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Energy Research and Development Division

**FINAL PROJECT REPORT**

# MarketZero: Taking an Existing Grocery Store to Scalable Near-Zero Net Energy

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# PREFACE

The California Energy Commission's (CEC) 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.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC 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.

*MarketZero:Taking an Existing Grocery Store to Scalable Near-Zero Net Energy* is the final report for Contract Number EPC-15-041 conducted by Prospect Silicon Valley. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/).

# ABSTRACT

MarketZero: Taking an Existing Grocery Store to Scalable Near-Zero Net Energy was a collaboration with Whole Foods Market, Arup, Lawrence Berkeley National Laboratory, the San Francisco Department of the Environment, and Prospect Silicon Valley to design and retrofit an existing San Francisco Whole Foods Market into the world's first zero net energy (ZNE) grocery store. The four-year project targeted grocery stores, one of the "final frontiers" in California's goal towards a ZNE future. The grocery sector represents a major technological challenge for reaching the state's energy efficiency goal to convert 50 percent of existing commercial buildings to ZNE by 2030.

The project site was a 25,187-square-foot Whole Foods Market located in San Francisco's Noe Valley neighborhood. The building had an initial energy use intensity of approximately 215 thousand British thermal units (Btu) per square foot per year (kBtu/ft2/yr). The project team issued an open call for innovations to discover and review new technologies in ZNE commercial buildings specific to energy consumption and refrigeration, for inclusion in the project. The project team selected two new technologies to incorporate into the project. The design team integrated the new technologies and innovative strategies to "design for scale." The team used an innovative genetic algorithm to identify the best set of energy conservation measures for the project and collected data to measure and verify energy usage savings, therefore validating the effect of the project's implementation. The team estimates energy savings of 44 percent from the retrofit, resulting in a final energy use intensity of approximately 120 kBtu/ft2/yr. The project is a major case study to inform a scalable ZNE retrofit approach for both existing and future grocery stores, both in California and elsewhere.

**Keywords**: Zero net energy, energy efficiency, deep energy retrofit, existing commercial building energy retrofit, energy conservation measures

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# EXECUTIVE SUMMARY

## Introduction

Reducing overall energy use, using energy more efficiently, promoting renewable energy sources, and using materials with lower greenhouse-gas (GHG) emissions are all essential strategies in California's efforts to mitigate climate change. Implementing these strategies can also reduce energy costs for both individuals and businesses and ultimately create a healthier environment for all Californians.

A key California goal is improving the energy efficiency of new and existing buildings; the state's commercial buildings is the second largest consumer of electricity and natural gas . The successful pathway for reducing energy use in commercial buildings combines energy efficiency with the on-site generation of renewable energy. The goal is to reach zero net energy, meaning that the amount of energy consumed annually equals the amount of energy generated by a building, finally netting out to zero.

California has adopted zero-net-energy goals for new and existing commercial buildings, to be realized by 2030, by which time half of existing commercial buildings will be converted to zero net energy and all new commercial construction will be zero net energy. Achieving zero net energy in grocery stores and supermarkets — the second-highest energy-consuming commercial building type in both California and the United States — presents unique challenges because of the high energy consumption required by refrigeration and other commercial-kitchen systems.

Existing research has evaluated energy-saving solutions for commercial refrigeration and kitchen-preparation systems. However, many of these analyses provide only a theoretical or modeled evaluation of benefits and costs and evaluate only technologies already recognized as cost effective. Updated information is required to determine best practices in grocery and supermarket operations and management to reduce both energy consumption and peak energy demand. Finally, members of the building industry, who often act as gatekeepers, need greater certainty about how to effectively and cost-effectively integrate innovative energy-efficiency strategies and technologies.

## Project Purpose

To overcome barriers to adopting more energy-efficient technologies in grocery stores and supermarkets, the project team designed and executed a deep-energy retrofit of a San Francisco Whole Foods Market. The team enhanced existing research by enlarging the portfolio of technologies and energy-conservation measures, expanding criteria for evaluating them, and rating the effectiveness of each measure as it worked in tandem with other energy-conservation measures. Engaging fully with innovative design and construction processes and the store's management and operations concerns, the team worked to address challenges in executing the retrofit. Team members created reproducible methods and models to assess energy use before and after the retrofit, and to help the store owner sustain energy savings over time.

The goal was to achieve at least 40 percent energy savings for the pilot store and create a transparent approach for other stores to follow. It determined that the Whole Food Market store in San Francisco's Noe Valley neighborhood was uniquely suited for the pilot location. Its constraints included its small size, which would typically imply that the benefits of a retrofit would not be worth its cost; its urban setting, which complicated access for normal construction and increased labor costs; the requirement to keep the store open during construction, which created a range of logistical issues including the need to perform most of the work at night; and its small roof, which meant that the opportunity for and benefits from installing solar panels were considerably less than optimal. These constraints ensured that any success the project achieved could be replicated more easily by other grocery stores.

California ratepayers ultimately benefit from both this project’s decrease in energy consumption and GHG emissions, and from development of an approach that other grocery stores can adopt to achieve similar savings and consequently reduce their own energy costs.

The project’s methods and lessons learned will interest a broad spectrum of professions: grocery store and supermarket facility and sustainability managers; architects, designers, and construction engineers; building energy analysts; local, regional, state and federal energy policy analysts, policymakers and regulatory experts; energy-efficiency consultants; zero-net-energy technology start-ups, and corporations.

This project had three specific goals, to:

- Develop a technically and financially feasible pathway to maximize energy efficiency and achieve zero net energy in supermarket and grocery buildings.
- Demonstrate a pathway to achieve deep-energy savings at an existing Whole Foods Market by implementing an integrated set of measures.
- Leverage the demonstration to accelerate commercialization of identified advanced technologies and strategies.

The project objectives were to:

- Identify and assess leading pre-commercial technologies for inclusion in energy-efficiency-retrofit packages.
- Design a cost-effective energy-efficiency-retrofit package that would both reduce overall energy use by at least 40 percent and be scalable across other California grocery stores.
- Deploy and monitor the retrofit package at the Noe Valley Whole Foods Market.
- Measure the performance of the retrofit package and validate energy savings through measurement and verification.
- Educate diverse stakeholders on the project objectives, design strategies, technology package and options, outcomes, challenges, and policy considerations.

## Project Approach

Project team members, their expertise, and their roles included:

- Whole Foods Market, a leading retailer of natural and organic foods with 508 stores in North America and the United Kingdom and nearly 100 stores in California, was the primary partner. The company is committed to environmental stewardship, including resource efficiency and high-performance buildings. It established owner requirements, engaged in knowledge-transfer activities, and managed construction and testing processes.

- Prospect Silicon Valley led the technology discovery process and provided overall project management that met California Energy Commission requirements. A nonprofit cleantech innovation hub, Prospect Silicon Valley focuses on advanced mobility and energy solutions for urban communities.
- Arup, a global independent firm of designers, planners, engineers, architects, consultants, and technical specialists, led the audit, analysis, and design efforts. An employee-owned firm, Arup espouses values of integrated design, social usefulness, and quality work.
- Lawrence Berkeley National Laboratory's Building Technology and Urban Systems Division monitored, modeled, and verified energy use and savings. The division conducts research and develops physical and information technologies to make buildings and urban areas more energy- and resource-efficient.
- San Francisco Department of Environment consulted on permitting issues, organized and publicized knowledge transfer activities, and participated as the project's municipal partner. The department creates policies to achieve San Francisco's ambitious sustainability and climate change goals.

The MarketZero project approach had five phases: audit, analyze, design, build, and monitor.

In the audit phase, the team surveyed the site to assess energy use and specific site conditions and constraints.

In the analysis phase, the team modeled the store's energy, using metered electricity and gas data. The team also analyzed the energy consumption of the building's major subsystems: refrigeration, lighting, and heating, ventilating, and air conditioning (HVAC). The team then integrated 2016 meteorological data to create a full year of energy consumption and applied this baseline data to potential modeling solutions. The team held a workshop composed of a diverse group of energy and building professionals to examine a wide range of possible technologies. To further expand the list, the team issued a call for innovation to discover and review emerging technologies specifically related to energy consumption and refrigeration. An initial list of 350 energy conservation measures was condensed by weighting those measures against project criteria: energy impact, innovation, customer experience, direct costs, maintenance, disruption to normal operations, integration with the rest of the systems, and scalability.

The team employed a novel genetic algorithm to analyze more than 2,400 combinations of measures to identify optimal packages. This method was used in conjunction with the 2016 baseline energy model that simulated the store's energy use. Ultimately, the analysis phase produced a proposed retrofit package of 20 energy-conservation measures.

In the design phase, the team gathered quotes and real costs for equipment, materials, and labor. Through a winnowing process the team then further refined the package and selected the measures that delivered the greatest impact for their cost. The team ultimately finalized the retrofit package with 18 measures, drew plans, and obtained approvals and permitting. Some of the major adopted energy-conservation measures included:

- Lighting
    - Upgrade interior and exterior store lighting to light-emitting diodes (LEDs).
    - Replace the gas rotisserie with an electric combination oven.

- HVAC
  - Replace gas-fired rooftop HVAC units with high-efficiency electric heat pumps.
  - Replace the factory installed motors on the two heat pump units with emerging technology Software Motor Company motors to increase efficiency.
- Refrigeration
  - Replace open refrigerated display cases with door cases.
  - Update compressor racks (which control cooling) with variable-frequency drive technology and digital controls.
  - Change out refrigerants to reduce GHG emissions.
  - Install emerging technology Viking Cold Solutions Thermal Energy Storage in walk-in freezers, combining intelligent controls with a phase-change material to reduce energy use.

In the build phase, the team hired contractors and procured, installed, and tested the equipment.

In the final monitor phase, the team measured the energy performance of the retrofit. Using energy-use data from the year before the retrofit, it modeled energy use and compared it with actual post-retrofit energy use to determine savings. Both electricity and gas usage were measured, and several electrical subsystems were monitored with submeters. The energy impact of the two emerging technologies was also estimated.

The team encountered a number of technical and logistical challenges in implementing the retrofit; these are described in the Lessons Learned section. One unique challenge involved equipment performance and its unexpected costs. The fans from the new roof-top units emitted a noise loud enough to disturb residents in surrounding buildings. The solution was to build sound barriers around the units, which added cost to the project. It also incurred schedule delays, including the timing of energy-use monitoring. In the four months the team investigated the problem and designed and implemented a solution, the heat-pump fan speeds had to be reduced, which both impacted the energy efficiency of the units and postponed any monitoring of their energy use.

One unfortunate limitation was the inability to pursue on-site energy generation to reach near-net-zero energy use in the building. Initial analyses projected that installing solar panels on the roof could provide approximately 200,000 kWh of electricity per year. However, because of tree shading, the viable roof area was insufficient, so this opportunity was abandoned. Nevertheless, other stores that do have the capability to install rooftop solar panels can combine on-site energy generation with the project's successful approach to achieve their own near-zero net energy use.

A technical advisory committee included architects; lighting and kitchen designers; refrigeration, mechanical, and construction engineers; behavioral scientists; building energy analysts; and renewable-energy researchers. This committee reviewed the team's strategies for identifying and evaluating energy-conservation measures and suggested both previously validated and emerging technologies for the team's further evaluation.

## Project Results

This retrofit exceeded the project's energy-saving goals. Energy savings from gas and electricity combined totaled 44 percent. Natural gas use was reduced by 90 percent, and electricity use was reduced by 21 percent.

Replacing the gas-space heating with an electric heat pump and swapping out the gas-fired rotisserie with an electric-combination oven greatly reduced gas usage, representing 68 percent of total energy savings. Of the electricity savings, replacing the fluorescent and halide lighting fixtures with LEDs netted a 64 percent reduction; upgrading the refrigeration systems produced 42 percent savings.

Two emerging technologies were evaluated separately for energy savings. The Viking Cold Thermal Energy Storage system produced 25 percent energy savings and the Software Motor Company motor replacement reduced energy use of the heat-pump fans by 7 percent.

The retrofit also reduced annual GHG emissions by 53 percent. This takes into account the reductions in gas and electricity use as well as the change in refrigerants, which was responsible for 70 percent of overall emissions savings. The total GHG savings were equivalent to removing 100 cars from the road.

Major lessons learned included:

- Integrated design and implementation were key factors in the project's success. Major project contractors and consultants, Source Refrigeration and DC Engineering, participated in the project's earliest stages and provided crucial feedback on costs, construction requirements, and operability.
- Continuity within the project team was essential for addressing challenges quickly. Arup, Whole Foods Market, and Source Refrigeration assigned the same team members from day one through completion of this complex 4-year project; this enabled the team as a whole to consistently tap into their knowledge and insights.
- Ensuring that equipment was staged and ready when needed facilitated efficient and flexible scheduling. The project suffered from a limited staging area and had to store virtually all equipment and materials at a location 50 miles from the site. This created additional logistic issues. All equipment was also custom built, which created longer-than-expected delivery lead times and altered planned construction sequences.
- Feedback on energy use throughout the project was a vital feedback loop. Normally the measurement and verification stages do not begin until project completion. For this project, Lawrence Berkeley National Laboratory monitored energy use at regular intervals to both analyze the impact of specific equipment installations and suggest refinements to improve efficiencies.
- Commissioning is a continuous effort and a partnership. Commissioning, a specific form of testing during the final stages of construction, tests installed systems under full operation and in various-use scenarios and compares to the design intent of the project and equipment. For this project, commissioning played an especially important role since the successful integration of energy-efficient and emerging technologies required multiple rounds of testing, adjustments, and retesting until the equipment performed optimally.

- A number of opportunities exist for improving the integration of emerging technologies and expanding adoption of new methods by design and construction industries. These are described in the next section.
- Permitting required more time than expected; introducing new technologies challenged municipal-building departments. Future project managers need to engage these departments early in the project and update them about technologies to be installed. There may, however, also be opportunities for educating these departments through state and other programs.

## Technology/Knowledge Transfer/Market Adoption

The project team worked with dozens of organizations and hundreds of individuals, sharing not only goals and methods but also the unique challenges of creating a deep-energy retrofit. Project team members attended and presented at over a dozen events including industry conferences, symposia, workshops, panels, webinars, and exhibits. Focused workshops drew up to 100 attendees and conferences and symposia attracted up to 300 participants.

In these events, team members provided specific and detailed knowledge to the targeted audience group and networked with other building industry, technology, and policy professionals. The target audiences included:

- Zero-net-energy technology providers, both startups and corporations.
- Building industry professionals involved in engineering, design, and construction.
- Building management including contractors, engineers, architects, owners, and facilities managers, especially those from supermarkets and grocery stores.
- Local, regional, and state and federal policymakers; policy consultants; and regulatory experts.

The Call for Innovation reached more than 67 organizations and 100 individuals in the same target audiences.

The San Francisco Department of Environment shared MarketZero project information with 15 of San Francisco's small- and medium-sized grocery stores, presenting the relatively low-cost but high-impact measures that owners could apply to their own stores.

Project results are applicable to the majority of grocery stores throughout California; these are discussed more thoroughly in the Benefits to California section. In addition, this work could indirectly impact California's refrigerated warehouse and restaurant markets, which together occupy almost twice the total floor area as grocery stores.

MarketZero methods and technologies have already been adopted in three other projects. Arup has applied the genetic algorithm to its design of the National Resources Defense Council headquarters in New York City to achieve net-zero-energy in that building. As a consultant to Carbon Free Boston, Arup used the genetic algorithm to model conservation measures for each of the building types within Boston's building stock to help that city reach its 2050 carbon-neutral goals. Whole Foods Market is again partnering with Arup for the deep-energy retrofit of another San Francisco store that will follow the MarketZero approach.

Future opportunities for knowledge transfer could include ARUP publishing detailed information about the genetic algorithm in a cited journal would share this knowledge with others who work in the building industry. This recommendation is based on the enthusiasm that team members received from presenting an overview of the genetic algorithm at a conference on energy-efficiency in buildings.

The project team also recommends greater investment in knowledge transfer, shifting from merely presenting project results to using the project to train designers and construction engineers in both applying the MarketZero approach and making it more scalable. This is an opportunity for a follow-up program that provides the construction and design community with elements of the project including design guidance on factors and constraints and integrating new technologies. This this training could be taken on by the IOUs.

## Benefits to California

This study presents a proven approach that can be adopted by grocery stores and supermarkets throughout California to realize widespread energy savings and cost benefits.

The size of the grocery store market in California and the square footage it inhabits suggests that energy and GHG emission savings in this segment could contribute substantially to California's ambitious energy goals. There were 4,700 grocery stores and supermarkets in California in 2019, and that number is expected to grow to 7,800 by 2024. The project team estimates the 2020 total market-segment floor area at about 160-million square feet. Currently, the mean energy use by grocery stores in California is estimated to be 167 kBtu/ft2/yr. The MarketZero approach reduced energy use in the pilot store from 215 to 120 kBtu/ft2/yr.

To estimate savings that could be achieved by all grocery stores in California by adopting the MarketZero approach, the team extrapolated the energy and GHG savings achieved in the pilot store with these results:

Total statewide energy savings of 2,552 GWh of electricity and 39.6 million therms of natural gas exceed the stated project goals of 2,400 GWh and 37 million therms, respectively, for a total estimated energy savings of 47 percent.

The team estimated total statewide GHG savings of 2.9 million metric tonnes $CO_2$-equivalent, or 56 percent, with refrigerant savings contributing 73 percent of total savings. These are equivalent to the emissions from 630,000 cars, or 0.7 percent of the total statewide GHG emissions goal for 2020.

# CHAPTER 1: Overview- Grocery Stores: The Final Frontier of a Zero-Net-Energy Future

## Project Context

This research project targeted one of the final frontiers of a zero-net-energy (ZNE) building future: grocery stores and supermarkets, the second-highest energy-consuming commercial building type per unit area. This project designed and implemented the retrofit of an existing grocery store to achieve near net-zero energy utilization, with an energy efficiency focus. The 4-year project included national and regional leaders in advanced building-energy systems and leveraged advanced strategies and technologies to design and implement a world-class building-retrofit showcase.

## Technical Need for the Project

The MarketZero project directly addresses two critical strategies of California's Long Term Energy Efficiency Strategic Plan:[1]

- All new commercial construction in California will be zero net energy by 2030.
- 50 percent of existing commercial buildings will be equivalent to zero net energy buildings by 2030 through the achievement of deep levels of energy efficiency and clean distributed generation.

California's commercial buildings consume more electricity and gas than residential buildings.[1] Among commercial building types, supermarkets, and grocery stores have one of the highest energy-use intensities (EUIs). They are also one of the most challenging due to their high-process energy use of refrigeration and commercial kitchen systems. The 2006 California Commercial End-Use Survey (2006 CEUS) indicated a statewide average of approximately 167 kBtu/ft$_2$/yr in existing grocery stores.[2]

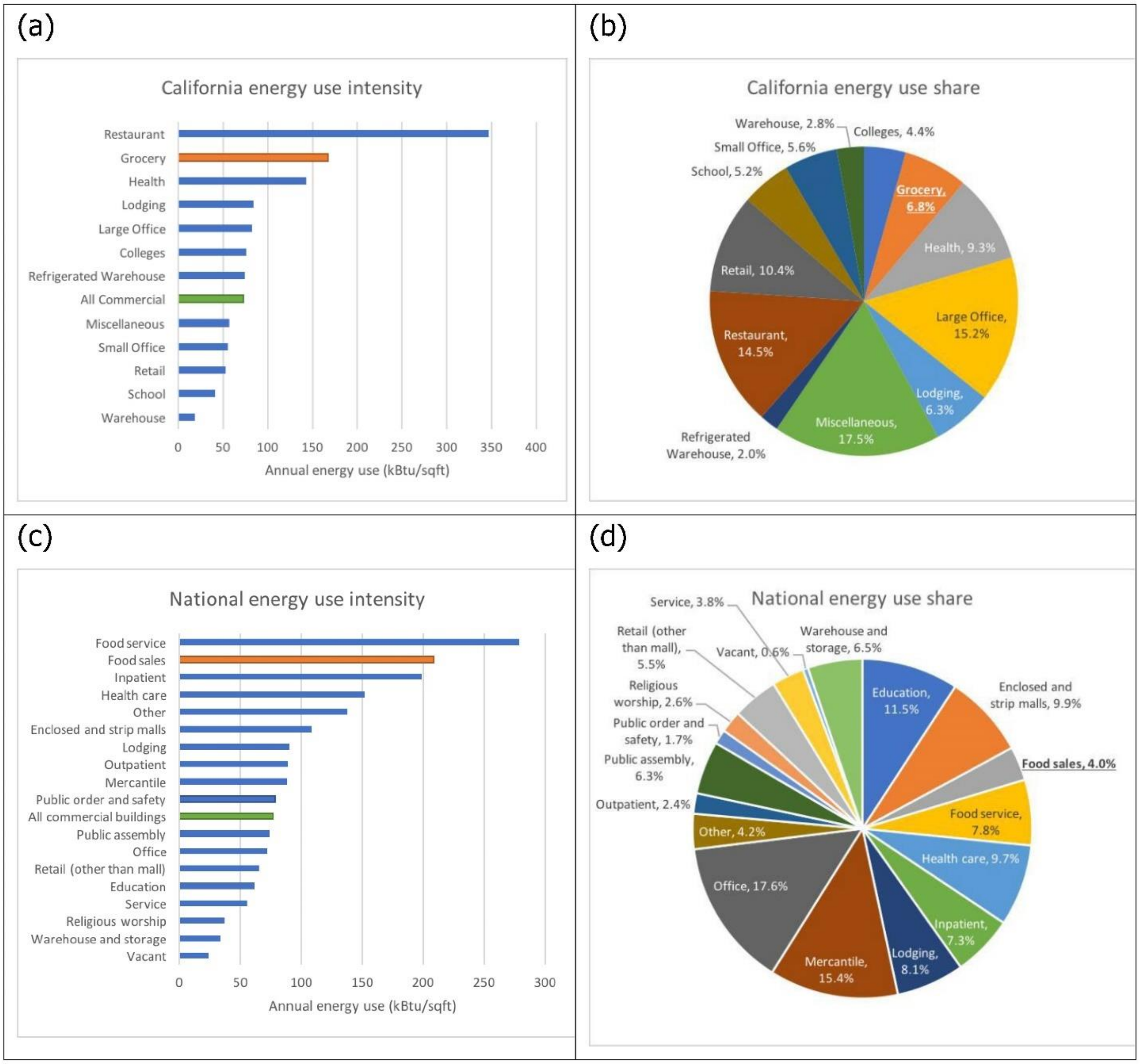
Figure 1 compares gas and electricity energy use in various types of commercial buildings in both California and the nation. Panels (a) and (b) show California's statewide data. Panel (a) shows grocery stores with the second-highest EUI. Panel (b) shows that grocery stores use 6.8 percent of all energy used by commercial buildings. Panels (c) and (d) summarize the national data.[3] Panel (c) shows that food sales have the second-highest EUI. Panel (d) shows that food sales consume 4 percent of the total energy used by commercial buildings.

[1] California Energy Commission, CA Energy Efficiency Strategic Plan, January 2011 Update, 28—29

[2] Based on California Energy Commission, 2006 California End-Use Survey (CEUS). Note 2006 (CEUS) or (CEUS) refers to this document and is used without footnotes for every reference.

[3] U.S. Energy Information Administration, 2012 Commercial Buildings Energy Consumption Survey (CBECS).

**Figure 1: Commercial Building Energy Use in California and the U.S.**




**Panel (a): California EUI by Commercial Building Type. Panel (b): California Energy Use Share by Commercial Building Type. Panel(c): U.S. EUI by Commercial Building Type. Panel (d): U.S. Energy Use Share by Commercial Building Type**

Source: 2006 CEUS, [2012 CBECS]

Existing research that supports updates to the Building Energy Efficiency Standards (Title 24 Part 6) and existing utility rebate programs have evaluated various energy-efficiency solutions for commercial refrigeration and kitchen/food preparation systems. However, many of these analyses provide purely theoretical or modeled evaluation of benefits and costs or evaluate only those technologies that demonstrate the highest perceived cost effectiveness. There is also limited information about best practices in grocery and supermarket operations and management about reducing energy consumption and peak demand. This project addresses those issues.

