft) and greenhouse gas emissions metrics for all buildings, as well as a percentile energy performance score for many eligible building types. In addition to the online tool, PG&E also offers benchmarking workshops and webinars. On-site audits are offered only to large customers.

Southern California Edison

Similar to PG&E, SCE offers several do-it-yourself audits and energy analyses through their website, including a survey and benchmarking (also using the ENERGY STAR Portfolio Manager tool). Advanced online tools (SCE Energy Manager) are available too, but only for medium and large customers whose demands exceeded 200 kW at least three times in the past 12 months. MTLC buildings are unlikely to qualify for this program.

A unique feature of SCE's program offerings, compared to PG&E, is the central role of third-party contractors in analyzing energy use and performing retrofits. The Continuous Energy Improvement program provides businesses with a dedicated energy expert to help assess, plan, implement, evaluate, and modify their energy strategies, at no cost. The energy advisor spends two years with the customer and coaches them through a comprehensive organizational and technical assessment, strategic energy planning, action plan implementation, evaluation of measured savings, and modification of plans, as needed, to provide continuous improvement in energy performance.

SCE also manages an HVAC-specific program called the HVAC Optimization Program that combines an aggressive maintenance plan with financial incentives. The program begins with an inspection of the customer's HVAC system by a contractor who then helps identify performance objectives and designs a maintenance plan that adheres to Standard 180.[42]

Another unique program managed by SCE is a direct install program that specifically targets small businesses. In this program, SCE sends a contractor to the customer's location. The contractor performs a 5-10 minute on-site energy consultation and then recommends improvements that can help reduce energy usage. SCE then pays for the costs of any installations the customer chooses to make.

San Diego Gas and Electric

Like both PG&E and SCE, SDG&E offers an online self-audit survey to business customers that collects basic billing data and provides recommendations for reducing energy use. Benchmarking through the ENERGY STAR tool is available, as are lists of rebates/incentives and demand response programs. SDG&E runs a direct install program that is very similar to SCE's for commercial rate customers who do not have monthly electrical demand over 100kW for three consecutive months during a twelve-month period.

The unique programs offered by SDG&E are on-site facility evaluations and audit programs that specifically target healthcare and lodging facilities. The on-site programs are offered free to customers using 20 kilowatts (kW) or more of electricity through the Technical Assistance and Technology Incentives (TATI) program.[43] These audits range from simple site assessments to comprehensive engineering studies and are designed to determine load reduction potential and identify energy efficiency opportunities. The healthcare and lodging energy efficiency programs perform audits and coordinate the implementation of energy efficiency projects that focus on HVAC, lighting, control

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42 http://www.hvacoptimization.com/standard

43 http://www.sdge.com/technical-assistance-technology-incentives

systems, boiler/hot water heaters, process loads, and other equipment for healthcare and lodging facilities. Benchmarking is required to participate in these specialized programs.

Municipal Utility Audit Programs

California's two largest municipal utilities–Sacramento Municipal Utility District (SMUD) and Los Angeles Department of Water and Power (LADWP)–also manage a portfolio of programs available to commercial customers.

SMUD's Complete Energy Solutions program coordinates a comprehensive energy assessment by a third-party contractor to evaluate lighting, HVAC, refrigeration, and other systems, and identifies opportunities for customers to save energy and money through other incentive programs. The customer receives a report detailing the recommended efficiency measures and then decides whether or not to install the upgrades. Rebates typically cover up to 80 percent of the project costs for small businesses and 60 percent for mid-size businesses, which results in a payback time after rebates of one to two years.[44]

LADWP does not offer any explicit audit programs, but does run a number of generous business rebate and incentive programs for its non-residential customers, including Commercial Lighting Efficiency, the Custom Performance Program, Chiller Efficiency, Commercial Water Conservation, New Construction, the Non-Residential Custom Express Program, Refrigeration, and Outdoor Area Lighting.[45]

Third-Party Implementers

In addition to the IOUs, Energy Service Companies (ESCOs) also provide energy audit services for commercial buildings in California, some at low or no cost. Several ESCOs specialize in performing audits and offer options covering the full range of ASHRAE levels of effort. [46]These companies conduct audits on site and then provide the client with information and recommendations for improving the efficiency of existing energy systems using other products and services that they provide. ESCOs advertise that clients can reduce their energy consumption by upwards of 60 percent, and advise clients on available rebates/incentives in a manner similar to IOUs. In general, ESCOs offer much more comprehensive audit programs than their IOU counterparts and often use proprietary software developed to benchmark consumption and measure savings. These software packages are also offered as products available for purchase.

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44 https://www.smud.org/en/business/save-energy/energy-management-solutions/complete-energy-solutions.htm

45 https://www.ladwp.com/ladwp/faces/ladwp/commercial/c-savemoney/c-sm-rebatesandprograms?_adf.ctrl-state=8966669tr_45&_afrLoop=433886980343000

46 http://renewage.com/our-services/

References

American Society of Heating Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE). (2011). *Procedures for Commercial Building Energy Audits* (Second ed.): American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

APPENDIX D: Multitenant Light Commercial Toolbox System Requirements

Requirements for EnergyPlus Simulation

To run an accurate simulation, EnergyPlus requires three different files.

- Input data file (IDF)—a comma-separated value (CSV) text file, which contains the detailed building model along with a list of energy consumption variables that will be outputted. The detailed building model is made up of objects within the building, each of which contain several parameters describing the object. The objects cover virtually every parameter in the building including energy consuming equipment, materials used in the building construction, envelope characteristics of the building, and geographical location variables. It is these objects and their parameters that get customized by the MTLC Toolbox, based on user specifications. All of these objects come together to model the building in consideration.
- Input dictionary data file (IDD)—a large text file, containing a dictionary of every possible object and parameter that could potentially be included in the IDF file. The simulation executable matches a specific object in the IDF file to the object definition in the IDD file to check if the IDF object structure matches the dictionary definition. It also uses the dictionary to automatically organize all the objects in the IDF file during runtime. This feature allows the IDF file to be in no specific order.
- Weather file (EPW)—contains several years' worth of real weather data, split hourly into 8,760 temperature points per year. Weather conditions are a huge factor in energy consumption, which is why the weather data file is an important requirement for an accurate EnergyPlus simulation.