## Affected Market Segments in California

This work could directly impact grocery stores and supermarkets. California's existing stock of grocery and supermarkets totaled 144 million $ft^2$ in 2006, equal to 3 percent of existing floor stock. The grocery market segment is also growing; in 2018, California opened 157,000 more square feet of grocery space than were opened in 2017.[4] The project team estimates the total market segment floor area to be about 160 million square feet in 2020.

With a mean EUI of 167 kBtu/$ft^2$/yr, this market represented approximately 9 percent of California's commercial building electricity consumption of 67 terawatt-hours per year (TWh/yr), and 3 percent of the state's gas consumption of 1,279 million therms per year (Mtherms/yr) in 2006 (CEUS).

This research work could also indirectly impact the refrigerated warehouse (refrigeration) and restaurant (commercial kitchen) markets in California. These markets represented approximately 149 million and 95 million square feet of existing floor stock, respectively, in 2006. (CEUS).

## Project Site and Partner – Noe Valley Whole Foods Market

Founded in 1978 in Austin, Texas, Whole Foods Market (WFM) is a leading retailer of natural and organic foods and the country's first "Certified Organic" grocer. In fiscal year 2014, it recorded sales of approximately $14 billion. As of March 2020, WFM had 508 stores in North America and the United Kingdom, with 95 in California. WFM has approximately 95,000 employees and has been ranked for 20 consecutive years as one of the "100 Best Companies to Work For" in America by *Fortune* magazine.[5,6]

In the early stages of this project, Prospect Silicon Valley (ProspectSV) and the global engineering and design firm Arup explored partnerships with multiple grocers, ultimately selecting WFM for its sustainability values and policies.[7] WFM was rated third on the United States Environmental Protection Agency (USEPA) list of "Top 25 Green Power Partners," and received a USEPA Green Power Award in 2004 and 2005. It also received the US EPA's Partner of the Year award in 2006 and 2007[8] and was rated the second-highest purchaser of green power nationwide.[9]9 As a partner of the USDOE Better Buildings Challenge, WFM committed to aggressive energy-efficiency improvements, including a 20 percent energy reduction by 2020

[4] "What's Next in California Grocery Real Estate," California Grocers Association (website).

[5] "Whole Foods Market celebrates 20 years as one of *Fortune*'s 100 Best Companies to Work for." Whole Foods Market (website)

[6] In June 2017, (after the project was awarded) Amazon purchased Whole Foods Market. Gensler, Lauren, "Amazon Is Buying Whole Foods for 13.7 Billion," *Forbes*

[7] "Whole Foods commits to reduce energy consumption by 25 percent per square foot by 2015," Whole Foods Market (Website).

[8] "Partner Profile" United States Environmental Protection Agency

[9] "EPA Top 25 Partners in the Green Power Partnership" United States Environmental Protection Agency

across almost 13 million square feet of retail space, and sharing energy reduction strategies and successes with the marketplace.

WFM recognized that the MarketZero project offered a unique opportunity for in-depth, data-driven decision making and true benchmarking of energy use and energy savings.

Achieving on-site ZNE for grocery stores is relatively feasible for large, single-story stores with ample parking lots.[10] It is far more challenging in dense, urban environments with limited parking; it is even more challenging to retrofit an existing store than design a new one. The team identified the Noe Valley store precisely because of its constraints (described in Chapters 2 and 5). The notion was if a deep energy retrofit could succeed in this store, it could succeed almost anywhere.

WFM took over the Noe Valley store site from Bell Market, which opened in 1968 and was one of the Bell supermarkets owned by Dominick Bell and his two brothers in the 1940s. In its last 40 years, Bell supermarkets were sold to various national grocery store chains as they increasingly shifted away from small neighborhood markets.

WFM spent $5 million to completely gut, remodel, and expand the structure before opening the Noe Valley store in 2009. That remodeling effort updated major systems including refrigeration, lighting, electricity, and heating, ventilation, and air conditioning (HVAC) to 2009 standards. The transformation to a gourmet, organic, full-service grocery reflected the dynamic of the neighborhood, now home to urban professionals and nicknamed "Stroller Valley."

## Goals and Objectives

The project goals were to:

1. Develop a technically and financially feasible pathway using advanced strategies to maximize energy efficiency and achieve ZNE in supermarket and grocery buildings.
2. Demonstrate the feasibility of the ZNE pathway by achieving significant deep-energy savings at an existing pilot WFM supermarket by implementing an integrated set of energy-conservation measures.
3. Leverage the demonstration to accelerate commercialization of identified advanced technologies and strategies.

The project objectives were to:

4. Identify and assess leading pre-commercial technology with demonstrated pilots for inclusion in the MarketZero energy-efficiency retrofit package.
5. Design a replicable, cost-effective, and high-impact MarketZero energy-efficiency retrofit package that will yield at least a 40-percent reduction in EUI of the target store, and that is also scalable to a reduction of at least 2,400 GWh and 37 million therms of gas annually in California grocery stores.
6. Implement and monitor the MarketZero energy-efficiency retrofit package at the selected San Francisco store location.

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[10] Arup, The Technical Feasibility of Zero Net Energy Buildings in California (2012)

7. Measure the performance of the retrofit package and validate energy savings through measurement and verification.
8. Educate diverse stakeholders, including investor-owned utilities (IOUs), municipal zoning and building officials, energy managers and engineers, technology innovators, and policymakers on the project's objectives, design strategies, technology package and options, outcomes, challenges, and policy considerations of advanced energy-efficiency and net-zero strategies for grocery stores.

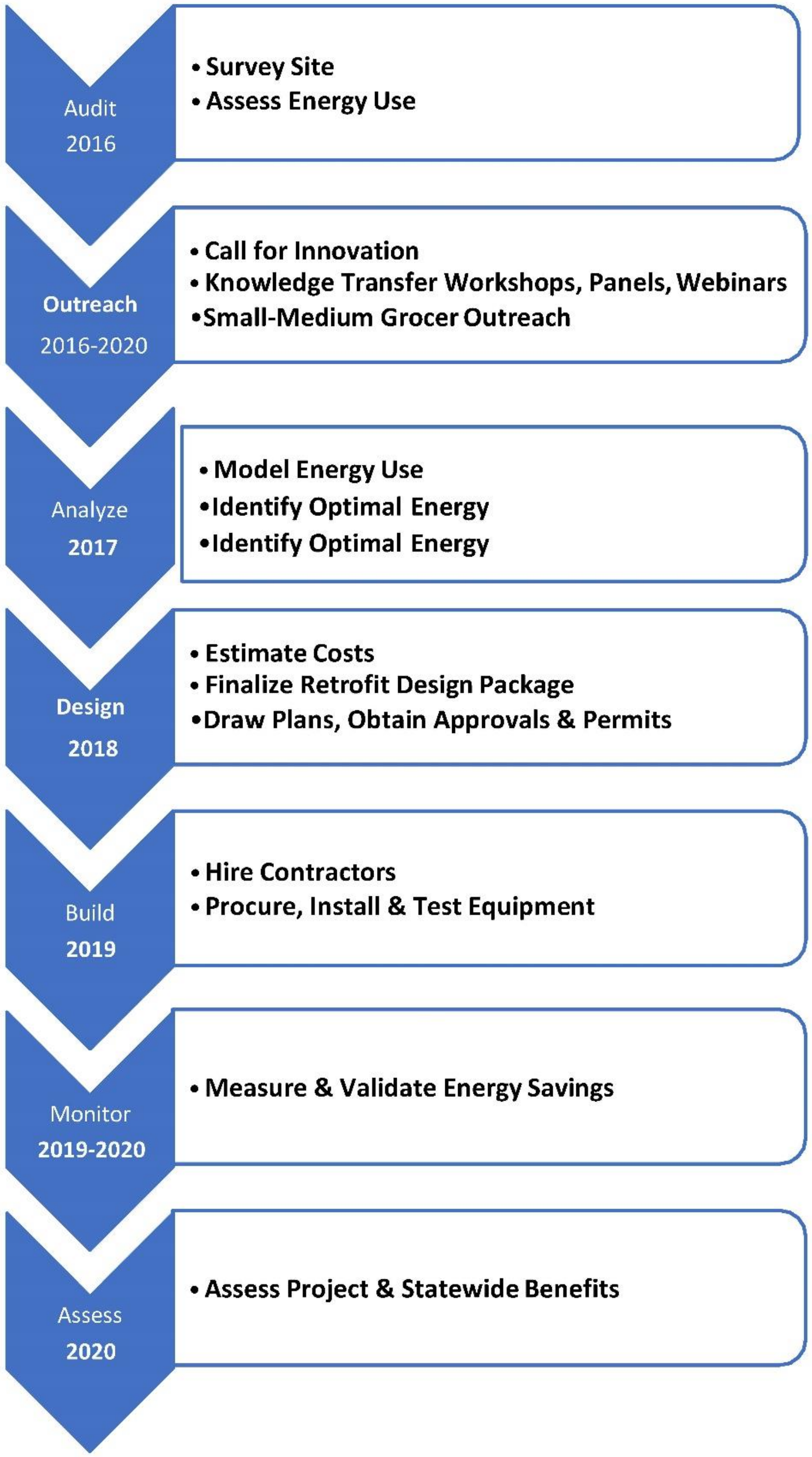
## Project Team

- WFM contributed to every aspect of the project from design to knowledge transfer, ultimately determined the retrofit package, and managed the construction and commissioning of the Noe Valley store.
- Prospect Silicon Valley (ProspectSV) led the technology discovery process and ensured that the project met Energy Commission requirements by providing overall project management. The nonprofit ProspectSV collaborated with critical public and private partners.
- Arup, an independent firm of designers, planners, engineers, architects, consultants, and technical specialists, led the audit, analysis, and design effort. The firm's 16,000 specialists work on projects in 140 countries, and Arup has aligned its business with the UN Sustainable Development Goals.
- Lawrence Berkeley National Laboratory (LBNL) Building Technology and Urban Systems Division provided measurement and verification (M&V) services. The division conducts R&D and develops physical and information technology to make buildings and urban areas more energy- and resource-efficient. The University of California, Berkeley manages this USDOE facility.
- The San Francisco Department of Environment (SFE), a department of the City and County of San Francisco, consulted on permitting issues, provided knowledge and technology transfer activities, and functioned as the project's municipal partner. The department designs policies to further San Francisco's ambitious sustainability and climate change goals, including obtaining 100 percent of residential and 80 percent of commercial electricity from renewable sources coupled with efficiency improvements to reduce energy usage.

## Summary of Project

To demonstrate a path to ZNE for even the most challenging supermarkets, the interdisciplinary project team executed these steps: energy audit and analysis, design and construction of the retrofit, and post-construction monitoring. The project showcased emerging technologies and best-in-class designs, identified vital energy-saving opportunities for urban groceries, and serves as a case study for future ZNE grocery stores. Figure 2 highlights the project's approach and milestones.

**Figure 2: Project Approach and Phases**




Source: ProspectSV

# CHAPTER 2:
# Energy Audit and Baseline Model

## Site Survey

Figure 3 shows the Noe Valley WFM store front. Figure 4 is a satellite photo of the store, its parking lot, and neighboring structures.

**Figure 3: Noe Valley Whole Foods Market Storefront**


Source: MarketZero project photograph

**Figure 4: Satellite Photo of Noe Valley Whole Foods Market and Surrounding Neighborhood**


Source: Imagery ©2020 Maxar Technologies, U.S. Geological Survey Maps Data ©2020

The 25,187 square-foot, split-level building consists of a single story for the sales floor (front of house) plus a mezzanine and second level for offices, storage, food preparation, and equipment in the back of the store (back of house). The front of house is covered by a lower roof, and the back of house is covered by an upper roof. Figure 5 shows the pre-retrofit store layout.

**Figure 5: Store Layout from Top to Bottom: Level 1, Mezzanine, and Level 2**


Source: Drawing created by Arup

## Survey of Subsystems

The site survey identified and described the subsystems—refrigeration, HVAC, lighting, building envelope, and kitchen—as well as the control systems that regulate and monitor them.

**Refrigeration**

The front of house featured low- and medium-temperature cases with the following characteristics:

- Most of the low-temperature freezers were enclosed.
- Anti-sweat heaters on the freezers, designed to reduce condensation, fog, and ice, did not have controls.
- The medium-temperature cases were vertical and open.
- Fabric night curtains on open medium-temperature cases were manually drawn down by staff.

The walk-in coolers located in the back of house had these characteristics:

- Medium-temperature coolers had strip curtains.
- Low-temperature coolers had doors and anti-sweat heaters.
- Walk-in coolers appeared to be losing energy around the doors.

A refrigeration plant on Level 2 serving both coolers included:

- An indoor 120-ton evaporative condenser equipped with a 15-Horsepower (HP) variable-speed fan.
- Two R-404a refrigerant compressor racks that produced different suction temperatures for different refrigeration circuits.

Heat was reclaimed off the refrigeration loop to heat the store's domestic water.

**Heating, Ventilation, and Air Conditioning**

- Two packaged units located on the lower roof served the front of house. The total 9,000 cubic feet per minute (cfm) constant-volume units provided 20 tons of cooling, using direct expansion (DX) and heating via a gas furnace.
- Several small HVAC systems served the back of house.

**Kitchen and Hot Water**

- A small kitchen in the back of house used an AO Smith 240 kBtu/hr gas-fired water heater that was 96 percent efficient.
- A gas rotisserie was used for roasting chickens several hours every day.

**Lighting**

The store had the following lighting types:

- T-5 fluorescent tubes lit refrigeration cases and cash registers in the back of house.
- Ceramic metal halides provided track lighting and spotlighting for displays in the front of house.
- The building front curtain wall and six skylights provided some natural daylight.

**Envelope**

The curtain wall faces south with a small overhang and roll-down shades to partially control glare.

The front of house 12,000 square-foot roof (lower roof) had these characteristics:

- Minimally insulated, highly reflective roof membrane
- Lower than neighboring buildings and shaded by a tree on the eastern side for part of the day
- Six small skylights and two small rooftop HVAC units

The back of house 5,000 square-foot gravel roof (upper roof) contained additional HVAC equipment, a large exhaust area for the interior fluid cooler, and gravity vents.

### Controls

- A Micro Thermo direct-digital-control (DDC) system located on Level 2 controlled HVAC, lighting, and refrigeration systems.
- A desktop interface to the Micro Thermo system was located in the compressor room on Level 2, and remote access was available through a secure website.
- The system supported tracking alarms, suction and discharge pressures, condenser water temperature, condenser fan speed, the cooler temperature, door switches, and fault detection.

## Store Energy Use

The Noe Valley store had a pre-retrofit EUI of 215 kBtu/$ft_2$/yr, slightly higher than the U.S. median grocery store EUI of 167 kBtu/$ft_2$/yr.[11] Electricity and gas use was relatively consistent throughout the year, with a large baseload. Daily energy use was relatively constant throughout the year, with a baseload of about 90 kW overnight and a peak load of about 160 kW during mid-afternoon.

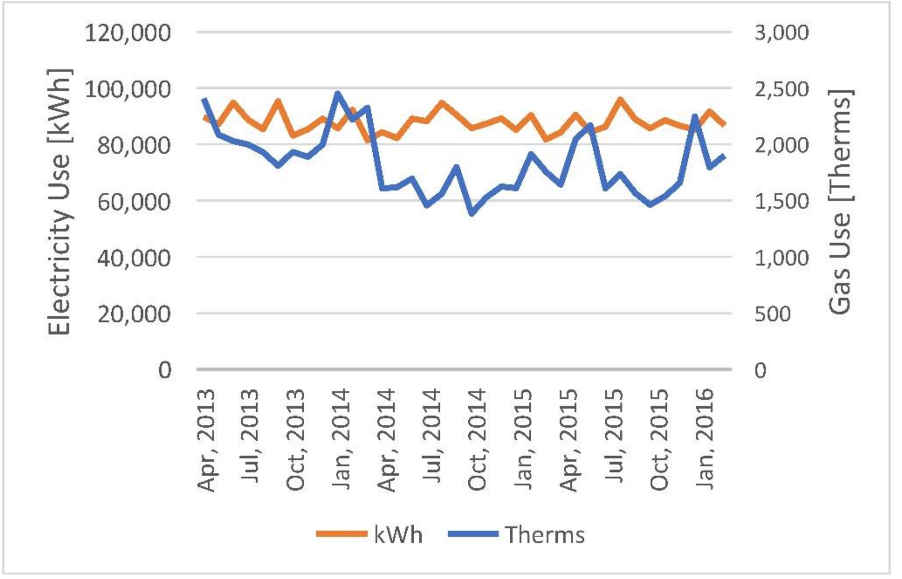
Figure 6 shows monthly electricity and gas data over three years. Electrical data shows a relatively large and constant baseload, as expected in a grocery store located in a mild climate, with peaks in the summer and valleys in the spring (likely due to HVAC use). Gas use showed no major seasonal trends, indicating a large process baseload.

Determining the breakdown of that usage by subsystem presented challenges for the team. A Parasense onsite energy and performance monitoring system tracked metered energy, but a significant portion was not metered. In addition, the panels that were submetered contained circuits with different end uses. Further, gas usage was not broken down by subsystem.

A full 37 percent of the power was uncategorized. The refrigeration system used 40 percent of the building’s power. Lighting was the next largest end user, accounting for nearly 20 percent of the power. The metered data corresponding to HVAC energy accounted for only about 5 percent of the electricity total since they were gas-fired units.

[11] From the Lawrence Berkeley Lab Building Performance Database

**Figure 6: Electricity and Gas Use**




Source: Electricity and gas meter data for the store

## Preliminary Conclusions and Opportunities

Based on the site investigation and available energy use data, the team presented the following considerations and opportunities for designing the retrofit package.

- Refrigeration. Refrigeration, a 24/7 load, used by far the most energy. Energy-conservation opportunities included enclosing refrigeration cases and installing high-efficiency compressors.
- Lighting. Lighting was the second-largest energy user, according to submetered data. Fluorescent and metal halide fixtures could be upgraded to high-efficiency LEDs. Daylight-integrated dimming and lighting controls could also provide savings.
- HVAC. Replacing the gas-fired rooftop units (RTUs) with higher efficiency units, removing the wall units serving the back of house, and employing energy recovery would increase energy efficiency and reduce gas use.
- Electrical. Properly sized, premium-efficiency transformers could reduce the entire store's energy consumption by 5 percent. Additional savings could be realized using a DC microgrid that minimizes AC/DC conversion losses between solar photovoltaics (PV), batteries, LED lighting, refrigeration compressors, and HVAC.
- Kitchen. Point-of-use water heating and reorganization of spaces into hot and cold areas could reduce hot-water use. The team recommended upgrading plug-in kitchen equipment to premium efficiency and installing better-controlled units.
- Facade. Largely uninsulated, the facade allowed significant thermal bridging through the roof and solar gains through the front facade. Energy improvements included adding roof insulation and reducing solar gains through window films or shading devices.

## Developing Baseline Energy Models

The team created two baseline energy models for the project. The first model, briefly described in this section, supported the retrofit design process. (Appendix A, Model Calibration and Validation, provides a full description of this model.)

The second model measured the energy savings realized by the constructed retrofit design and supports the measurement and verification process, as described in Chapter 6.

### Calibrated Energy Model

To improve energy usage, Arup built a calibrated energy model that mimicked the store's operation. The modeling team tightened the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) Guideline 14 standards for the statistical tests and performance boundaries for calibrating models used for the retrofit as follows:

- Normalized Mean Bias Error (NMBE) of ±10 percent using hourly data across one full year
- Coefficient of variation of the root mean squared error (CV[RMSE]) of less than 15 percent using hourly data across one full year

These two tests serve different purposes. NMBE tests if there is a continuous over- or under-estimation of energy performance within the model. CV[RMSE] tests if the magnitude of difference between the modeled and observed data is significant.

First, the team created an EnergyPlus model using the following information:

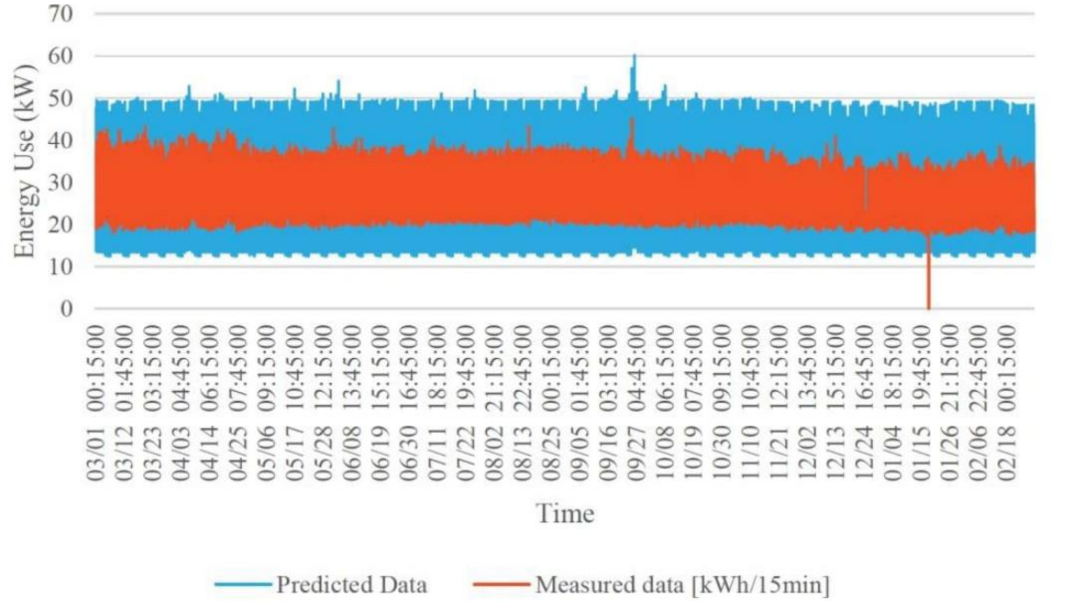
- As-built construction drawings of the store
- Equipment schedules from construction documents
- Information from on-site surveys
- Schedules and information provided by the store manager

Next, they ran the uncalibrated model, which produced an NMBE of 0.73 percent, indicating that the model was relatively unbiased. However, using 15-minute-interval data, the CV[RMSE] was 29 percent, indicating that the loads were not well calibrated. Visual inspection revealed that the model showed a consistent bias toward higher daytime and lower nighttime loads, as shown in Figure 7.

Given both the statistical unacceptability of the results and the concerns of consistent over- and underestimation, the team took the following steps to produce a calibrated model:

- Obtained additional data on store performance from the building management system and onsite temporary metering of end uses and circuits
- Extracted operating schedules and values for lighting and plug-load circuits for thermostat setpoints, fans, refrigeration equipment, and heat recovery
- Updated parameters of incompletely modeled elements of the refrigeration system to match the actual design

**Figure 7: Predicted versus Measured Energy Use**




Source: Data from model created by Arup and meter data

This additional data produced a well-calibrated electricity model that met the required tolerances. However, further inspection revealed that the gas consumption was not calibrated as modeled. Only six end uses for gas existed within the building, so each was inspected in turn. These values were modified to produce accurate calibration for gas usage: the gas rotisserie operating schedule, airflow between zones within the building, and domestic hot-water-use schedules.

As with electricity, achieving the calibrated tolerance for gas required several iterations. Table 1 shows that NMBE and CV[RSME] for both electricity and gas fell within the target ranges of ±10 percent and <15 percent, respectively.

**Table 1: Model Calibration Statistics**

| Fuel | NMBE | CV[RMSE] |
|---|---|---|
| Electricity | 0.96% | 7.26% |
| Gas | -3.45% | 10.08% |

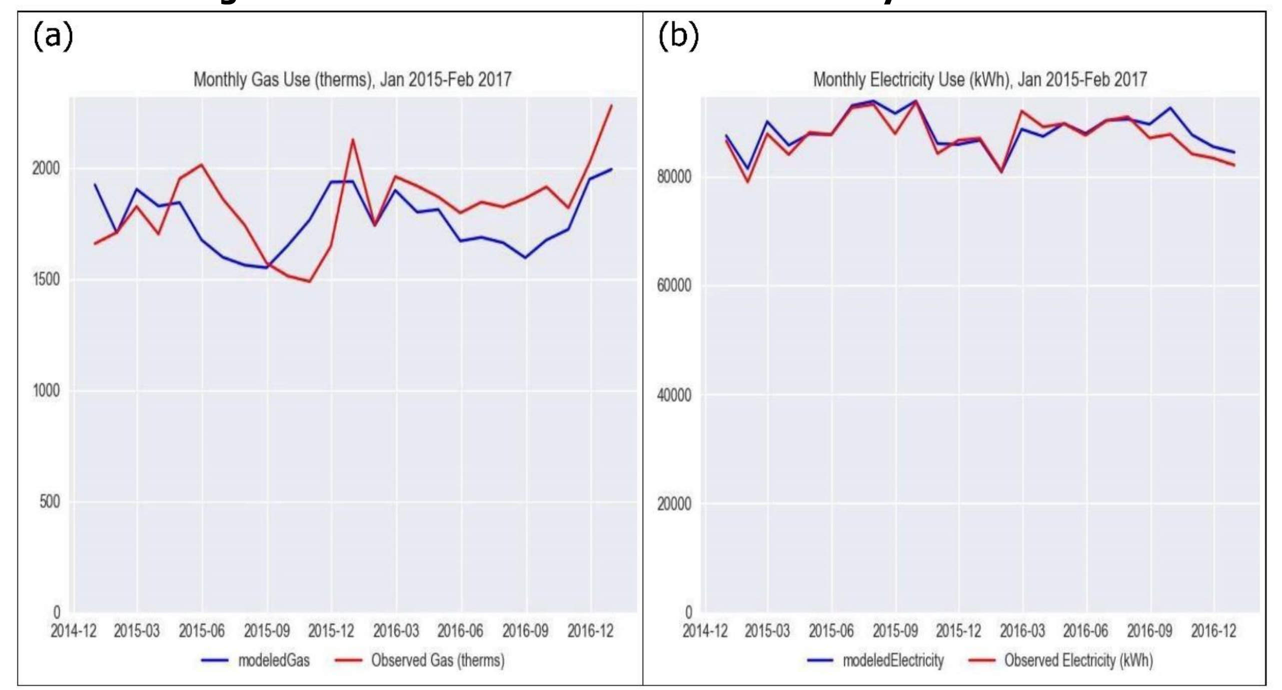
Source: Data from model created by Arup

Figure 8 compares calibrated and measured energy use. Panel (a) shows gas use. Panel (b) shows electricity use.

The team ran the calibrated model with meteorological data for San Francisco in 2016 to model energy by end use. Figure 9 shows the breakdown of energy by end use. Panel (a) shows gas use. Panel (b) shows electricity use.

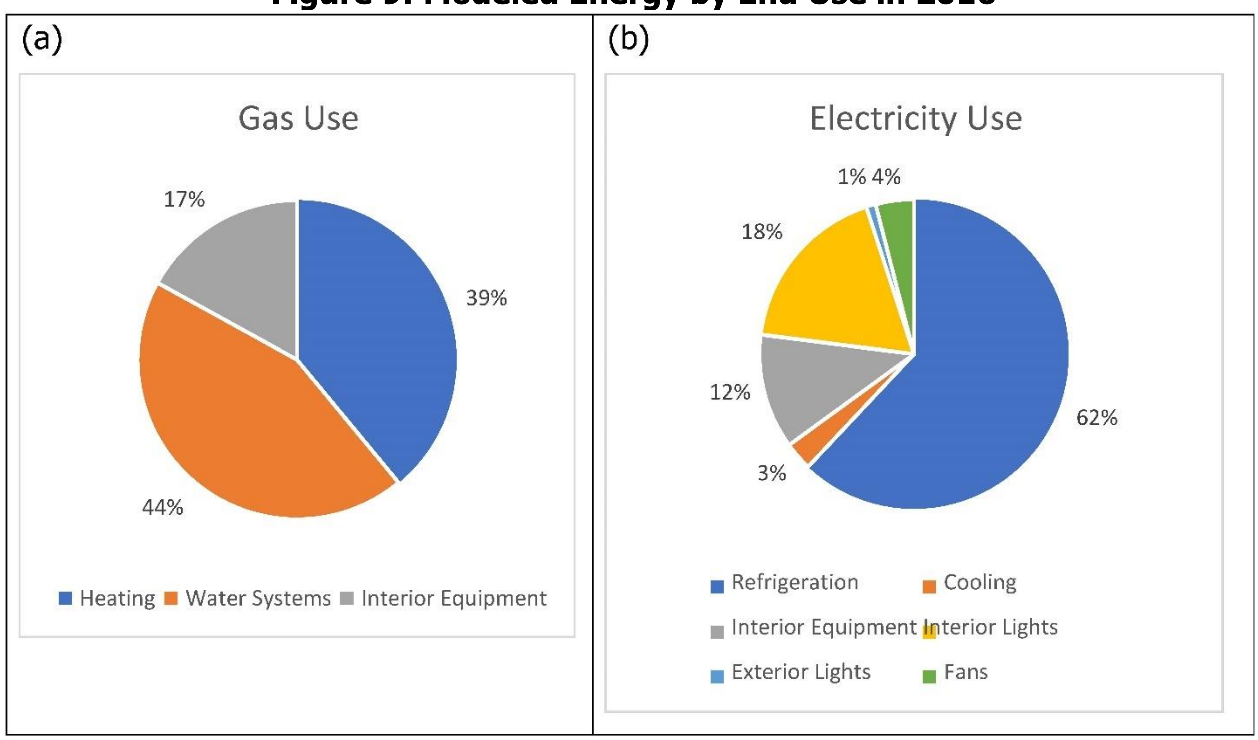
According to the model, over half of the electricity use in the store was from the refrigeration compressors, cases, and condenser. Interior lighting and plug loads accounted for the next two major sources of electricity use. Space and water heating contributed more than 80 percent of gas consumption.

**Figure 8: Calibrated vs. Measured Electricity and Gas Use**




Source: Data from model created by Arup and meter data

**Figure 9: Modeled Energy by End Use in 2016**



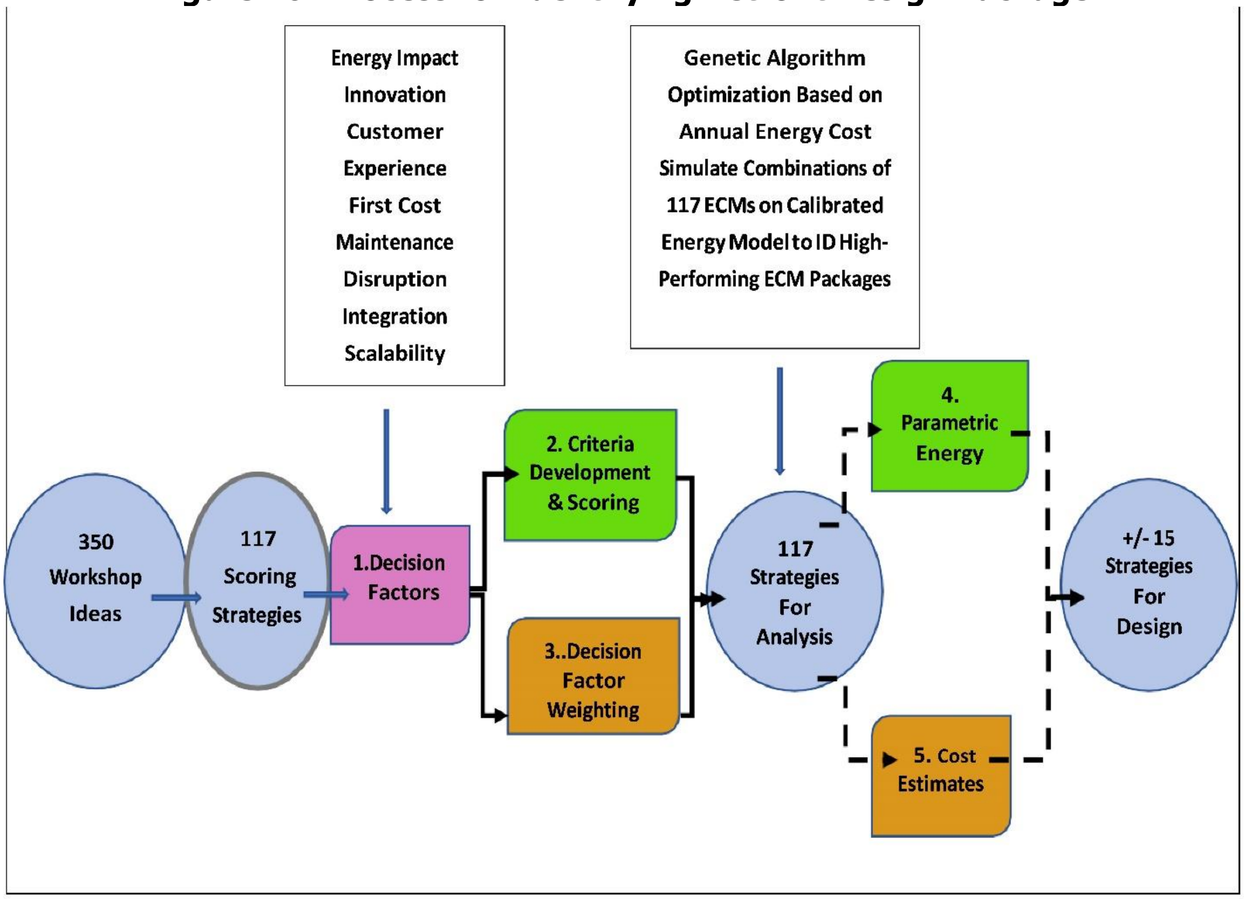

Source: Data from model created by Arup

# CHAPTER 3:
# Retrofit Design Process and Package

## Developing Design Decision Criteria

Figure 10 summarizes the process for determining the energy conservation measures (ECMs) included in the retrofit design package.

**Figure 10: Process for Identifying Retrofit Design Package**




Source: Diagram created by Arup

### Selecting Energy Conservation Measures

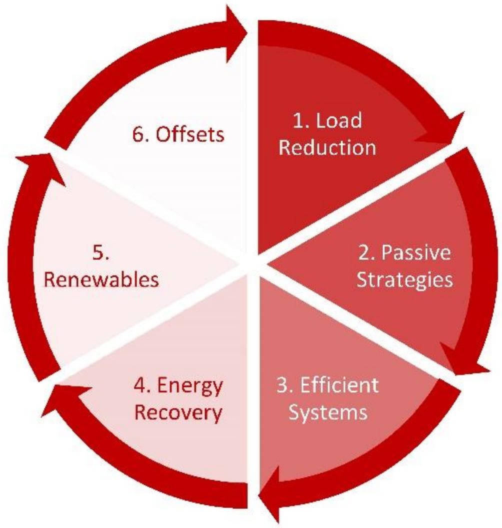
In the summer of 2016, the project team held an intensive design workshop with 40 experts in diverse fields including energy efficiency, lighting design, refrigeration, kitchen design, behavioral science, MEP (mechanical, electrical, and plumbing) engineering, permitting, and the grocery industry.

At the workshop, the team presented the results of the site investigation and a preliminary analysis of metered electricity and gas use. To create a structure for the discussion, Arup presented its "Path to Net Zero Energy" strategy. It adopted an efficiency-first approach to maximize energy savings at the lowest cost to achieve the best opportunity to reach ZNE.

Figure 11 illustrates the path to ZNE. First, loads such as solar gains, plug loads, and setpoints are reduced as much as possible. Next, passive systems such as natural ventilation and daylighting, meet the remaining load. Where passive systems are insufficient, efficient active systems are used — for example, energy-saving motors, high-performance transformers, and LED lighting.

Once incorporated into the building, energy is retained and reused as much as possible — for example, using air-to-air energy recovery and refrigeration-heat recapture. Finally, onsite renewable sources are implemented; solar PV would be one example. Offsite renewable energy sources meet any remaining non-renewable energy use.

**Figure 11: Arup's Path to Zero Net Energy Strategy**




Source: Arup, *Zero Net Energy and Carbon*, November 2019, Slide 9

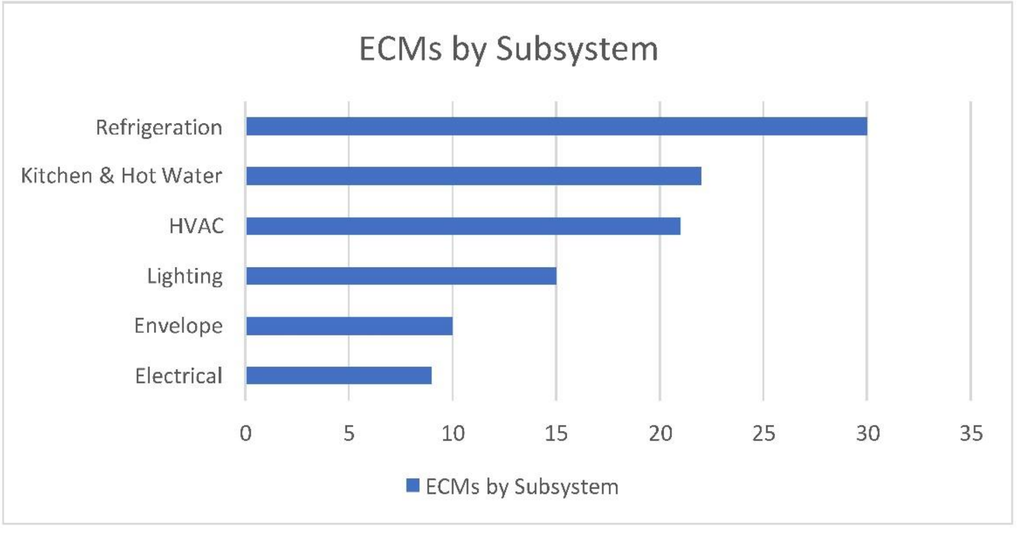
Workshop members used the path structure to help stimulate and organize the brainstorming process. They drew on their collective expertise to develop a list of an astonishing 350 energy-conservation and renewable-energy strategies designed to reduce energy consumption in the targeted building subsystems.

The project team further added to that list by selecting several emerging technologies that offered better performance than industry equivalents in either product or laboratory tests. ProspectSV had introduced these emerging technologies to the project through a discovery competition designed to promote the use of new, innovative energy-saving technologies in the store. Chapter 4 summarizes their efforts and the technologies they discovered.

Next, the team consolidated similar technologies and eliminated those that were obvious non-starters due to space or availability limitations. The team evaluated how well each of the remaining 117 ECMs fit the store and identified specific products and technical performance criteria for quantifying each ECM's impact on the store's energy use. Arup estimated rough order of magnitude (ROM) construction costs for each ECM. Using the calibrated EnergyPlus model (described in Chapter 2), the project team assessed the energy savings of each ECM. Given this data, the project team evaluated and scored the ECMs for energy savings potential, feasibility, cost, scalability, innovation, disruption to the store, and reliability.

This process reduced the list to 107 ECMs, broken down by subsystem in Figure 12.

**Figure 12: Number of Energy Conservation Measures by Subsystem**




Source: Data and analysis created by Arup

## Modeling Energy Conservation Measures

The next step was to determine which combination of ECMs would deliver the best energy savings. Typically, designers use whole-building energy-simulation software to model the impact of individual ECMs on energy consumption. They then select the best ECMs and model them together, tweaking the package until it reaches energy goals.

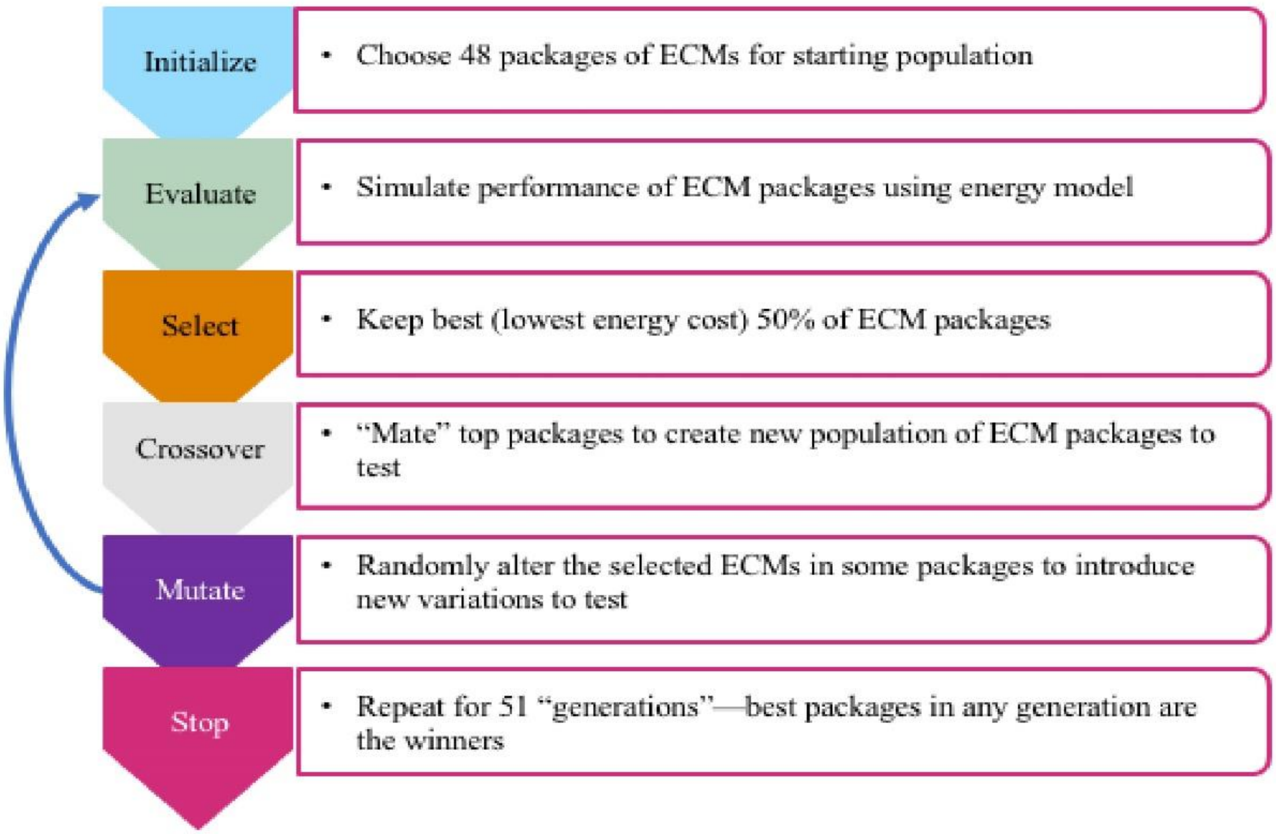
Arup designers recognized that this approach ignores interactions among the full list of ECMs. For example, enclosing open refrigerated display cases would decrease the heating load and consequently reduce energy savings from heating-system upgrades. Capturing these interactions would be critical to reaching the goal, yet no existing software package supported this approach.

To address this, Arup developed an innovative approach using a genetic algorithm to optimize the evaluation of combinations of ECMs. A genetic algorithm simulates Darwinian evolution, where "survival of the fittest" is determined by energy savings. It first randomly generates a set of proposed solution sets before modeling the performance of these sets and recording energy performance and cost. New solution sets are created by combining the characteristics of the best sets and adding some random variation. These last two steps mimic the evolutionary processes of reproduction and mutation.

Written in the programming language Python and applied to the calibrated EnergyPlus model, the program iterated through thousands of combinations of ECMs to identify the lowest energy combination for implementation at the store. In all, the program tested 2,448 ECM packages using this approach.

Figure 13 summarizes the generic algorithm optimization process.

**Figure 13: Flow Chart of Steps in the Genetic Algorithm Program**




Source: Chart and process created by Arup

Next, the team eliminated solutions that did not meet two constraints: first, all direct current ECMs had to be modeled together, and second, the solution could not exceed the project's $2 million capital cost budget. This left 770 tested solutions. Of these, 280 had an energy cost between $10,000 and $11,000 for the representative 4-month period modeled. Within these 280 solutions, 114 different variants of ECMs appeared at least once. Appendix B, ECM Modeling Report presents the 114 variants with energy-cost savings, and scores for innovation, customer experience, maintenance, disruption, integration, and scalability.

Further analysis identified a small number of ECMs that appeared in the majority of solutions and were responsible for the majority of savings. In fact, four ECMs appeared in all 280 solutions and accounted for roughly 30 percent of total energy savings realized in any package. Other frequently occurring solutions could be added to the final package, based on energy cost and the qualitative indicators previously evaluated by the project team and WFM.

The team recommended three sets of ECMs for further evaluation:

- **High Impact Measures**
  - Replace gas rotisseries with electric combination ovens (combi oven).
  - Convert all interior lighting to LED.
  - Provide occupancy sensors on all lights in sales and the front-of-house area.
  - Provide a secondary refrigeration loop for medium temperature cases.

  - Replace produce and dairy open back-loaded cases with enclosed reach-in front-loaded cases.
- **Quick, Low-Cost Wins**
  - Upgrade computers
  - Change staff behavior by turning off registers, computers, and office equipment plug loads at night.
  - Turn off cooler on level 2.
  - Upgrade ice machine.
  - Install occupancy sensors in restrooms.
  - Install gaskets and door closers on medium-temperature and low-temperature walk-ins.
  - Install occupancy sensors in refrigeration cases for lighting.
  - Install time clock for hot water recirculation.
- **Measures for Additional Consideration**
  - Change to DC electrical system for lighting and compressors.
  - Provide doors on all refrigerated cases.
  - Upgrade fans and lights and add insulation (0.5” additional) on walk-ins.
  - Add electronic expansion valves to compressors.
  - Install heat pump domestic-water heater or point-of-use water heating.
  - Replace RTUs with variable frequency drive (VFD) air handling unit (AHU) or heat pump.
  - Install adiabatic gas-cooling condenser.

Whole Foods Market engineering and operations staff evaluated the recommendations for feasibility and cost and consulted with DC Engineering. They selected a high-savings refrigeration package proposed by DC Engineering. The team then simulated the other ECMs with the refrigeration solution to determine the best combination of ECMs for overall energy savings within the capital cost budget. They identified a base set of ECMs that would reduce annual energy use by 55 percent, at a preliminary estimated cost of approximately $1.4 million. An additional set of measures in an optional package could increase energy savings to 59 percent for an additional preliminary estimate of $400,000.

Table 2 lists the savings potential of the proposed base and additional ECMs.

The team also recommended investigating rooftop PV. Preliminary analysis showed that covering the lower roof area with PV could provide approximately 200,000 kWh annually, based on an initial area calculation from PV Watts.[12] This could account for as much as 60 to 70 percent of the remaining store load, depending on the ECMs implemented.

[12] National Renewable Energy Laboratory, PV Watts Calculator.

**Table 2: Proposed Energy Conservation Measures**

| Proposed Measure | Individual ECM Energy Saving Potential |
|---|---|
| **Base Set of ECMs** | |
| Refrigeration High Savings Option | 8.96% |
| Lighting Retrofit to LEDs (Interior and Exterior) | 10.43% |
| Insulated Ducts with AHU + VFD | 9.85% |
| Solar Air Preheat | 4.83% |
| Heat Pump Water Heater | 6.48% |
| Increased Ceiling Reflectance + Reduced Ambient Sales Floor Lighting | 7.35% |
| Replace Rotisserie with Combi Oven | 3.66% |
| Insulate Walk-Ins, Replace Lighting and Fans with Higher Efficiency Components | 1.86% |
| Upgrade Computers | 0.93% |
| Behavioral Program for Plug Load Switching | 0.56% |
| Replace Gaskets on Walk-Ins and add Door Closers | 0.53% |
| Time Clock for Hot Water Recirculation | 0.20% |
| Ice Machine Upgrade | 0.17% |
| Disconnect L2 Cooler 10 Months per Year | 0.97% |
| **Base Option Total** | **56.54%** |
| **Add-On ECMs** | |
| Occupancy Sensors in Restrooms | 0.08% |
| Occupancy Sensors in the Back of House Spaces | 0.08% |
| DC Lighting Bus | 1.50% |
| Replace Refrigerated/Deli Tables | 0.16% |
| Fit Sinks with 1.15 gallon per minute (GPM) Spray Valves | 0.10% |
| Increase Insulation on Refrigeration Lines | 0.02% |
| Refrigeration System Hybrid Condenser | 0.65% |
| **Base and Add-On Totals** | 59.35% |

Source: Table data created by Arup

## Retrofit Package

The final step entailed bringing a contractor into the store to compile quotes for equipment, materials, and labor. These costs were much higher than the estimates used in the design phase, particularly the labor costs, and also reflected the unique constraints of the store from a construction-management perspective. The team prioritized the measures that gave the greatest savings for the least cost in determining the final retrofit package.

The specific measures in the retrofit package were to:

- Upgrade interior and exterior store lighting to LEDs.
- Increase ceiling reflectance and reduce lighting levels.
- Replace walk-in refrigerators lighting.
- Add occupancy sensor-lighting controls in restrooms and back-of-house spaces.
- Replace gas rotisserie with an electric-combi oven.
- Replace rooftop HVAC units with heat pumps with VFDs on board (high-efficiency variable air volume (VAV).
- Replace back-of-house HVAC with a variable refrigerant flow (VRF) system.
- Replace open refrigerated display cases with door cases.
- Add retrofit door to open refrigerated display cases.
- Update compressor racks with VFD, digital controls, and re-align loads to proper operating conditions.
- Consolidate the walk-in cooler and use one cooler only seasonally.
- Replace gaskets on walk-in doors and add automatic door closers.
- Add a time clock for hot-water recirculation.
- Use subcooling and cascade refrigeration loops for compressor racks.
- Fit sinks with 1.15 gallons-per-minute (GPM) spray valves.
- Change from hydrochlorofluorocarbon (HFC) to a hydrofluoroolefin/ hydrochlorofluorocarbon (HFO/HFC) blend refrigerant.
- Add SMC motors to two RTUs.
- Install a Viking Cold Storage TES system in the two freezer walk-ins.

Included in the refrigeration upgrade was changing the refrigerant. Changing from a high Global Warming Potential (GWP) refrigerant HFC R404A (or R507) to a lower GWP HFO/HFC blend refrigerant (R448A or R449A) had an energy reduction potential for the operating refrigeration system. Manufacturers of this refrigerant report a potential 10-percent reduction in energy use over R404A/R507.

The last two items on the list reflected the team's desire to integrate innovative energy savings technologies into the package. These technologies are described in Chapter 4.

# CHAPTER 4: Emerging Technologies

Based on the conditions and opportunities identified in the site investigation and working in collaboration with the project team, ProspectSV issued an open Call for Innovation in the fall of 2016. The call sought new technologies for the MarketZero project and created an opportunity to foster new ecosystem connections between product development teams and the building owners, designers, and engineers who serve as gate keepers to new technology adoption. ProspectSV's goal was to use the specifics of the MarketZero demonstration project to help move the entire innovation ecosystem forward.

ProspectSV conducted a global search for new technologies that were both demonstration-ready and site-appropriate for the MarketZero project. It tapped the networks of project partners in architecture and design in the building industry and reached out to more than 60 organizations and 100 individuals. The outreach included the following institutions:

- Incubators: Tumml, Los Angeles Cleantech Incubator, Cyclotron Road, Greentown Labs, Incubate Energy Network, CleanTech Open, Austin Technology Incubator, Energy Excelerator, Innosphere, NextEnergy, NY Acre, Oregon Best, Powerhouse, Urban.US, and TomKat
- Research Institutions and Academia: National Renewable Energy Lab (NREL), Lawrence Berkeley National Lab (LBNL), ARPA-E, Caltech's FLoW, UC Berkeley, and San Jose State University
- Funds: Prelude Ventures, Evok Innovations, Westly Group

The call elicited more than 40 responses, with submissions from 12 states and 6 countries. Members of the project team, as well as the Technical Advisory Committee, provided additional applicants.

## Criteria for Evaluation

The project team established five criteria in assessing the applicants with scored submissions:

- Technology readiness: What is the product's stage of development? Has the product had previous pilots? If not, is there a working prototype?
- Energy performance and cost: How does this product differ from current competitors in the market? What are the energy-saving benefits of installing this product? What is the cost of the installation?
- Site applicability: Does this product answer specific challenges for the selected store, its existing energy system's stores, its energy goals, and the building's vintage?
- Ease of installation and interoperability: What does the installation process entail? What kinds of disruptions will these cause for occupants? How easily does this technology integrate into existing systems?
- Ease of operations and maintenance (O&M): What is the maintenance effort, and what level of expertise is needed to complete it?

## Emerging Technologies Considered for Evaluation

This section summarizes the information and evaluations (including applicability scoring of 0-10), for the five finalists selected for further consideration.

### Viking Cold Solutions, Inc.: Phase Change Material cells (vikingcold.com)

- Product: Thermal storage
- Description: Thermal energy storage (TES) solution that combines intelligence with phase change material (PCM) to maximize the energy efficiency of a refrigeration system. Viking Cold PCM cells add thermal mass to a room, providing the ability to hold designated temperatures for much longer periods, which helps reduce refrigeration runtimes. Controls and an energy-management system help maintain a constant temperature and alert facilities to any mechanical malfunction or power outage.
- Pros: Provides low-impact thermal storage, includes simple controls, and provides product redundancy in case of electrical outage. Failure risk is low.
- Cons: New to California market, with unclear O&M implications (perceived to be limited). Cost is still high since the product is not at scale.
- Applicability to MarketZero: 9 out of 10 Applicability to Grocery: 9 out of 10. Technology Status: Pilot testing. Company Maturity: Start-up.

### Nelumbo: Ice-Nein (nelumbo.io)

- Product: Coating for coils (refrigeration or HVAC)
- Description: Nelumbo deploys advanced materials for energy solutions to improve energy efficiency, minimize fouling, and reduce downtime for any size or model of commercial refrigeration and air conditioning equipment. Their hydrophobic coil coating, Droplet(R)ejection™ improves cooling efficiency by up to 30 percent and reduces the defrost cycle frequency and duration by more than 20 percent.
- Pros: Reduced potential for bacteria buildup or fouling of coils, likely decrease in the maintenance of coil cleaning, California-based company, potential to make a direct comparison of coil efficiency in side-by-side units, and increased heat transfer efficiency. Failure risk to other systems is low.
- Cons: A pre-revenue company with only research test data, the risk of coating loss persistence could lead to loss of performance or potential chemical-leak issues.
- Applicability to MarketZero: 9 out of 10. Applicability to Grocery: 9 out of 10. Technology Status: Pilot-testing.
- Company Maturity: Startup established 2016.

### Software Motor Company: Vulcan Motor (softwaremotor.com)

- Product: High-efficiency motor and controls
- Description: A new electric motor that delivers improvements in electrical-energy consumption of 75 percent or more, depending on the application. When securely connected to central-data repositories, these internet of things (IoT)-ready motors generate data that can be visualized and analyzed, providing real-time insights into operating performance and efficiencies of motor-drive systems.

- Pros: Drive-integrated motor with IoT controls; high-efficiency, especially at partial load; California-based company.
- Cons: Unproven technology, limited field deployments, and limited product horsepower ranges.
- Applicability to MarketZero: 8 out of 10. Applicability to Grocery: 9 out of 10. Technology Status: Already deploying.
- Company Maturity: Start-up.

### Bosch: DC MicroGrid Platform (bosch.us)

- Product: DC Microgrid (turnkey)
- Description: DC-power server module that integrates AC grid power, DC onsite renewables, and DC battery storage that enable DC-powered lighting and HVAC systems. The resulting electrical system has significantly lower conversion losses.
- Pros: Eliminates conversion losses between solar storage and building loads that can use DC power such as electric vehicle charging, lighting, pumps and motors, integrated software and energy management solutions and other commercial building management tools from the same provider. An established large company, DC-power division based in California, and multiple pilot projects, including some funded by the CEC.
- Cons: DC compatibility may be limited and have limited options for lighting and HVAC, unclear security measures for either ZigBee or BacNet protocols, and DC systems likely to be available only as part of match funding. Failure risk is rather high.
- Applicability to MarketZero: 7 out of 10. Applicability to Grocery: 7 out of 10. Technology Status: Already deploying.
- Company Maturity: Well capitalized, willing to put in additional funding.

### Nextek Power Systems: Power Hub Driver (nextekpower.com)

- Product: DC Power supply module (LEDs)
- Description: DC-Power Hub Driver to integrate AC grid power, DC on-site renewables, and DC battery storage to enable DC-powered lighting and HVAC systems. The resulting electrical system will have significantly lower conversion losses.
- Pros: DC LED connection capability for reduced lighting energy use, ability to integrate with multiple DC LED lighting options, ability to integrate with fans and other DC equipment, and has worked on other Bay Area WFM stores.
- Cons: Compatibility may be limited, may have limited options for lighting and HVAC, unclear security measures for either ZigBee or BacNet protocols, and DC systems likely to be available only as part of match funding. Failure risk is rather high.
- Applicability to MarketZero: 7 out of 10. Applicability to Grocery: 7 out of 10. Technology Status: Already deploying.
- Company Maturity: Founded in 1995.

## Analysis of the Technologies

The team considered the DC-power technologies presented by Bosch and Nextek because of potentially generating onsite electricity by adding PV solar panels to the roof. Solar would create a DC-power source and a need to store and possibly convert from DC to AC power for AC-powered equipment. Also, with a DC-power source, the team could consider DC-powered LED lighting. At this stage of the project, there were no refrigeration systems that ran on a DC power source, so only the lighting and compressors would have benefited from installing this network. Unfortunately, the contractor determined that tree shading and equipment significantly limited the available roof area for installing PV solar. In analyzing the costs, WFM found that, at least for the foreseeable future, it could purchase clean energy from other sources more cheaply than it would cost to generate it onsite by installing solar. As a result, the team eliminated the technologies from Bosch and NexTek from further analysis.

The team included the remaining three technologies in the ECM modeling described in Chapter 3 and on the recommended ECM list.

## Technology Implementation

In the next phase of rigorous cost and design analysis, the team identified market-readiness issues with the Nelumbo HVAC coating technology. This technology was promising because it addressed a common energy issue in HVAC systems. Typically, humidity causes condensation, which causes ice to form. Heat is turned on to melt the ice. The Nelumbo hydrophobic coiling repels water, so ice never builds up, so the heat is not needed.

Unfortunately, the company wasn't up to scale at the time of the project for two reasons. First, there were physical constraints. The coils needed for the WFM freezer units were far larger than Nelumbo's production line could manufacture, and they were unable to make a change in the lines quickly enough for the project's timeline. Second, there were warranty issues. The manufacturer of the freezer case wouldn't accept liability if anything broke since the coils were not part of the original case.

The two remaining technologies, the Viking Cold TES system and the SMC motors, were included in the retrofit-design package and installed and tested in the construction phase of the project, described in Chapter 5.

## Challenges in Incorporating Emerging Technologies

This phase of the project allowed for reflection on the challenges in incorporating emerging technologies for this and any other deep-energy retrofit.

There may have been a missed opportunity in not including large firms in the call for innovation. Companies like Honeywell or Siemens may have had something to contribute with their deeper knowledge of the required operability and constructability.

This is insight and experience that start-ups typically do not have, and it is a significant barrier to the early adoption of emerging technologies.

The Nelumbo case flags a common concern; for emerging technologies, warranty issues can be a real barrier. To overcome it, these companies have to either partner with other companies or be acquired by a larger manufacturer of the kind of equipment needed to update and improve their own emerging technology.

Construction and design firms need confidence in what they specify and install. They tend to eliminate what they don't understand, trust, or can profitably implement. These are the purchasing barriers to innovation.

Pre-commercial technology and innovation firms are generally not attuned to how their technology will actually be installed, utilized, and maintained, or how it will function within a building. These companies need to better understand what a buyer (contractor or owner) needs to know to have enough confidence to purchase and install the technology.

While there is an obvious burden on the technology start-ups to work hard to improve their chances of being included in a major project, other members of the building community need to step up as well:

- The design community must take on the job of working with start-ups to translate their technologies' value in the design process. Specifically, this community must develop a better awareness of innovative technology and take some responsibility for understanding its importance and translating its value into the design process.
- Architects need to become conversant with specialty designers and understand how and where new technologies apply.
- Mechanical engineers need to embrace innovative technology, learn how it might apply, and develop a mastery of how it might fit into various environments. They must come to see it as a real added value, something they can confidently offer to customers and asset owners.
- Contractors need to determine how best to integrate technology and how to reduce its risk. Construction firms look for constructability and operability, but they have a lot of latitude in their ability to reduce risks and reduce costs.

Chapters 5, 6, and 8 show how the two new technologies identified and evaluated in this chapter were integrated into the construction, M&V, and benefit-analysis phases of the project.

# CHAPTER 5: Construction: Procurement, Installation, Commissioning, and Owner Training

In the preconstruction phase of the project, the team drew and gained approval for plans, final-cost and schedule estimates, obtained permits, and hired contractors. (Appendix C, Schematic Design Report includes drawings for each of the subsystems.) In addition, new electric submeters were installed to improve monitoring of energy use. Construction on the retrofit began in January 2019.

## Construction Team

WFM chose contractors and subcontractors that had worked together before on many WFM projects. Team members and their primary responsibilities follow:

- Source Refrigeration joined the project early on, attending the design charrette, and subsequently acted as general contractor liaising between WFM and the rest of the team.
- H.A. Bowen Electric Inc. handled the lighting retrofit as well as refrigeration wiring.
- RoundTree Plumbing Inc. installed kitchen and hot water systems.
- BSM Construction Inc. provided general contracting.
- Air Systems Inc. installed the HVAC systems.
- e2s energy efficiency services llc. provided commissioning services.

WFM Director of Sustainability and Facilities provided overall construction project management and coordination.

## Construction Tasks

### Heating, Ventilation, and Air Conditioning

The HVAC upgrade included replacing two main sales-floor RTUs with new Trane package units and replacing several in-wall air-conditioning units with a separate Daiken VRF system. The major construction tasks were to:

- Replace existing gas-fired RTUs.
- Replace existing AC wall units.
- Install two new Trane high-efficiency electric package heat pumps with:
  - 23 tons DX cooling capacity and 304,000 BTUH heating capacity.
  - Variable speed and digitally controlled compressors.
  - 9,000 total supply air ft3/min with VFDs.
  - Factory-installed Trane controllers.
- Install Daiken VRF HVAC System with fan coils and piping.
- Replace Trane motors with high-efficiency SMC fan motors.

- Air balance the entire system.

### Refrigeration

Refrigeration accounted for the largest portion of electrical load in the building. Major tasks were to:

- Upgrade the main refrigeration racks.
- Install a valve to turn off one walk-in freezer except during the holiday season.
- Install new Hussman display cases for the sales area.
- Install Hussman retrofit doors on existing open-display cases.
- Replace gaskets on walk-ins.
- Increase insulation on refrigeration lines.
- Install a Viking Cold Solutions TES system and strip curtain.
- Modify the main compressor system including refrigerant change, satellite compressors, and adjustments in controls.

### Lighting

The lighting load was the second-largest electrical load in the building. Major tasks were to:

- Replace the existing lighting system with LED lighting.
- Install daylight sensing controls for fixtures in areas with daylight access.
- Install occupant sensing controls in restrooms, offices, stairwells, and storage and shelving spaces.
- Consolidate multiple lighting panels onto one panel except for the refrigerated case lighting.

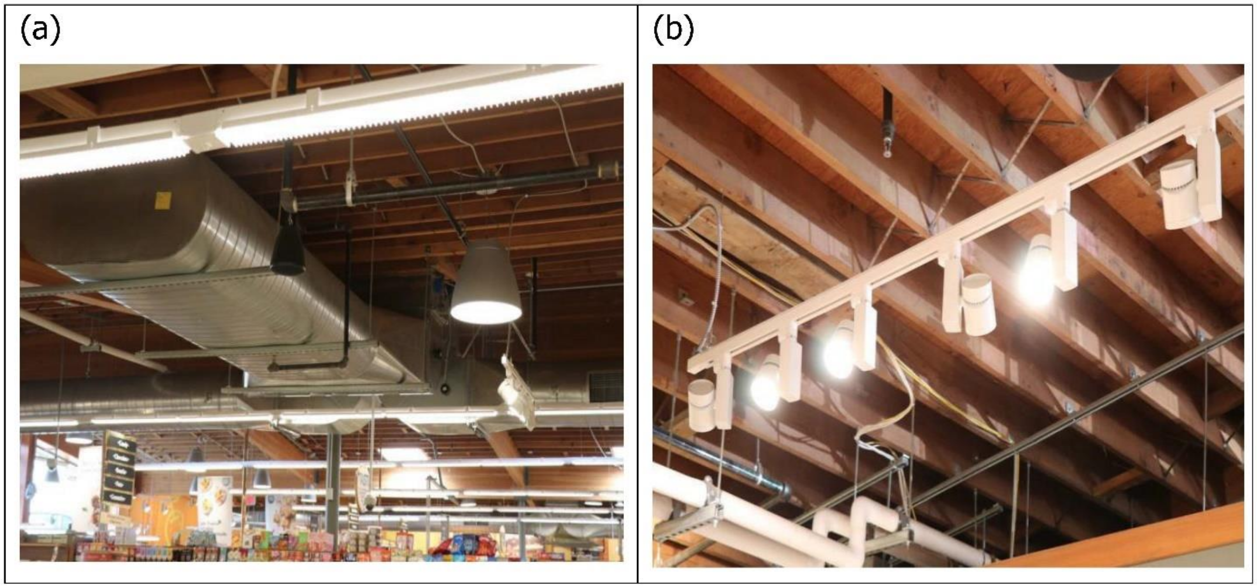
### Kitchen and Hot Water

- Replace gas rotisserie with an electric combi oven.
- Fit sinks with low-flow (1.15 GPM) spray valves.
- Install a time clock to manage hot-water recirculation.

## Construction Photographs

Figures 14 through 19 show photographs of replaced and installed equipment.

**Figure 14: LED Lighting Replaced Fluorescent Lighting on the Sales Floor**




**Panel (a) shows the old fluorescent lighting. Panel (b) shows the new LED lighting.**

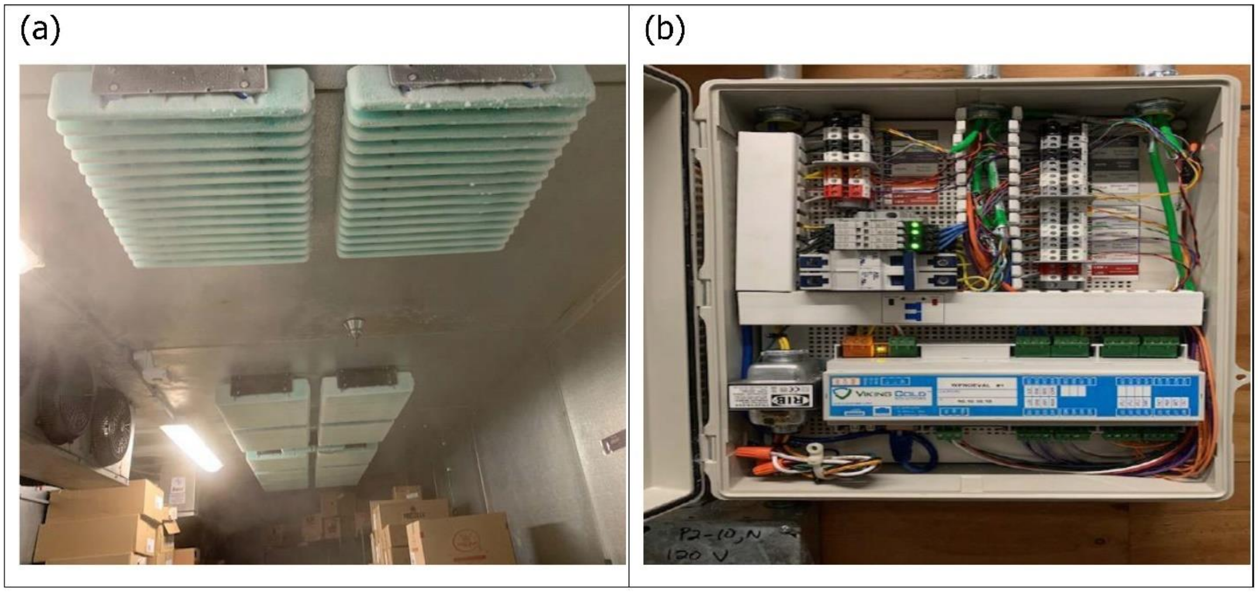
Source: Source Refrigeration

**Figure 15: Replace Open Cases with New Door Cases**


**Panel (a) shows the old open cases. Panel (b) shows the new enclosed cases.**

Source: Source Refrigeration

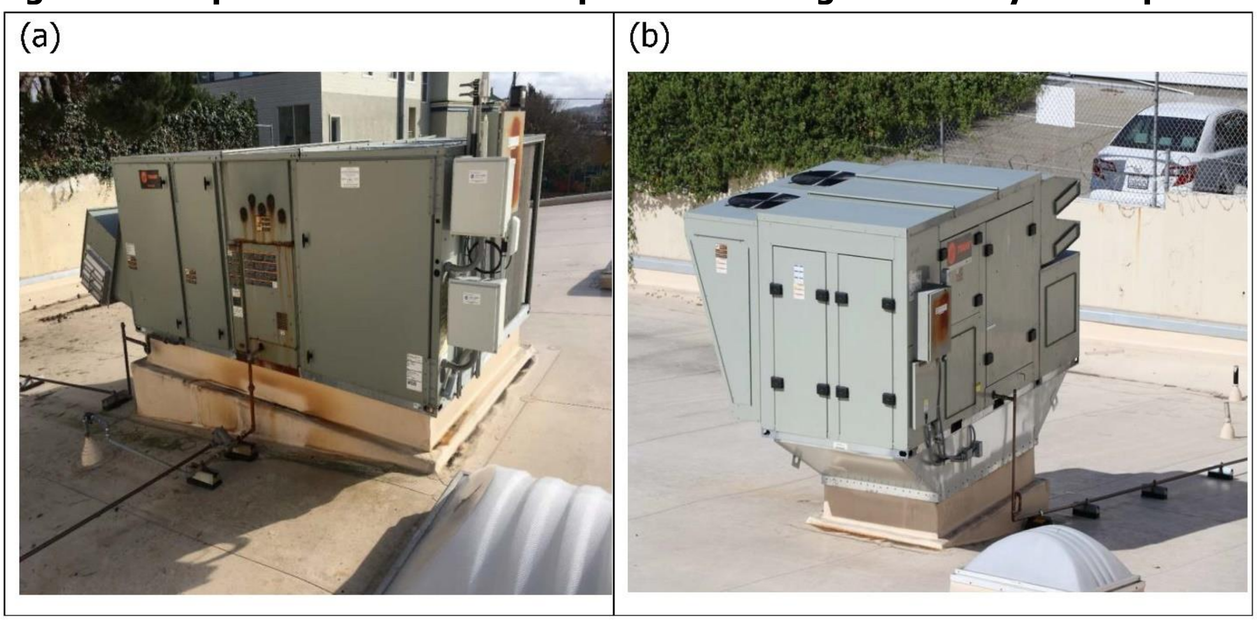
### Figure 16: Viking Cold Solutions Thermal Energy Storage System




**Panel (a): Viking Cold storage unit. Panel (b): Viking Cold control box.**

Source: Source Refrigeration

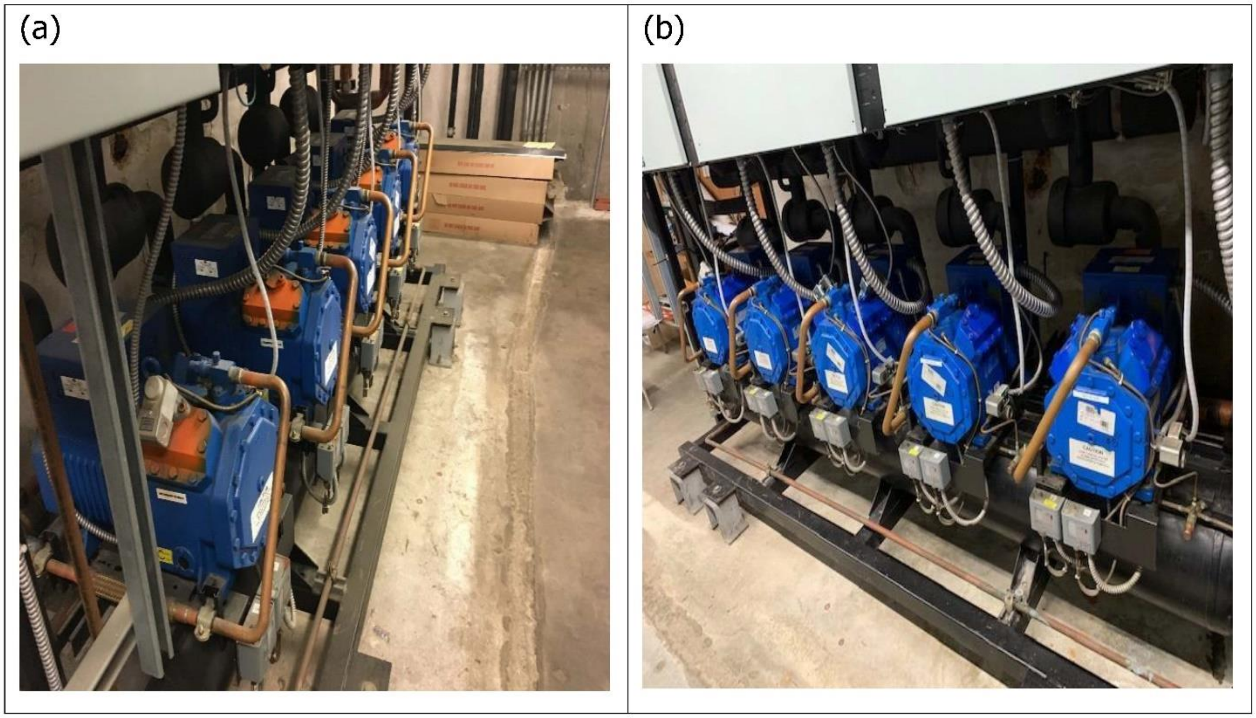
### Figure 17: Replace Gas-Fired Rooftop Units with High-Efficiency Rooftop Units




**Panel (a): Gas-fired RTU. Panel (b): Electric heat pump with variable-speed evaporator and condenser fans**

Source: Source Refrigeration

**Figure 18: Refrigerant Change Out**



**Changing the refrigerant reduced GHG emissions. Panel (a) Old R404A refrigerant; global warming potential (GWP) of 3,922: Panel (b) New R448A refrigerant; GWP of 1,273**

Source: Source Refrigeration

Once construction was complete, commissioning began. Whole Foods Market engaged e2s to commission all elements of the mechanical HVAC systems, refrigeration systems, electric lighting systems, and special building equipment for central systems. e2s also created a commissioning plan based on WFM's requirements. The commissioning included performance verification, which is dynamic testing of systems (rather than just components) under full operation. Systems were tested in various modes such as during low cooling or heating loads, high loads, component failures, unoccupied, varying outside air temperatures, fire alarm, power failure, and under other conditions.

The systems were run through all of the control system's sequences of operation, and components were verified as responsive per expected sequences of operation. The installing contractor or vendor performed the equipment and systems testing.

The following systems were commissioned:

- Refrigeration system
- AHUs
- VAVs
- Exhaust fans
- Kitchen exhaust fans and hoods
- Door air curtains
- Testing, adjusting, and balancing verification
- Energy-management system

- Interior lighting-zone controls
- Lighting override devices
- Exterior daylight controls
- Electrical power
- Air-distribution systems and access

Representatives from WFM, Arup, DC Engineering, Source Refrigeration, and e2s all served on the commissioning team.

e2s prepared a final report detailing all the items addressed on site, observations for WFM facilities team, a commissioning issues log, and photos of issues before and after they were addressed.

## Construction Project Challenges and Impacts

Several construction project challenges stemmed from the unique constraints presented by the layout, operation, and environment of the store. These included:

- A small but high-volume and densely populated store.
- A limited staging area for storing new and replaced equipment.
- Location of the mechanical equipment on the second floor.
- A small 15,000 square-foot parking lot.
- Residential neighbors on all sides.
- Pedestrian, bicycle, and vehicle traffic, including city buses.
- The need for the store to be fully operational throughout construction.

### Scheduling Issues

The MarketZero project was estimated to require six months of construction. However, like most retail operations, grocery stores have increased traffic, deliveries, and sales during November and December. As a result, construction could not begin in earnest until January 2019. Nevertheless, the team completed the bulk of the planned work by the end of March 2019.

Since construction could not disrupt customer or staff activities and since the store is open to the public from 8 am to 10 pm and staffed by WFM employees from midnight to 4:00 a.m., the majority of the work had to be performed at night, which created logistical complexities.

### Logistics

With the store's limited staging area, materials and equipment had to be shipped, received, assembled, inventoried, and inspected off site at a location 50 miles from the job site. As a result, delivery to the job site had to be scheduled precisely, on an as-needed basis. A small storage unit was placed in the parking lot to help mitigate this issue; using it also required precise scheduling.

The timing constraints meant that each task had to start and end within a night-time window. Contractors had to remove all materials, equipment, and tools from the store interior at the end of the night shift. Changes to temperatures of refrigerated units also had to be returned to correct levels before being re-merchandised for the start of business. One big job, changing the refrigerant, was particularly challenging. It required shutting down all refrigeration systems, pulling out the refrigerant, and installing the new one before reaching the temperature setpoints by morning.

Also, since all equipment was custom built, equipment delivery lead times took longer than estimated, which affected planned construction sequences.

## Noise

Shortly after the crew installed the new RTU's, the City of San Francisco notified the store that neighbors had complained about noise coming from the roof. The electric heat pumps that replaced relatively quiet gas heaters made enough noise to cross the allowable noise limits set by the city. Since the store roof is lower than the residential buildings and trees that surround it, the sound of the fan motors in the RTUs intensified in unpredictable ways. WFM hired a consultant to investigate and design a solution.

Plans for sound barriers enclosing each of the RTU's were designed, approved, and permitted. Source Refrigeration implemented the solution, which included adding beams inside the building on the sales floor to support the additional weight of the sound barriers on the roof. The entire process added several months to the project as well as unbudgeted costs.

The SMC motors, which replaced the motors on the Trane heat pumps, also created a noise issue. The ductwork carried the sound of the motors from the roof onto the sales floor. The motor speed was adjusted to reduce the noise.

## Project Complexity

The project was inherently complex because it wasn't simply a commercial retrofit; it was also a demonstration project that required significant monitoring, communications, and modifications by the construction and project teams to track progress in reaching energy-savings goals.

Adding the sound barriers to the roof created even more unforeseen layers of complexity. The solution required a new cycle of design, construction, and testing, and caused delays for other tasks. For example, while initial commissioning for refrigeration, HVAC, and air-balance checks were completed in March 2019, other testing had to wait until after the sound barrier had been built and tested. Specifically, the Trane heat pumps had been modified to reduce the noise until the solution was in place. Once the sound barriers were complete, the SMC motors in the heat pumps could be adjusted and tested for optimum energy savings.

This add-on schedule also compressed the time available for the M&V process to compile the project's achievements.

## Managing Impacts

The team adopted specific measures that helped mitigate the impact of these challenges as they arose. These included expanding the role of the general contractor, Source Refrigeration, to act as a liaison between the manufacturers and WFM. This action ensured that the custom plans and specifications would produce the desired result. Source Refrigeration also provided a full-time job site superintendent to coordinate all the activities of the trades, meet with the store managers every day, coordinate activities inside the store, and keep everyone informed.

In addition, there were weekly project meetings with the construction team and WFM, with frequent communication between sessions.

The team reported that these and other measures for managing impacts were successful in large part because there was extensive cooperation across the trades and because the contractors and WFM had already built established partnerships.

## Owner Training

The WFM Director of Sustainability and Facilities managed the construction and was involved with the installation and testing of all the equipment on the site. As a result, WFM now has expert in-house knowledge for all the systems. A final task for the construction phase of the project was to provide the information on installed systems to WFM.

The Whole Foods Noe Valley ZNE Project's O&M manuals cover all major HVAC, refrigeration, lighting, and control systems: Trane high-efficiency heat pumps, Hussmann display cases, Hussmann retrofit doors, Daiken's VRF HVAC system, and Viking's Cold Solutions TES system.

# CHAPTER 6: Data Analysis

Lawrence Berkeley National Laboratory determined the M&V methodology, created the models and applied them to the project data, and analyzed the results. Appendix D, Measurement and Verification Report provides all the details of the M&V process and results. This chapter highlights its work.

## Data Acquisitions and Monitoring Energy Use

Before the retrofit, the store had six electricity meters monitoring a small selection of end uses including the main lighting panel, the rooftop RTUs, and the two refrigeration racks. This metering accounted for about two-thirds of the building load.

To better understand building energy use, WFM installed 12 new submeters just before the retrofit construction. One meter was installed in parallel with the PG&E utility meter and recorded the total store electricity consumption. Seventeen submeters are now installed throughout the electrical system of the store and measure critical loads such as refrigeration components, RTUs, and lighting. Parasense provided the electrical metering system. Data from all 18 electricity meters became available after December 14, 2018.

Natural gas loads were not individually metered, so unfortunately little information was available about end-use gas consumption beyond the whole-facility gas use.

## Measurement and Verification of Energy Savings

### Methodology

The main goal of the M&V was to verify energy savings from the aggregate of ECMs implemented in the store. The LBNL team adopted the International Performance Measurement and Verification Protocol (IPMVP), which verifies savings from energy projects and measures through a systematic process. The IPMVP defined four M&V options (options A through D) that meet different needs based on the risk tolerance and M&V budget. Table 3 summarizes these options.

Table 4 summarizes the M&V options and strategies the team selected for the MarketZero project ECMs. They evaluated some ECMs using both the aggregate and individual retrofit isolation-based approach. For the ECMs that were mostly equipment replacements or upgrades, where the potential for energy savings was small, the savings were not evaluated at the individual level but were included at the store level.

**Table 3: Overview of International Performance Measurement and Verification Protocol Options**

| IPMVP Option | How Savings Are Calculated | Typical Applications |
|---|---|---|
| **A. Retrofit Isolation: Key Parameter Measurement**<br>• Savings are determined by field measurement of the key performance parameter(s) that define the energy use of the ECM's affected system(s) and/or the project success.<br>• Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period.<br>• Parameters not selected for field measurement are estimated.<br>• Estimates can be based on historical data, manufacturer's specifications, or engineering judgement.<br>• Documentation of the source or justification of the estimated parameter is required. The plausible savings error arising from estimation rather than measurement is evaluated. | Engineering calculation of the baseline and reporting period energy from:<br>• Short-term or continuous measurements of key operating parameter(s); and<br>• Estimated values.<br>Routine and non-routine adjustments as required. | • A lighting retrofit where power draw is the key performance parameter that is measured periodically.<br>• Estimated operating hours of the lights are based on facility schedules and occupant behavior. |

| IPMVP Option | How Savings Are Calculated | Typical Applications |
|---|---|---|
| **B. Retrofit Isolation: All Parameter Measurement**<br>• Savings are determined by field measurement of the energy use of the ECM-affected system.<br>• Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period. | • Short-term or continuous measurements of baseline and reporting-period energy, and/or engineering computations using measurements of proxies of energy use.<br>• Routine and non-routine adjustments as required. | • Application of a variable-speed drive and controls to a motor to adjust pump flow. Measure electric power with a kilowatt (kW) meter installed on the electrical supply to the motor, which reads the power every minute. In the baseline period this meter is in place for a week to verify constant loading. The meter is in place throughout the reporting period to track variations in power use. |
| **C. Whole Facility**<br>• Savings are determined by measuring energy use at the whole facility or sub-facility level.<br>• Continuous measurements of the entire facility's energy use are taken throughout the reporting period. | • Analysis of whole facility baseline and reporting period (utility) meter data.<br>• Routine adjustments as required, using techniques such as simple comparison or regression analysis.<br>• Non-routine adjustments as required. | • A multifaceted energy management program affecting many systems in a facility. Measure energy use with the gas and electric utility meters for a 12-month baseline period and throughout the reporting period. |
| **D. Calibrated Simulation**<br>• Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility.<br>• Simulation routines are demonstrated to adequately model actual energy performance measured in the facility.<br>• This option usually requires considerable skill in calibrated simulation. | • Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.) | • A multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period.<br>• Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation.<br>• Baseline energy use, determined using the calibrated simulation, is compared to a simulation of reporting period energy use. |

Source: Efficiency Valuation Organization (EVO), Core Concepts: International Performance Measurement and Verification Protocol, EVO 10000-1:2016, October 2016

**Table 4: Summary of the Measurement and Verification Plan for the MarketZero Energy Conservation Measures**

| ECM | ECM Description | M&V Option | Summary of M&V Plan |
|---|---|---|---|
| Aggregate | The aggregate of all ECMs | Options C and D | Continuous baseline and post-installation kW metering; calibrated baseline model. |
| Lighting | Lighting retrofit to light-emitting diodes (LEDs) (interior and exterior) | Option B | Short-term monitoring baseline; post- installation kW metering. Daylight responsive dimming of lighting requires Option B (using metered data over a longer period), instead of Option A (spot measurements). |
| Refrigeration | Refrigeration scope of work, Viking Cold Storage | Option B | Pre-retrofit monitoring baseline; post- installation kW metering; comparing energy consumption pre-retrofit and post-retrofit. Evaluate correlation with weather or time-of- day to correct for routine events. |
| Refrigeration – Viking Cold Storage | Apply Viking Cold Storage TES system to the walk-in freezer | Option B | Manufacturer to measure baseline consumption and post-retrofit consumption and provide savings and raw data. Corroborate these savings and the approach with others. |
| HVAC | RTU replacement | Option B | Pre-retrofit monitoring baseline; post- installation kW metering; comparing energy consumption pre-retrofit and post-retrofit. Evaluate correlation with weather or time-of- day to correct for routine events. Separate analysis for cooling and ventilation due to change of heating from gas to electric. |
| HVAC | SMC Motors | Option B | Pre-retrofit monitoring of fan speeds in the RTU. Short term monitoring of speed vs. power characteristics for Trane and SMC motors. |

Source: Analysis performed and table created by LBNL. See Appendix D for further details.

## Energy Upgrade Analysis

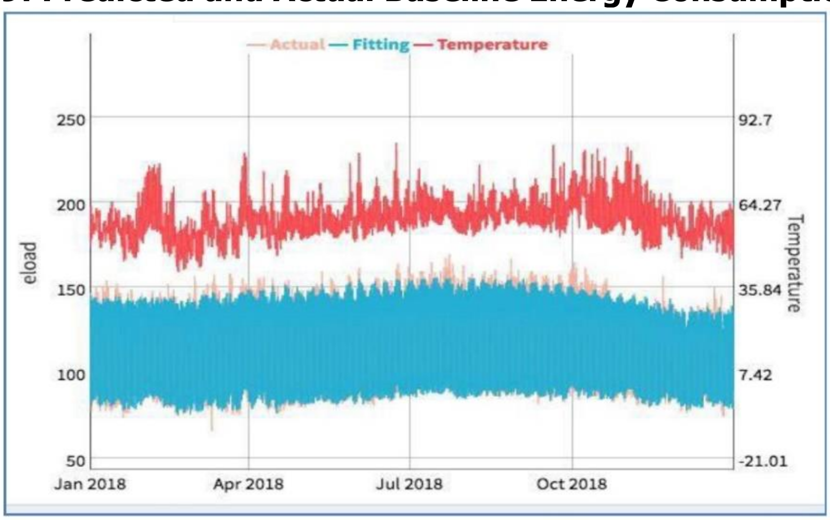
To measure energy savings from the retrofit, the team first calculated a baseline for total energy consumption for a period before the retrofit (mid-2018 through early March 2019), using the selected M&V options and strategies. This is called the 2018 baseline period.

The same M&V options and strategies were then used to measure subsequent savings after the retrofit beginning April 1, 2019 and extending until February 15, 2020. The team projected energy use February 16 through April 1, 2020 to estimate savings for one full year. This is called the post-retrofit period.

To estimate electricity benefits, the team first created a new baseline model of what the energy consumption would have been in the post-retrofit period if the retrofit had not taken place. They began by creating a calibrated model of the 2018 baseline period and adjusting it to reflect 2019 conditions of both the outdoor air temperature and the time of week. LBNL's time of week and temperature (TOWT) algorithm was used to develop this model. The TOWT algorithm accurately predicts building energy use for non-residential building types and includes flexibility for improving model fit. (Originally developed in 2011,[13] LBNL modified it in a recently released version.[14]) The algorithm then compared post-retrofit energy consumption estimates with the new baseline model's results showing the energy that would have been consumed in this same period. (Appendix D describes this modeling approach in more detail.)

Figure 19 shows the energy consumption predicted by the new baseline model (in blue, labeled "Fitting"), along with actual consumption used to develop the model and the independent variable of outside-air temperature.

**Figure 19: Predicted and Actual Baseline Energy Consumption in kW**




**Temperature is in Fahrenheit and eload is in kW.**

Source: Analysis performed and graph created by LBNL

[13] Mathieu, J. L., P. N. Price, S. Silicate, and M. A. Piette. 2011. Quantifying Changes in Building Electricity Use, With Application to Demand Response. IEEE Transactions on Smart Grid 2(3), pp. 507– 518.

[14] Lawrence Berkeley National Laboratory, GitHub RMV2.0.

Table 5 summarizes the goodness of fit by applying statistical methods recommended by IPMVP and other M&V guidelines.

**Table 5: Summary of Goodness of Fit for the Baseline Model**

| Statistic | Criteria | Value |
|---|---|---|
| Coefficient of Determination ($R^2$) | [a]IPMVP: $R^2$ > 75% | 94.21% |
| Coefficient of variation of the root mean squared error CV(RMSE) | [b]ASHRAE G14 < 25% | 4.21% |
| Net determination bias (NTB) | < 0.5% | -0.04% |

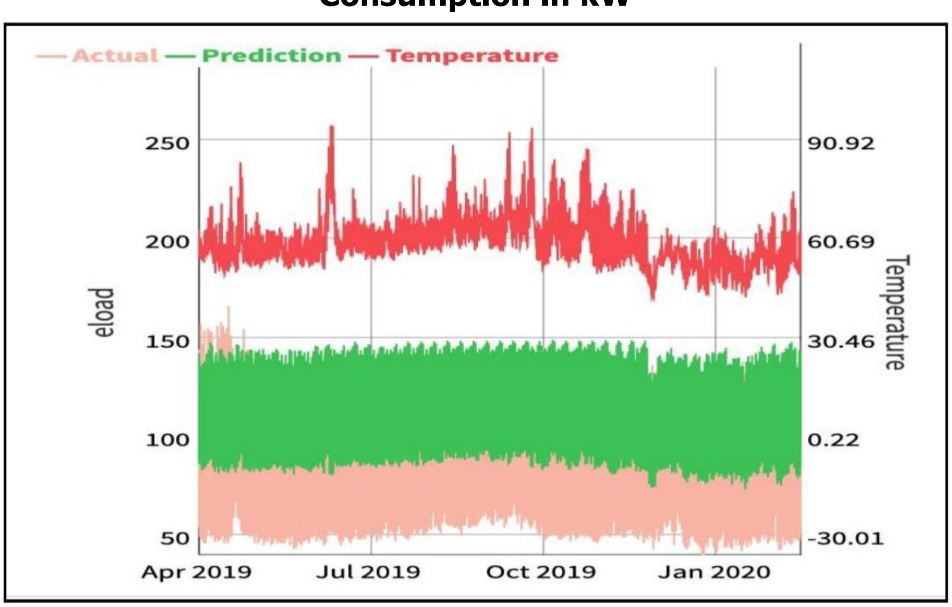
Source: (a). Efficiency Valuation Organization (EVO), Core Concepts: International Performance Measurement and Verification Protocol, EVO 10000-1:2016, October 2016. (b). ASHRAE Guideline 14 (2014). ASHRAE Guideline 14-2014 for Measurement of Energy and Demand Savings, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, Georgia.

Using this new baseline model, the team estimated the energy consumption for the post-retrofit period without the retrofit. This estimate is called the adjusted baseline energy use.

This adjusted baseline energy use was then compared with the estimated post-retrofit energy consumption (with the retrofit implemented) to arrive at the savings created by implementing the retrofits.

Figure 20 shows the savings outlined in Table 5.

**Figure 20: Predicted Baseline Electricity Compared With Post-Retrofit Energy Consumption in kW**




**Temperature is in Fahrenheit and eload is in kW.**

Source: Analysis performed and graph prepared by LBNL

Table 6 summarizes verified savings for the evaluation period, along with predicted savings for the project. The predicted savings were based on the simulation analysis performed by Arup during selection of the ECMs.

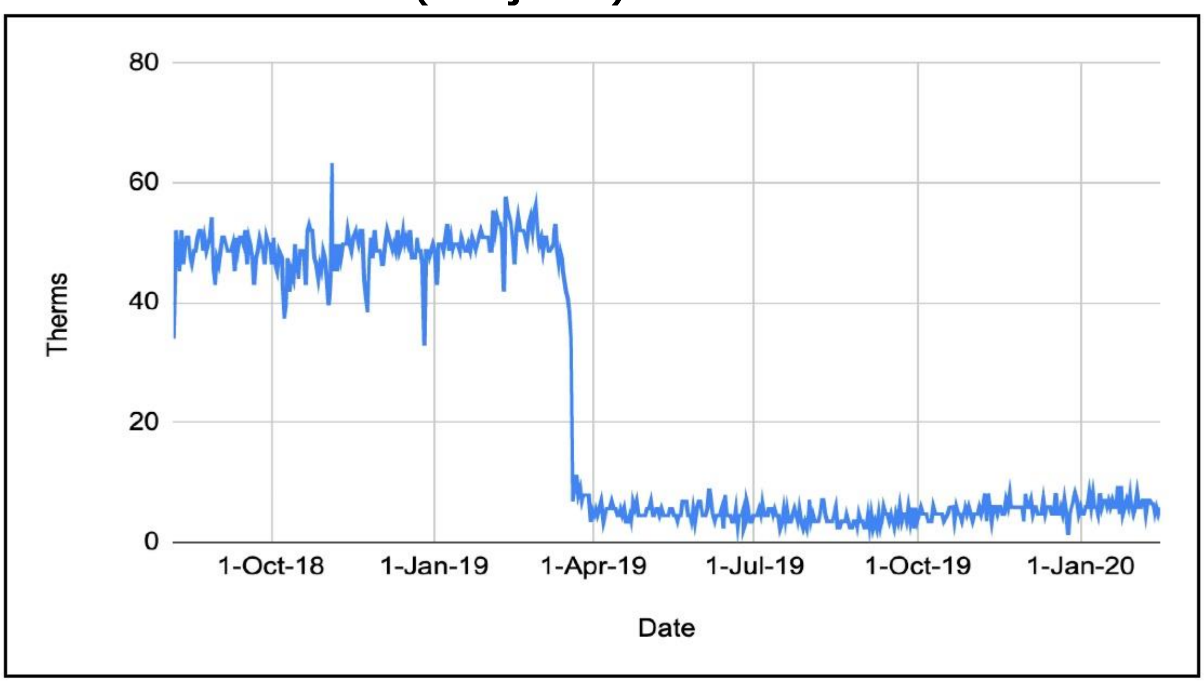
**Table 6: Verified Savings for the Post-Retrofit Period Using the Option C Whole-Facility-Level Analysis**

| | Total Energy Use (Mega-joules) | Total Energy Use (MMBtu) | Electric Energy Use (kWh) | Natural Gas (Therms) |
|---|---|---|---|---|
| Baseline Use | 5,014,101 | 4,752 | 927,434 | 15,871 |
| Post-Retrofit Period | 2,803,993 | 2,658 | 731,281 | 1,618 |
| Savings | 2,210,108 | 2,095 | 196,153 | 14,253 |
| **% Savings/ Baseline** | **44.1%** | **44.1%** | **21.2%** | **89.8%** |
| Annualized Baseline Use | 5,701,392 | 5,404 | 1,054,559 | 18,046 |
| Annualized Savings | 2,513,051 | 2,382 | 223,040 | 16,207 |
| Predicted Annual Savings (Arup model) | 2,438,068 | 2,311 | 351,374 | 11,119 |

Source: Analysis performed and table prepared by LBNL

Figure 21 compares the raw natural gas consumption between the baseline and post-retrofit phases of the project.

**Figure 21: Plot of Pre- and Post-Retrofit Natural Gas Consumption (unadjusted) in Therms**

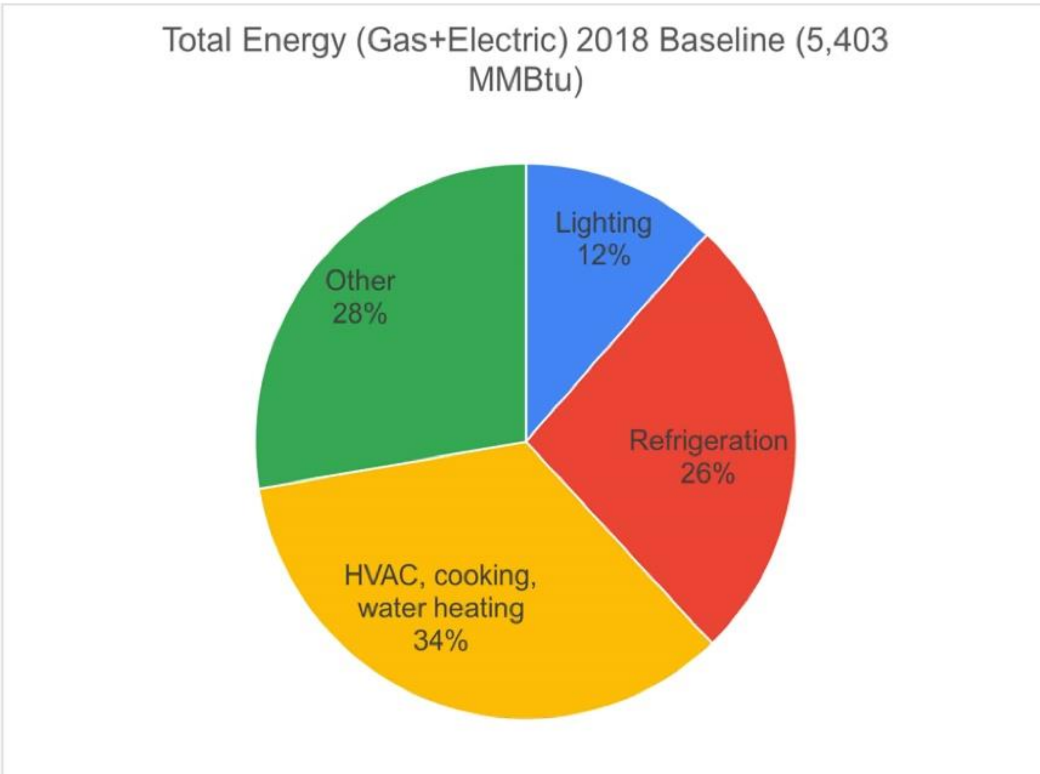



Source: Analysis performed and figure prepared by LBNL

Total energy consumption refers to a metric that converts the energy content of gas (measured in therms) and electricity (measured in kWh) to a common metric: MMBtu (million British thermal units). This conversion allows a comparison of savings measures, some that affect only electricity, and others that affect both gas and electricity consumption.

Figure 22 shows how the 5,403 MMBtu consumed during the 2018 baseline period were distributed across various end-use load categories for the store. The loads associated with gas consumption (HVAC, cooking, and domestic hot water (DHW) make up 35 percent of the store's total energy consumption.

**Figure 22: 2018 Baseline Total Energy (Gas+Electric) Consumption by Category**



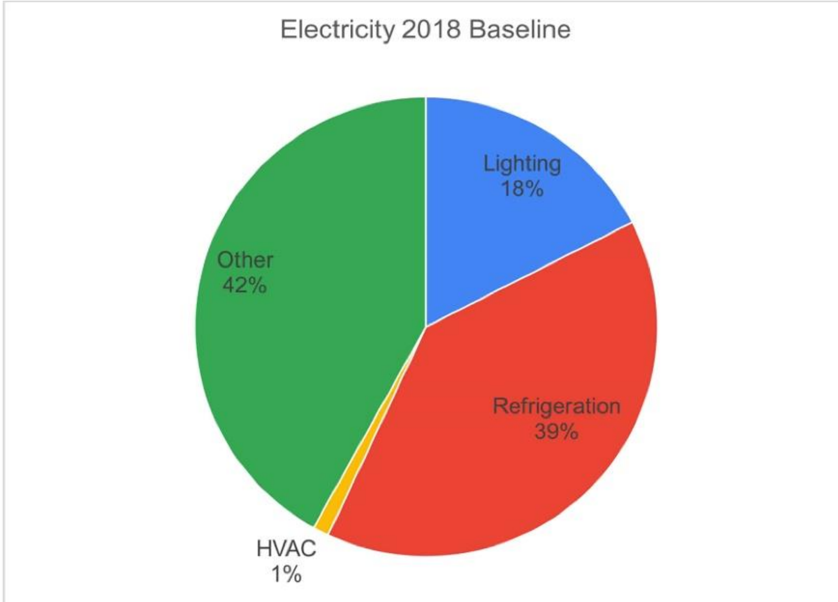

Source: Analysis performed and graph prepared by LBNL

The next largest category is "Other," which is also sometimes referred to as miscellaneous electrical loads (MELs) and includes plug loads like cash registers, the hot food bar, and back-of-house loads like conveyor belts and roll-up doors.

Refrigeration accounts for about one-quarter (26 percent) of all the energy consumed, followed by lighting at 12 percent.

Figure 23 shows the electricity portion of the 2018 baseline.

**Figure 23: Categories of Electricity Consumption for the 2018 Baseline Period**



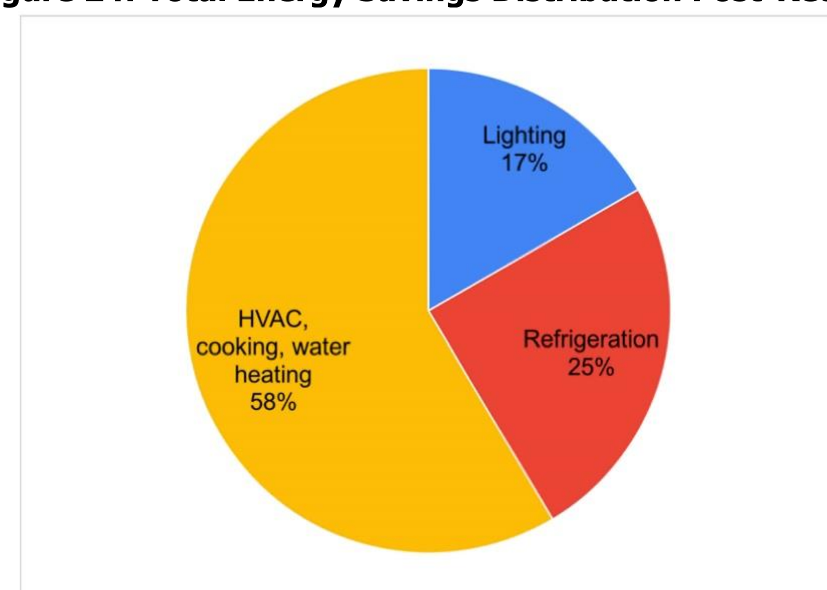

Source: Analysis performed and graph prepared by LBNL

Refrigeration and other loads are each responsible for about 40 percent of the load, lighting accounts for 18 percent, and HVAC energy makes up only 1 percent of baseline electrical consumption. The HVAC electricity consumption is low because the heating portion of the baseline HVAC system was natural gas.

The cooling consumption was limited because the open refrigerated cases unintentionally provided space cooling. However, this required cooling the cases at a much lower temperature, which took more energy than it would have to cool the space air to 70°F to 72°F.

Figure 24 shows the distribution of the savings among the major end-use categories.

**Figure 24: Total Energy Savings Distribution Post-Retrofit**

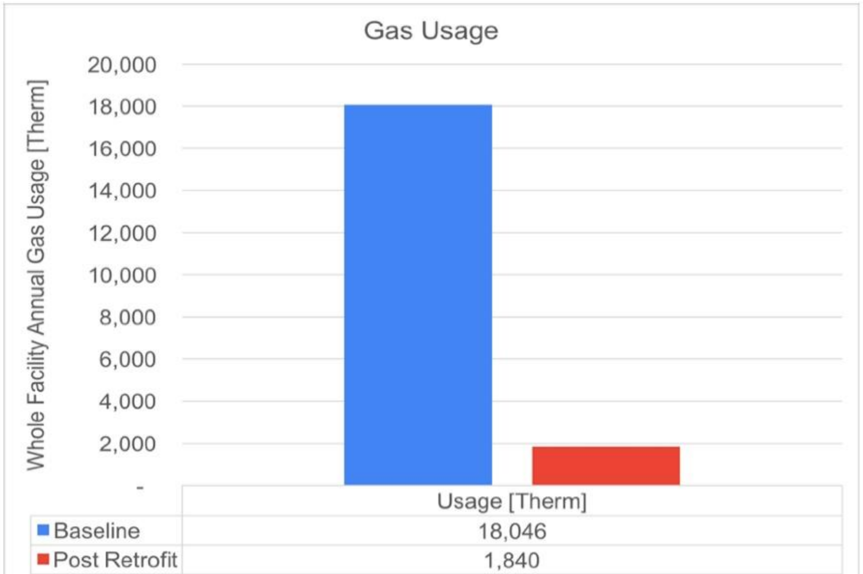



Source: Analysis performed and figure prepared by LBNL

The large reductions in the HVAC, cooking and DHW categories are due to the large decrease in gas usage.

Figure 25 shows how the retrofit reduced gas consumption by 90 percent.

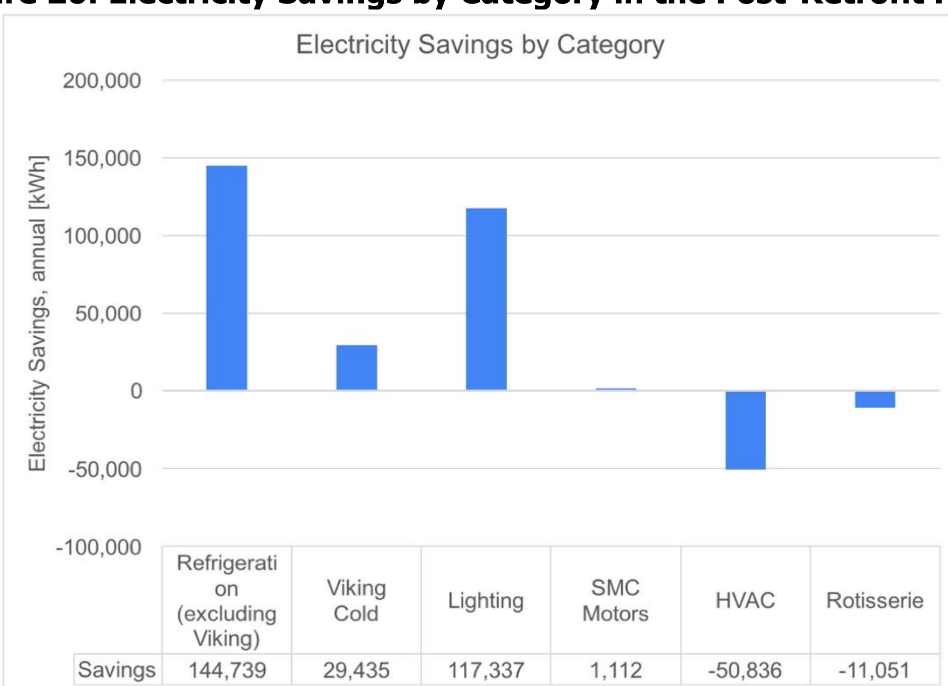
**Figure 25: Baseline vs. Post-Retrofit Gas Usage**




Source: Analysis performed and graph prepared by LBNL

The 90 percent gas savings represented a 1,621 MMBtu reduction in total energy, which is 68 percent of the store's total energy savings. Some of this reduction in gas consumption resulted in increases in electricity consumption, such as the electric heat pump in the HVAC rooftop units, which offset gas space heating, as shown in Figure 26.

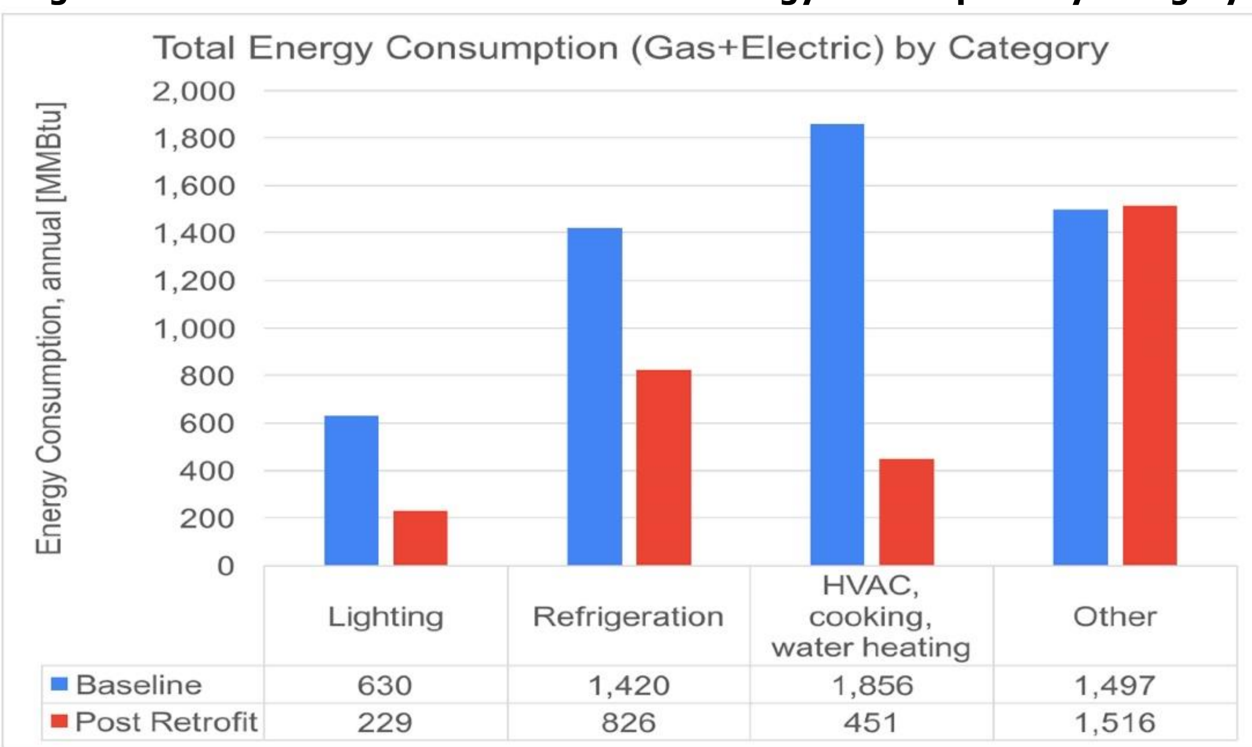
**Figure 26: Electricity Savings by Category in the Post-Retrofit Period**




Source: Analysis performed and graph prepared by LBNL.

Figure 27 compares the baseline and post-retrofit energy use for each end load. The largest drop was for the HVAC, Cooking, and DHW category due to the significant reduction in gas consumption.

**Figure 27: Baseline vs. Post-Retrofit Total-Energy Consumption by Category**




Source: Analysis performed and graph prepared by LBNL

## Summary of Savings

The largest energy savings were from reducing natural gas consumption. By replacing the gas space heating with an electric heat pump and swapping out the gas-fired rotisserie for an electric-combi oven, the gas usage in the store was reduced by 90 percent, representing 68 percent of overall total energy savings.

The overall total energy savings from the retrofit was 44 percent for the combination of gas and electricity, and resulted in an EUI of 120 kBtu/ft$_2$/yr.

Table 7 summarizes the breakdown of savings and Table 8 shows the EUI for the store.

**Table 7: Annualized Energy Savings Overview**

| | Baseline | Savings | Savings fraction |
|---|---|---|---|
| **Electricity (kWh)** | | | |
| Lighting | 184,481 | 117,337 | 63.6% |
| Refrigeration | 416,191 | 174,174 | 41.8% |
| HVAC heating | 1,898 | -51,881 | N/A |
| HVAC cooling + ventilation | 9,858 | -67 | -0.7% |
| Cooking | 3,413 | -11,051 | N/A |
| Other | 438,717 | -5,472 | -1.2% |
| Whole facility | 1,054,559 | 223,040 | 21.2% |
| **Gas (MMBtu)** | | | |
| HVAC heating, cooking, water heating | 1,805 | 1,621 | 89.8% |
| **Total energy (MMBtu)** | | | |
| Lighting | 629.6 | 400.5 | 63.6% |
| Refrigeration | 1,420.5 | 594.5 | 41.8% |
| HVAC heating, cooking, water heating | 1,822.8 | 1405.9 | 77.1% |
| HVAC cooling + ventilation | 33.6 | -0.2 | -0.7% |
| Other | 1,497.3 | -18.7 | -1.2% |
| Whole Facility | 5,403.9 | 2,381.9 | 44.1% |
| **Emerging Technologies (kWh)** | | | |
| HVAC heating and cooling fans (SMC motor* retrofit) | N/A | 1,112 | 7.1% |
| Walk-in freezer (Viking Cold retrofit) | 117,831 | 29,435 | 25.0% |

***Baseline inferred from 2019 operations without emerging technologies in place**

Source: Analysis performed and table prepared by LBNL

**Table 8: Energy-Use Intensity Savings**

| | Before | After | Savings |
|---|---|---|---|
| Energy Use Intensity (EUI) [kBtu/ft$^2$/yr] | 215 | 120 | 44.1% |

Source: Analysis performed and table prepared by project team

## Persistence of Savings

The team developed both a statistical model and a detailed building energy simulation model to predict the store's energy consumption. By analyzing the difference between the actual store energy consumption and the predicted energy consumption, the team can detect potential problems with equipment or operation of the equipment that could reduce future energy savings. Appendix D details both these models, the method used for identifying anomalies between the two models, and the results of the analysis. In brief, the team can detect anomalies, but they require further investigation to determine if there are any potential problems with the equipment installed in the retrofit.

## Challenges in Obtaining Data

There were challenges in scheduling the manufacturer's technicians for onsite testing. For example, in testing the RTUs, Trane had to first turn off the heating and cooling before SMC changed the speeds at 45-minute intervals. Then the commissioning agent had to go on site to collect the data before LBNL could analyze it. This was a laborious but essential process for LBNL to make the necessary adjustments for optimal energy savings. It was further complicated by the compressed M&V schedule, as explained in Chapter 5.

## Lessons Learned

Refrigeration systems are sometimes called the heart of grocery stores because they are both essential to the store's operation and critically important for food safety. Stores usually have dedicated control systems to manage their refrigeration systems. Typically, these control systems connect to the Internet and have an alarm function; a technician diagnoses the problem remotely and dispatches a service technician "before the ice cream melts." These are 24/7 services.

This level of attention to a refrigeration system is in stark contrast to the operation of rooftop units that provide HVAC. Unlike the complexity of refrigeration systems, RTUs are often sold as a packaged system with relatively basic controls embedded in the device that are programmed at the factory. A thermostat is often the only external communication element for an RTU. The building operator sets the temperature and schedule, and the RTU provides the service.

For this project, the team exploited the limited communication between the RTU and the building-management system that verifies operation of the system. They developed a custom sequence of operation (SoO) to pursue the RTU's most energy-efficient operation. This custom SoO was more complex than the usual factory-standard operation and required substantial unit troubleshooting and reprogramming. One issue discovered during the M&V process was a programming error that incorrectly set the source for space heating to use electric resistance heating instead of the heat pumps, which is roughly three times more efficient. The electric space heating option was intended only as a backup heat source in case the heat pumps failed. Another discovery was that, at some point, the fan speed settings on the RTU (which were supposed to operate in response to temperature changes) were overridden to run at maximum speed (100 percent) all the time, which prevented energy-efficient operation of the units.

The team recommends that a custom SoO only be implemented if there are enough resources to carefully observe the operation of the RTU for at least six months. Research underway at LBNL and other partners is addressing the issue with proper implementation of specified control sequences. The Open Building Control15 project has defined a control description language to be used during the design, simulation, implementation, and commissioning of

[15] Wetter, Michael, Jianjun Hu, Milica Grahovac, Brent Eubanks, and Philip Haves. "OpenBuildingControl: Modeling feedback control as a step towards formal design, specification, deployment and verification of building control sequences." In Proc. of Building Performance Modeling Conference and SimBuild, vol. 775782. 2018

building systems like RTUs. This common language can help reduce mistakes and misunderstandings during the design and construction process.

Lastly, warranties are a crucial barrier to integrating emerging technologies into construction projects. A new technology often replaces a component on a larger unit to make the entire product more energy efficient. However, the manufacturer of the original equipment does not warrant its product if factory-installed components are changed. Contractors are unwilling to take the risk.

# CHAPTER 7:
# Technology/Knowledge/Market Transfer Plan

## Knowledge Transfer Plan Objectives and Target Audiences

San Francisco Department of Environments (SFE) created a detailed plan defining objectives for transferring knowledge about the project to target audiences.

Objectives:

- Educate and engage building and energy-sector stakeholders with decision-making authority.
- Influence design strategies, technology packages and options, outcomes, challenges, and policy considerations for advanced energy efficiency and net-zero strategies for their respective market segments and building types.

Audiences:

- ZNE technology providers, both start-ups and corporations
- Building industry professionals involved in engineering, design, and construction
- Building management including contractors, engineers, architects, owners, and facility managers, especially those associated with supermarkets and grocery stores
- Local, regional, state, and federal policymakers; policy consultants, and regulatory experts

## Technology/Knowledge Transfer Activities

The project team successfully engaged a large number of organizations and individuals to communicate not only goals and methods but also the unique challenges of creating a deep-energy retrofit.

### Events for Industry, Technology, and Policy Professionals

Project team members attended and presented at over a dozen events including industry conferences, symposia, workshops, panels, webinars, and exhibits. Focused workshops drew 40-100 attendees, while conferences and symposia drew 100-300 participants, and the Energy Fair, an event open to the public, drew 450 attendees.

In these events, team members provided specific and detailed knowledge to targeted audiences and networked with other building industry, technology, and policy professionals.

Table 9 summarizes each knowledge-transfer event.

**Table 9: MarketZero Knowledge Transfer Events**

| Event | Audience | Participation |
|---|---|---|
| Electric Program Investment Charge Program Symposium Showcase, December 1, 2016 Sacramento, CA<br><br>California Energy Commission<br><br>Annual symposium showcases grant recipient projects as innovative solutions for reaching California's 2030 energy goals. | Policy and technology professionals (200-300 attendees) | WFM presented "Innovative Strategies to Achieve Zero Net Energy in Grocery Stores (San Francisco)" in the session "Getting to Zero Net Energy Buildings." |
| Innovation and Impact Symposium 2017, June 14, 2017<br><br>Mountain View, CA (Microsoft campus)<br><br>ProspectSV annual symposium focuses on the convergence and interdependence of emerging technologies in advanced mobility, energy, and the built environment. | Start-up, corporate, public, and research community leaders<br><br>(250 attendees) | WFM panelist on "Driving Sustainability at Scale."<br><br>Arup panelist on "Applied Technologies for Next-generation Buildings."<br><br>ProspectSV moderated a panel on "Tech-to-Market: Challenges and Solutions to Commercialization" featuring the Call for Innovation participants: Nelumbo, International Wastewater, Software Motor Corp., and Keewi. |
| Energy Upgrade Services in San Jose Multifamily Housing, Fall 2017 Event Series San Jose, CA<br><br>Co-hosted by ProspectSV, Sustainable Silicon Valley, and The City of San Jose<br><br>Series of workshops designed to increase participation in energy efficiency and to upgrade resource programs using a whole-building approach | Local government representatives, energy efficiency service providers and program managers, building owners and managers | ProspectSV networked with program managers who serve all building types and who became a resource for MarketZero. |
| NBI Workshop Zero Net Energy (ZNE) for Existing Buildings, ProspectSV, New Building Institute December 13, 2017<br><br>San Jose, CA | Architects, city planners, utilities, developers, and building owners<br><br>(40 attendees) | Arup and ProspectSV presented MarketZero. |

| Event | Audience | Participation |
|---|---|---|
| Networking Event ProspectSV February 21, 2018<br><br>Delta Americas LEED Platinum and net zero headquarters Fremont, CA | (70 attendees) | ProspectSV presented "Driving Innovation, Efficiency & Performance in the Built<br><br>Environment." |
| Innovation and Impact Symposium 2018, ProspectSV. Host committee included LBNL Director of the Building Technology and Urban Systems Division<br><br>May 31, 2018, San Jose, CA<br><br>The 2018 symposium emphasized the collaborative efforts of the public & private sectors, the introduction of new technologies and business models, and the involvement of industry leaders in the deployment of community initiatives. | Start-up, corporate, public and research community leaders<br><br>(250 attendees) | Arup, panelist for "Pushing the<br><br>Envelope: The Future of ZNE<br><br>Buildings."<br><br>SFE, panelist for "The Smart City Race to the Future: Local Initiatives and Global Impact."<br><br>Non-team panelists from Open Energy Efficiency, Navigant, NRDC, City of Palo Alto, City of San Jose, Microsoft. |
| ACEEE 2018 Summer Study on Energy Efficiency in Buildings<br><br>The 2018 ACEEE Summer Study is the 20th biennial ACEEE conference on Energy Efficiency in Buildings. Focuses on cutting-edge technologies, strategies, and programs for reducing energy use and addressing climate impacts. The 2018 theme: "Making<br><br>Efficiency Easy and Enticing." | Policymakers, utility staff, architects, clean-tech investors, manufacturers; engineers; local, state, and federal agency personnel; energy researchers; NGOs; consultants; behavioral scientists; and energy efficiency professionals<br><br>(100 attended the presentation by Arup.) | Arup presented a paper "An Innovative Approach to Evaluating Energy Efficiency Measure for Zero Net Energy Supermarkets." |

| Event | Audience | Participation |
| --- | --- | --- |
| 10th Annual Statewide Energy Efficiency Conference, Local Government Commission, in partnership with the Statewide Energy Efficiency Collaborative, June 26-27, 2019<br>Long Beach, CA<br>Forum focused on empowering local governments to implement energy efficiency measures while helping meet the state's ambitious climate and energy goals. | Local and regional government representatives and policy professionals | SFE presented a poster,<br>"MarketZero: Taking an Existing Grocery Store to Near-ZNE." (Poster presented as Figure 30) |
| Innovation and Impact Symposium 2019, ProspectSV June 19, 2019<br>San Leandro, CA<br>The 2019 symposium examined what it takes to integrate and implement solutions for maximum impact. | Start-up, corporate, public and research community leaders<br>(250 attendees) | ProspectSV, WFM, Arup & Source Refrigeration presented a panel on "Green up on Aisle 3: Whole Foods Goes ZNE."<br>Panel moderated by Navigant. |
| California Low-GWP Refrigerants Workshop, NASRC, PG&E July 18, 2019<br>San Francisco, CA<br>Tools and resources to prepare for pending California regulations. | Supermarket retailers, service contractors, equipment manufacturers and suppliers, engineering and design firms, and consultants | SFE networked with attendees. |
| GreenerBuilder, USGBC Northern California July 25, 2019<br>San Francisco, CA<br>Annual one-day conference to discuss industry trends, new research, and emerging technologies. | Architects, engineers and contractors | WFM and SFE networked with attendees. |

| Event | Audience | Participation |
|---|---|---|
| Getting to Zero National Forum, New Buildings Institute, Rocky Mountain Institute, October 9-11, 2019<br><br>Oakland, CA | Leading designers, owners, operators, commercial real estate professionals, policymakers, manufacturers, and others working on zero energy and zero carbon performance in residential and commercial projects.<br><br>(50 attended the presentation) | SFE presented "How did they do that? Getting to Zero in Complex Building Types: MarketZero Taking an Existing Grocery Store to Scalable Near-ZNE." |
| San Francisco Energy Fair, SFE, February 25, 2020<br><br>San Francisco, CA<br><br>Focused on renewable energy, energy efficiency and electrification offering 6 educational sessions, 20+ speakers, 27 exhibitors with live demonstrations, workshops, and energy exhibits, including an induction cooking demonstration with SF Mayor London Breed, electric kitchen advocate chef Rachelle Boucher and culinary scientist Julian Weisner of Hestan Cue. | Small-business owners, home owners, residential building industry professionals, local policy professionals, and clean energy activists.<br><br>(450 attendees to the fair; 70 attendees to the MarketZero presentation) | WFM, Arup, SFE presented<br><br>"MarketZero: Not Your Average Green Grocer." |
| Webinar, Business Council on Climate Change, North American Sustainable Refrigeration Council<br><br>March 10, 2020 Virtual | 70 attendees from the grocery store industry including representatives of Target, Sprouts, Albertsons, and Costco | WFM, Arup, Source Refrigeration presented "MarketZero: Taking an Existing Grocery Store to Near ZNE." |

Source: Table compiled by SFE and ProspectSV

Figure 28 shows team members at the San Francisco Energy Fair presenting to an audience of about 70 attendees, including small-business owners and industry professionals.

**Figure 28: MarketZero Team Presents at the San Francisco Energy Fair**


**Panel (a) Erica Levine from Arup, Tristam Coffin from Whole Foods Market, and Barry Hooper of San Francisco Department of the Environment present the MarketZero project at the San Francisco Energy Fair. Panel (b) Attendees at the MarketZero presentation**

Source: Photographs taken by ProspectSV

## Knowledge Transfer Opportunities

Team members routinely shared the goals, technology, methods, and status of the project with  targeted audiences throughout the project.

At the beginning of the project, ProspectSV's "Call for Innovation" went out to over 67 organizations and 100 individuals. The team also generated broad interest in the project, creating follow-on publicity opportunities using the following media channels:[16, 17]

- Social Media: Twitter, LinkedIn (including groups: Green Building Products, Building Green, Sustainable Silicon Valley, Cleantech, Cleantech Open, Cleantech.org, OnStartups, Lean Startup, GreenBiz, Green & Sustainability Innovators, Sustainable Silicon Valley, US Green Building Council)
- Media: City Minded, Fast Company's Co. Exist, Solar Thermal Magazine, Meeting of the Minds, CleanTechnica, The RegistrySF, PR Newswire, and Govtech

Other opportunities follow:

- ProspectSV convened a technical advisory committee, expanding the community of professionals both aware of and invested in the project and its outcome.

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[16] Ryan, Kelly, Grocery Stores and Fast Food Restaurants Striving for Net Zero, Vertical Group (website), April 11, 2017.

[17] Calling All Innovative Energy Startups for Zero Net Energy Projects, Solar Thermal Magazine (website), August 12, 2016.

- Arup updated its global colleagues on the project and provided specific details on the use of the genetic algorithm's optimization methodology.
- LBNL and ProspectSV announced the project on their respective websites and WFM referenced the project as an example of its sustainability goals on both its website and in media coverage.
- WFM explained the goals of the project to its staff so they were able to answer general questions from customers.

### Small-to-Medium Grocer Outreach

SFE reached out to San Francisco's small and medium grocers by leveraging existing partnerships in the "Keep It Tuned" program, a refrigeration maintenance pilot working with small groceries to increase equipment efficiency and provide training to business owners.

In the fall of 2019, SFE shared MarketZero project information with 15 grocers, focusing on the relatively low cost but high-impact measures that grocers could adopt in their stores.

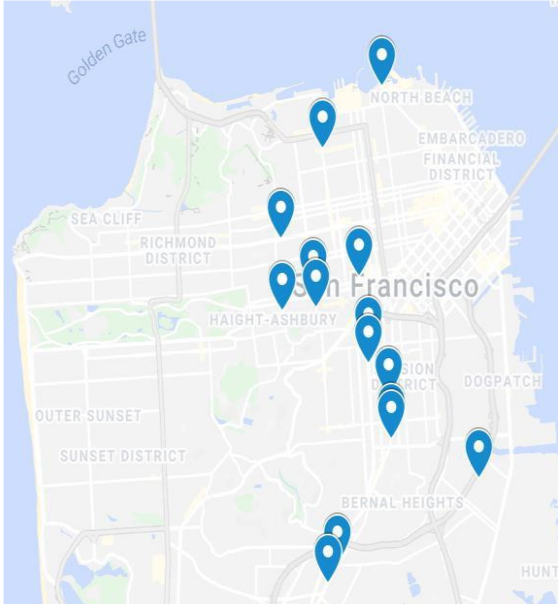
Table 10 lists the grocers and the dates that SFE visited. Figure 29 shows a map of the store locations in the outreach program.

**Table 10: Small-to-Medium Grocer Outreach Program**

| Grocer | Date of Visit |
|---|---|
| Casa Guadalupe | 09/04/19 |
| Evergreen Market | 10/09/19 |
| Mission Silver Market | 10/09/19 |
| Amal's Deli | 10/25/19 |
| New Star Ell | 11/01/19 |
| Superette Market | 11/01/19 |
| Nabila's Natural | 11/15/19 |
| Argonaut Hotel and Blue Mermaid Restaurant | 11/15/19 |
| Cooks Produce | 11/19/19 |
| Casa Guadalupe | 11/22/19 |
| Michaelis Wine & Spirits | 11/26/19 |
| Subway Geary | 11/26/19 |
| K and D Market | 11/26/19 |
| Casa Lucaz #3 | 11/26/19 |
| Pay & Save Market | 11/26/19 |

Source: Table compiled by SFE

**Figure 29: Locations of Grocers in the Outreach Program**




Source: Map data © 2020 Google

**Figure 30: Poster for the 10th Annual Statewide Energy-Efficiency Conference**


Source: MarketZero

## Lessons Learned

The technology and knowledge transfer program reached hundreds of individuals in targeted communities throughout the project. Team members reported positive and engaged responses from participants in these outreach events. In retrospect, the team has identified additional opportunities for expanding outreach to increase market penetration and address existing barriers. Future Energy Commission projects might consider and adapt these strategies in their knowledge-transfer plans.

### Engaging With Social Media

A plan for social media outreach, beginning with the project's inception right through to its conclusion, invites these platforms, in addition to other audiences, to experience the project as it is developed. Communicating early and consistently with social media would also create an accessible archive of key decisions and milestones that could present new avenues for knowledge transfer now that the project is complete.

### Leveraging the Whole Foods Market Customer Community

Whole Foods Market presented the project on its website to demonstrate how it is advancing its sustainability goals. But there was also the specific opportunity for the project team to engage directly with the WFM Noe Valley store's customer community. This engagement would inform customers about their neighborhood project and how it helped realize California's energy goals, as well as provide the opportunity for SFE to promote other local energy-efficiency and sustainability programs. Actions might include a project team member hosting a table at the weekly farmer's market in front of the store along with the San Francisco Public Utilities Commission's CleanPowerSF program, or displaying project information within the store, with pointers to a robust project website. Additionally, MarketZero was one of several WFM sustainability retrofit and new-construction projects in the Bay Area. Finding ways to coordinate events with other stores would deepen the public's understanding of WFM's environmental commitment and expand its outreach to an even broader customer community.

### Leveraging Project Experts

Early in the project, ProspectSV tapped its network of project partners in architecture and design in the building industry to build participation in the "Call for Innovation." Likewise, in its stakeholder meetings, the team engaged 40 experts in diverse fields including energy efficiency, lighting design, refrigeration, kitchen design, behavioral science, MEP, and the grocery industry. These experts provided valuable expertise and insight for each of these events. However, they could also provide additional and ongoing value for the project. For instance, as members of knowledge-transfer target communities, they could introduce the team to leaders of relevant trade and professional organizations to develop co-sponsored outreach and events. Leveraging these relationships would mirror the kind of engagement the team created with its successful webinar, co-sponsored with the National Sustainable Refrigeration Council, which drew 70 attendees from the grocery-store industry including representatives from Costco, Target, Sprouts, and Albertsons.

### Repackaging the MarketZero Approach

While knowledge-transfer events reached hundreds of building-industry professionals (and this report presents many details on the design and construction process), addressing how to overcome existing barriers might take other forms as well. The team envisions a modified structure for the final report that could take on a second, parallel purpose: a case-study tool kit for designers and construction engineers focused on grocery-store retrofits. Professionals could use the tool kit to follow the project team's decision-making processes in overcoming existing barriers, and perhaps even simulate overcoming other barriers, using the same process. The tool kit would include design considerations, construction operability issues, and methods for integrating emerging technologies developed by the team.

Another opportunity for addressing existing barriers would drill down further into how the team applied the decision tree generated by the genetic algorithm and identified the optimal package of retrofit strategies. Publishing in a cited journal would convey this knowledge to the researchers and energy-efficiency consultants whose work impacts the building industry. This recommendation reflects the enthusiastic response that team members received from presenting an overview of the genetic-algorithm application at a conference on energy-efficiency in buildings.[18]

[18] Best, Rob and Erica Levine, An Innovative Approach to Evaluating Energy Efficiency Measures for Zero Net Energy Supermarkets. ACEEE 2018 Summer Study on Energy Efficiency in Buildings

# CHAPTER 8: Benefits to Ratepayers

The total energy savings from the retrofit was 44 percent for the combination of gas and electricity and resulted in an EUI of 120 kBtu/$ft_2$/yr. Chapter 6 presents a detailed summary of savings in Table 7.

This chapter summarizes the benefits specific to the project, including GHG benefits, and extrapolates those benefits statewide.

## Project-Specific Benefits

The project directly demonstrated substantial energy savings by implementing energy-efficiency measures at the WFM site. Disseminating the project's approaches, methods, and results to the broader market and stimulating changes to local policy and programs will indirectly generate energy savings in organizations that implement similar measures. The project additionally provides ratepayer benefits:

- Annual electricity and thermal savings
- GHG savings
- Reduced reliance on natural gas, improving energy resiliency

### Greenhouse Gas Savings for the WFM Project

To estimate GHG savings from energy reductions, the team used the latest California Air Resources Board estimates for electricity and natural gas GHG intensities available (2016).[19] Greenhouse-gas intensities for natural gas are virtually identical across California and nationally since a national pipeline network supplies natural gas. There is also virtually no biogas in the system. For electricity, GHG intensities will differ depending on the local electric utility; additional uncertainties exist based on how electricity is allocated around the state and the GHG intensity of imported electricity.

Electricity GHG intensities can also vary across a single day or season, so to determine an accurate GHG intensity requires knowledge of hourly GHG intensities throughout the year. Instead of doing such detailed analyses, the team opted to use statewide estimates that provide average impacts, which are valid given high-baseload store energy demands. For electricity, the team used 227.9 $gCO_2e$/kWh, which represents a combination of in-state and imported electricity generation in California; for natural gas the team used 0.0668 $gCO_2e$/Btu.

For refrigerant GHG savings, the team used the 100-year GWP from the IPCC AR4[20] to estimate $CO_2$-equivalent emissions for baseline and retrofit refrigerants, assuming an 18 percent annual leakage rate which is consistent with estimates for commercial refrigeration

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[19] California Air Resources Board, California Climate Investments Quantification Methodology Emission Factor Database

[20] IPCC Fourth Assessment Report (AR4) Climate Change 2007: The Physical Science Basis

systems in California.[21] Note that because of differences in refrigerant properties, the amount of refrigerant (or charge) differed in both the baseline and retrofit. Table 11 shows refrigerant assumptions.

**Table 11: $CO_2$-Equivalent Emission from Refrigerant Change-Out**

| | **Baseline** (R404A) | **Retrofit** (R448A) | **Savings** |
|---|---|---|---|
| Refrigerant charge (kg) | 760 | 907 | N/A |
| GWP (kgCO2e/kg) | 3,922 | 1,273 | N/A |
| Refrigerant charge (kgCO2e) | 2,980,600 | 1,155,200 | 1,825,400 |
| Refrigerant leakage rate (kgCO2e/year) | 536,500 | 207,900 | 328,600 |

Source: Analysis performed and table prepared by Emerging Futures

Refrigerant GHG savings provided 70 percent of total savings, resulting in overall project savings of 53 percent. Total GHG savings were equivalent to taking 100 cars off the road.[22] See Table 12.

**Table 12: Annual GHG Emission Savings for MarketZero Project**

| | **Baseline** (metric tonnes CO2e) | **Savings** (metric tonnes CO2e) | **Savings Fraction** |
|---|---|---|---|
| Gas | 95.9 | 86.1 | 89.8% |
| Electricity | 240.4 | 50.8 | 21.2% |
| Refrigerant | 536.5 | 328.6 | 61.2% |
| Total | 872.8 | 465.5 | 53.3% |

Source: Analysis performed and table prepared by Emerging Futures

## Extrapolating State-Level Energy Savings

The 2006 CEUS[23] provides the statewide electricity and gas use of commercial grocery stores by both total consumption and 13 categories of end use. These categories were combined to correspond with the more aggregated end-use categories assigned to measure WFM savings.

The 2006 statewide energy use estimates were projected forward to 2020 using California population growth estimates from World Population Review.[24] The team estimated the 2006

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[21] California Air Resources Board, Potential Impact of the Kigali Amendment on California HFC Emissions, December 15, 2017.

[22] The average car emits 4.6 metric tonnes/yr. US EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle.

[23] California End-Use Survey (CEUS)

[24] World Population Review, California Population 2020

population by fitting a quadratic growth curve through population estimates for 2000, 2010, and 2020, resulting in a growth factor between 2006 and 2020 of 1.1103. This factor was multiplied by statewide energy-use estimates to arrive at energy-use projections for 2020.

The team acknowledges that the location of the WFM project did not represent average conditions for neither a grocery store nor a state-wide average climate. However, given the number of other uncertainties associated with estimating project savings, the team decided to directly extrapolate the WFM savings by aggregated end-use category to the statewide level, recognizing those caveats. Total savings for California grocery stores were estimated by multiplying projected energy use for electricity and gas by estimated savings percentages determined in the WFM project. Table 13, Table 14, and Figure 31 show the results.

**Table 13: Estimated Statewide Savings in 2020 Based on WFM Project Results**

| | Baseline | Savings | Savings fraction |
|---|---|---|---|
| **Electricity** | *GWh* | *GWh* | |
| Lighting | 1,521 | 967 | 63.6% |
| Refrigeration | 3,590 | 1,502 | 41.8% |
| HVAC heating, cooking, water heating | 331 | 91 | 27.6% |
| HVAC cooling + ventilation | 874 | -6 | -0.7% |
| Other | 248 | -3 | -1.2% |
| Whole facility | 6,563 | 2,552 | 38.9% |
| **Natural Gas** | *Mtherms* | *Mtherms* | |
| HVAC heating, cooking, water heating | 44.07 | 39.57 | 89.8% |
| Other | 0.13 | 0.00 | 0.0% |

Source: Analysis performed and table prepared by Emerging Futures

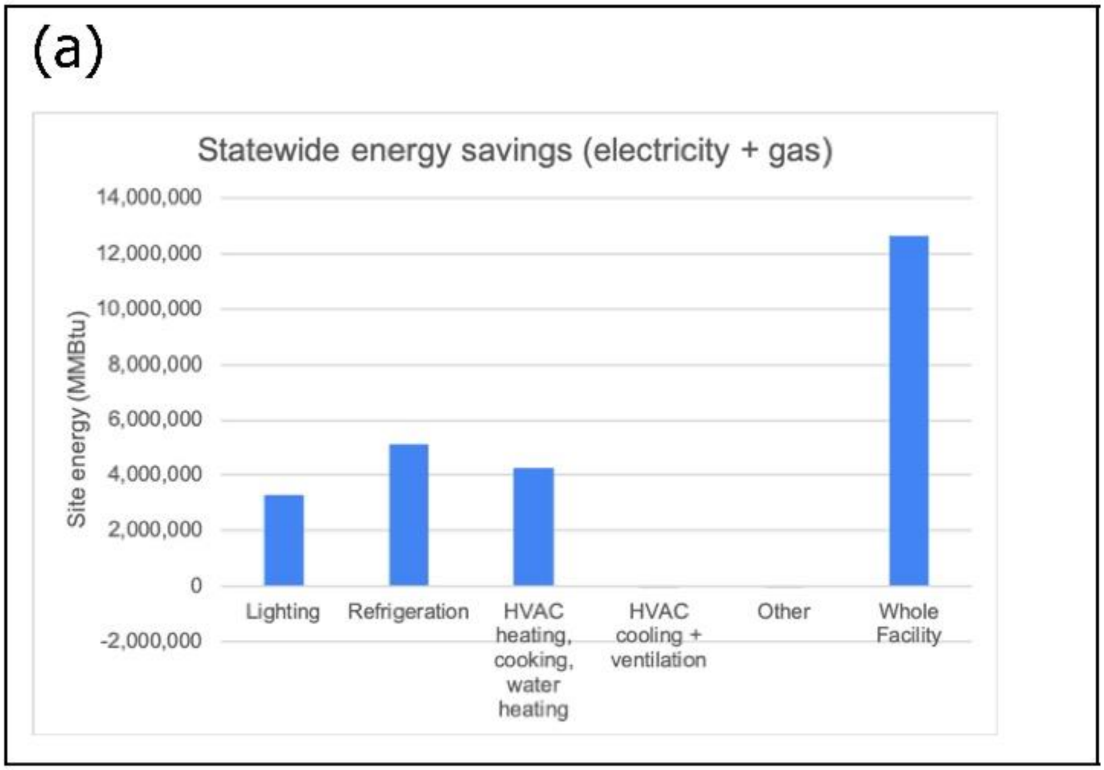
**Table 14: Total Estimated Statewide Savings in 2020**

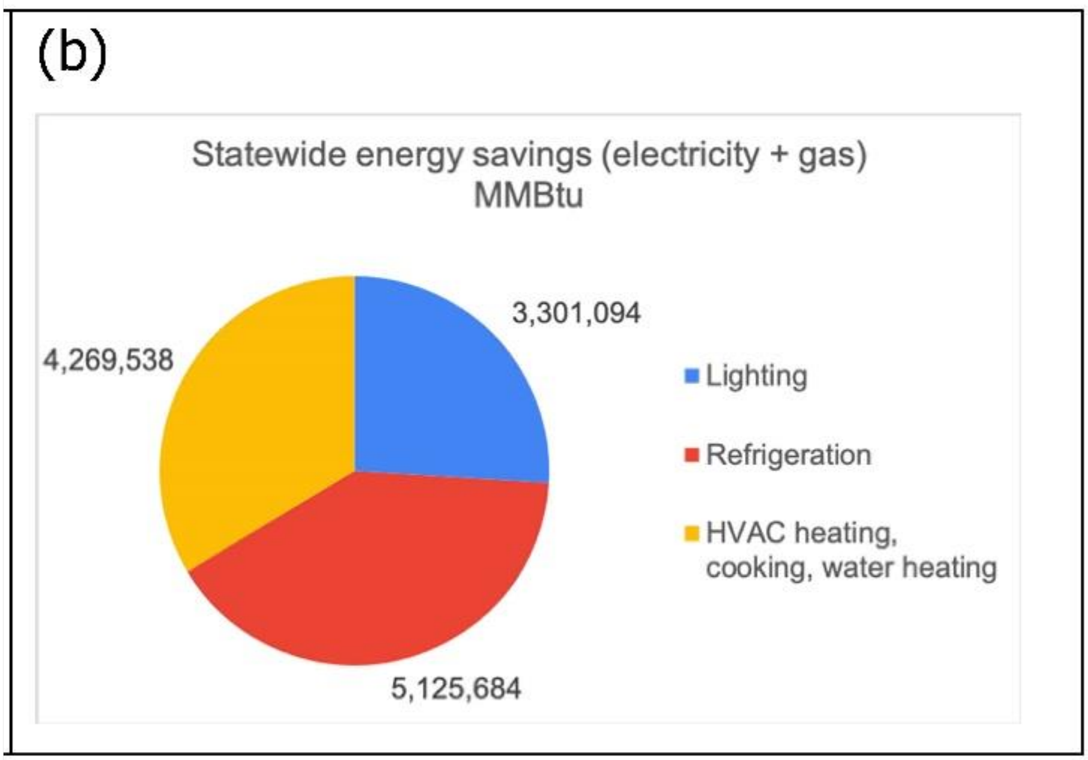
| | Baseline | Savings | Savings fraction |
|---|---|---|---|
| Total | 44.20 | 39.57 | 89.5% |
| **Total Energy** | *MMBtu* | *MMBtu* | |
| Lighting | 5,190,093 | 3,301,094 | 63.6% |
| Refrigeration | 12,247,861 | 5,125,684 | 41.8% |
| HVAC heating, cooking, water heating | 5,535,607 | 4,269,538 | 77.1% |
| HVAC cooling + ventilation | 2,981,462 | -20,358 | -0.7% |
| Other | 858,134 | -10,536 | -1.2% |
| Whole Facility | 26,813,157 | 12,665,421 | 47.2% |

Source: Analysis performed and table prepared by Emerging Futures

Total statewide energy savings of 2,552 GWh of electricity and 39.6 Mtherms of natural gas exceed the stated project goals of 2,400 GWh and 37 Mtherms, respectively, for a total estimated energy savings of 47 percent.

**Figure 31: Estimated Statewide Savings in 2020**




Source: Analysis performed and graph prepared by Emerging Futures

The team applied the same GHG intensities presented in the WFM GHG savings to arrive at the total statewide GHG savings estimates shown in Table 15 and Figure 32. To estimate refrigerant GHG savings, the team assumed that total refrigerant leakage scaled with grocery store area since there was no specific data available on grocery store refrigerant charge amounts.

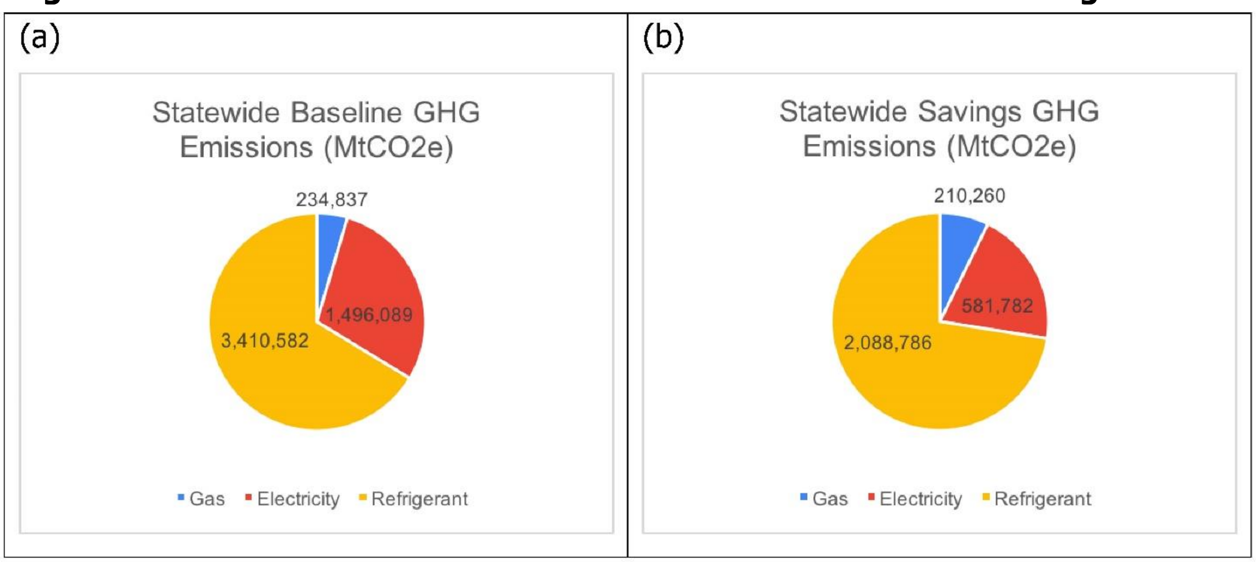
Estimated overall GHG savings were 56 percent, with refrigerant GHG savings contributing 73 percent of total savings. These are equivalent to the emissions from 630,000 cars, or 0.7 percent of the total statewide GHG emissions goal for 2020.[25]

**Table 15. Estimated Statewide GHG Savings in 2020**

| | Baseline (Metric tonnes CO2e) | Savings (Metric tonnes CO2e) | Savings fraction |
|---|---|---|---|
| Gas | 234,837 | 210,260 | 89.5% |
| Electricity | 1,496,089 | 581,782 | 38.9% |
| Refrigerant | 3,410,582 | 2,088,786 | 61.2% |
| Total | 5,141,508 | 2,880,828 | 56.0% |

Source: Analysis performed and table prepared by Emerging Futures.

**Figure 32. Estimated Statewide Baseline GHG Emissions and Savings in 2020**




Source: Analysis performed and graph prepared by Emerging Futures

[25] The average car emits 4.6 metric tonnes/yr., US EPA, Greenhouse Gas Emissions from a Typical Passenger Vehicle.

# CHAPTER 9: Recommendations and Conclusions

## Recommendations

For this project, LBNL monitored energy use at regular intervals to analyze the effects of specific equipment installations and suggest refinements to improve efficiencies. Extending this practice to the broader market will require more experience with this kind of analysis and testing and a commitment to continue to analyze the results to produce and sustain optimal energy efficiencies.

Integrating new technologies introduces complexities into the design and implementation process. Project team members must learn how the technologies interact with other new and existing equipment, devise testing strategies that ensure optimal efficiencies across the systems and devote time to educating municipal building departments about the technologies.

Creating a project team with members who are involved from the earliest stages of design supports developing the cross-team knowledge and insights needed to fully take advantage of energy-efficiency opportunities throughout the project.

The potential for integrating new and emerging technologies into the design and implementation of both new and existing grocery stores throughout California depends on engaging the ecosystem of product development teams and building owners, designers, and engineers:

- Pre-commercial technology and innovation firms need to better understand what a contractor or owner needs to know so they can confidently purchase and install the technology.
- The design community must work with startups to translate their technologies' value in the design process.
- Architects need to become conversant with specialty designers to better understand the application of new technologies.
- Mechanical engineers need to more fully embrace innovative technologies and master how they might fit into various environments.
- Contractors need to determine how best to integrate technology and reduce risk.

The MarketZero team recommends using the project as a template to train designers and construction engineers in applying and scaling the MarketZero approach. This is an opportunity for a follow-up program that provides the construction and design community with design guidance on factors and constraints and the integration of new technologies.

The team also believes that replacing refrigerants with lower-global-warming refrigerants is not only a winning proposition for other grocery stores but additionally has broader implications for statewide energy-efficiency policies. Retailers could couple the refrigerant gas change with an energy-reduction project to address forthcoming California Air Resources Board regulation requirements, reduce greenhouse gas emissions from leaks in refrigeration systems, and reduce energy consumption.

## Conclusions

The MarketZero project developed and executed a successful approach for retrofitting an existing grocery store to produce substantial savings in both gas and electricity consumption and in greenhouse gas emissions.

The retrofit produced total energy savings of 44 percent, decreased energy-use intensity from 215 kBtu/$ft^2$/yr to 120 kBtu/$ft^2$/yr, and achieved a considerable difference from the statewide average of 167 kBtu/$ft^2$/yr in existing grocery stores. The retrofit reduced the store's greenhouse gas emissions by 53 percent and reduced energy costs by an estimated $47,000 per year.

Extrapolating these benefits statewide to all California grocery stores in 2020, the team estimates energy savings of 47 percent and greenhouse gas emissions savings of 56 percent.

The approach that produced the retrofit's remarkable results included:

- Investigating the conditions and opportunities for energy savings at the store site.
- Analyzing and integrating emerging technologies with proven technologies.
- Applying a novel genetic algorithm to develop an optimum package of energy-conservation measures.
- Executing an integrated design and implementation strategy.
- Monitoring energy use by testing energy-conservation measures throughout the project.
- Simulating both energy use and energy savings for each of the major end-use categories.

# LIST OF ACRONYMS

| Term | Definition |
|---|---|
| AC | Air conditioning |
| AHU | Air Handling Unit |
| ASHRAE | American Society of Heating Refrigeration and Air Conditioning Engineers |
| CARB | California Air Resources Board |
| (CV[RMSE]) | Coefficient of Variation of the Root Mean Squared Error |
| DDC | Direct Digital Controls |
| DX | Direct Expansion |
| ECM | Energy Conservation Measure |
| EUI | Energy Use Intensity |
| EVO | Efficiency Valuation Organization |
| GPM | Gallons Per Minute |
| GHG | Green House Gas |
| GWP | Global Warming Potential |
| HFC | Hydrochlorofluorocarbon |
| HFO/HFC | Hydrofluoroolefin/Hydrochlorofluorocarbon |
| HVAC | Heating Ventilating Air Conditioning |
| IPMVP | International Performance Measurement & Verification Protocol |
| NMBE | Normalized Mean Bias Error |
| M&V | Measurement and Verification |
| MELs | Miscellaneous Electrical Loads |
| MEP | Mechanical Electrical Plumbing |
| O&M | Operations and Maintenance |
| PCM | Phase Change Material |
| PV | Photovoltaic |
| RTU | Roof Top Unit |
| SoO | Sequence of Operations |
| TES | Thermal Energy Storage |
| TOWT | Time of Week and Temperature |

| Term | Definition |
|---|---|
| USGBC | United States Green Building Council |
| VFD | Variable Frequency Drive |
| VAV | Variable Air Volume |
| VRF | Variable Refrigerant Flow |
| ZNE | Zero Net Energy |

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# APPENDIX A: Model Calibration and Validation, Deliverable 2.1

## Introduction

Existing grocery stores in urban settings present one of the most challenging sectors for a zero-net-energy (ZNE) California. With EPIC grant funding from the California Energy Commission, the 4-year Market Zero project designed and executed the retrofit of an existing Whole Foods Market in the Noe Valley neighborhood of San Francisco to achieve net-zero-energy utilization, with a focus on energy efficiency. The project team included Prospect Silicon Valley, Arup, Whole Foods Market, and Lawrence Berkeley National Laboratory (LBNL).

To reduce current energy usage, Arup and LBNL built a calibrated energy model that mimics operation of the existing store. Once the calibrated energy model was validated, it was used to assess the energy-

savings potential of various energy upgrades. This report summarizes the model calibration method, inputs, and status.

## Calibration Method

### Approach

ASHRAE Guideline 14 sets standards for the statistical tests and performance boundaries for calibrating models used for retrofit. The Guideline specifies:

“The computer model shall have an NMBE [Normalized Mean Bias Error] of 5% and a CV(RMSE) [Coefficient of Variation of the Root Mean Squared Error] of 15% relative to monthly calibration data. If hourly calibration data are used, these requirements shall be 10% and 30%, respectively.”

For the MarketZero study, we propose that the requirements for a well-calibrated model be tightened. We propose that the model meet:

Normalized Mean Bias Error (NMBE) of ±10% using hourly data across one full year

Coefficient of Variation of the Root Mean Squared error (CV[RMSE]) of less than 15% using hourly data across one full year

These two tests serve different purposes. NMBE tests if there is a continuous over- or under-estimation of energy performance within the model. CV[RMSE] test if the magnitude of difference between the modeled and observed data is significant.

Calculation of NMBE and CV[RMSE] involves comparing the modeled data in each time period, $M_i$, with the observed data in the same time period, $O_i$. With the total number of data points indicated by $N$, the formula for NMBE, denoted $B_{NMB}$, is given as:

$$B_{NMB} = \frac{\sum_{i=1}^{N} (M_i - O_i)}{\sum_{i=1}^{N} O_i} \times 100\%$$

CV[RMSE], denoted $CV_{RMSE}$, is calculated by:

$$CV_{RMSE} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2}}{\frac{1}{N}\sum_{i=1}^{N} O_i}$$

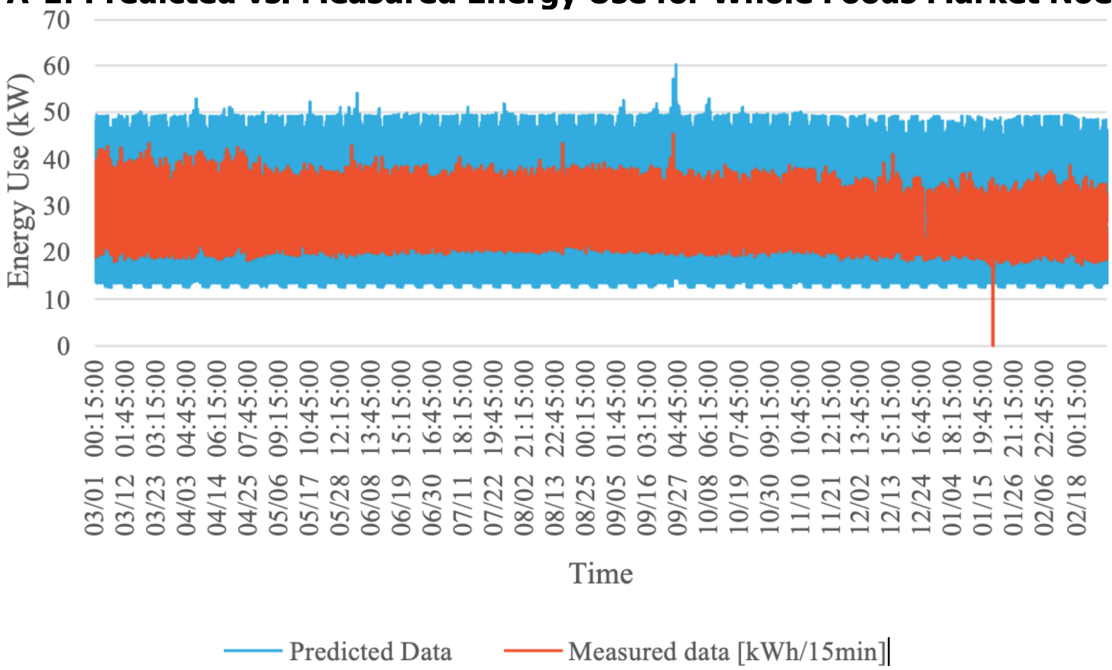
Baseline (Un-Calibrated) Model

The EnergyPlus model for the Noe Valley Whole Foods was constructed from:

- As-built construction drawings of the store and equipment schedules from construction documents.
- Information noted during on-site surveys of the store.
- Schedules and information verbally provided by the store manager.

Running the un-calibrated model and evaluating statistical performance based on calibration requirements produced an NMBE of 0.73% indicating that the model is relatively unbiased. Using 15-minute interval data, however, the CV[RMSE] was 29%, indicating that the loads are not well calibrated. Visual inspection revealed that the model shows a consistent bias toward higher daytime and lower nighttime loads, as shown in Figure A-1.

**Figure A-1: Predicted vs. Measured Energy Use for Whole Foods Market Noe Valley**




Source: LBNL

Given both the statistical unacceptability of the results and the concerns of consistent over and under estimation from the plot, additional calibration is required.

## Calibration Steps

Additional data on store performance was obtained from the Building Management System and on-site metering of end uses and circuits conducted by Arup. These are the primary source for data used in calibrating the EnergyPlus model.

One-week submetering data for lighting and plug load circuits gathered from the store was statistically analyzed to extract operating schedules for different zones and equipment types where possible. These schedules and values were updated in EnergyPlus to match the average operating schedules determined through metering.

BMS data was statistically analyzed to determine schedules and values for thermostat setpoints, fans, refrigeration equipment, and heat recovery. These schedules and values were updated in EnergyPlus to match the BMS data.

Schedules derived from BMS and submetering are shown in Appendix A.

After updating schedules and values for lighting, plug, HVAC, and refrigeration systems, the model still exhibited abnormally low nighttime loads. Closer inspection revealed that the refrigeration system, which accounts for about 50% of the store's total energy use, was not modeled completely as designed. Some of the items were previously discussed to use default values from example EnergyPlus models, such as compressor curves, but others were not. To correct the refrigeration system to match actual design, the following parameters were updated:

- Walk-in coolers that were previously modeled as cases
- Additional cases that were not previously included
- Compressor curves
- Case dimensions
- Case capacities
- Case setpoints
- Case schedules
- Case lighting power consumption
- Case fan power consumption
- Case anti-sweat heater power consumption

Once refrigeration modeling was corrected, calibration proceeded by tuning parameters with the highest uncertainty in the model. While some parameters are considered certain (e.g., store geometry), others have a high degree of uncertainty. These include:

- Occupancy schedules.
- Equipment operating schedules not recorded by the BMS.
- Plug load schedules, levels/values, and contribution to internal thermal gains for which submetering data was not collected.
- Refrigeration anti-sweat heater and lighting schedules.

Tuning of uncertain parameters proceeded iteratively to find the set of parameters that best represents the observed performance of the store. After each calibration step, the results of the statistical tests were compared with the required values, and the time series of data points was inspected.

Adjusting the aforementioned parameters resulted in a well calibrated electricity model that met the required tolerances. However further inspection revealed that the gas consumption was not calibrated as modeled. Only six end uses for gas exist within the building, so each was inspected in turn. The values modified to produce accurate calibration for gas were the:

- Gas rotisserie operating scheduled.
- Air flow between zones within the building.
- Domestic hot water use schedules.

As with electricity, several iterations were required to achieve the calibrated tolerance.

## Calibration Results

As shown in Table 1, NMBE and CV[RSME] for both electricity and gas fall within the target ranges of ±10% and <15%, respectively.

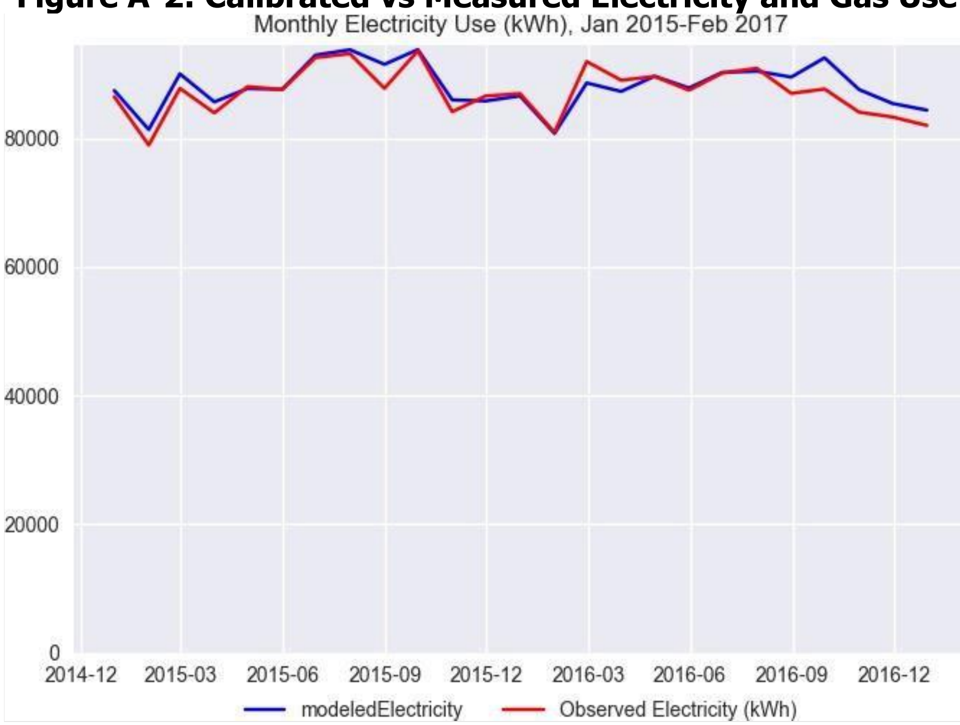
**Table A-1: Model Calibration Statistics**

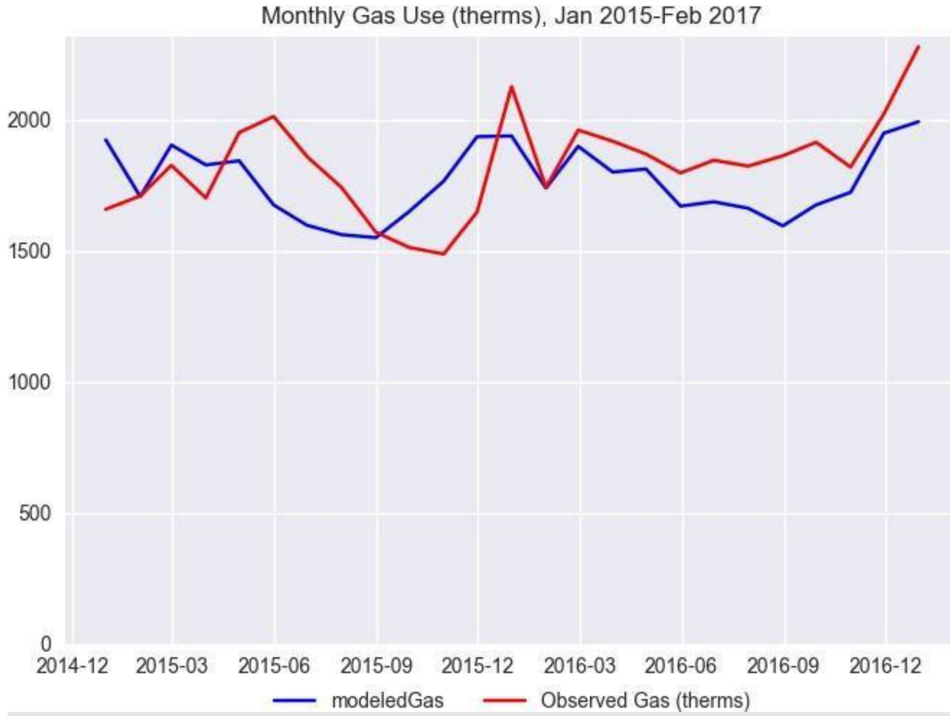
| Fuel | NMBE | CV[RMSE] |
|---|---|---|
| Electricity | 0.96% | 7.26% |
| Gas | -3.45% | 10.08% |

Source: LBNL

A comparison of calibrated and measured electricity and gas use is illustrated in Figure 2. Appendix B provides tables of several key modeling schedules and inputs.

**Figure A-2: Calibrated vs Measured Electricity and Gas Use**



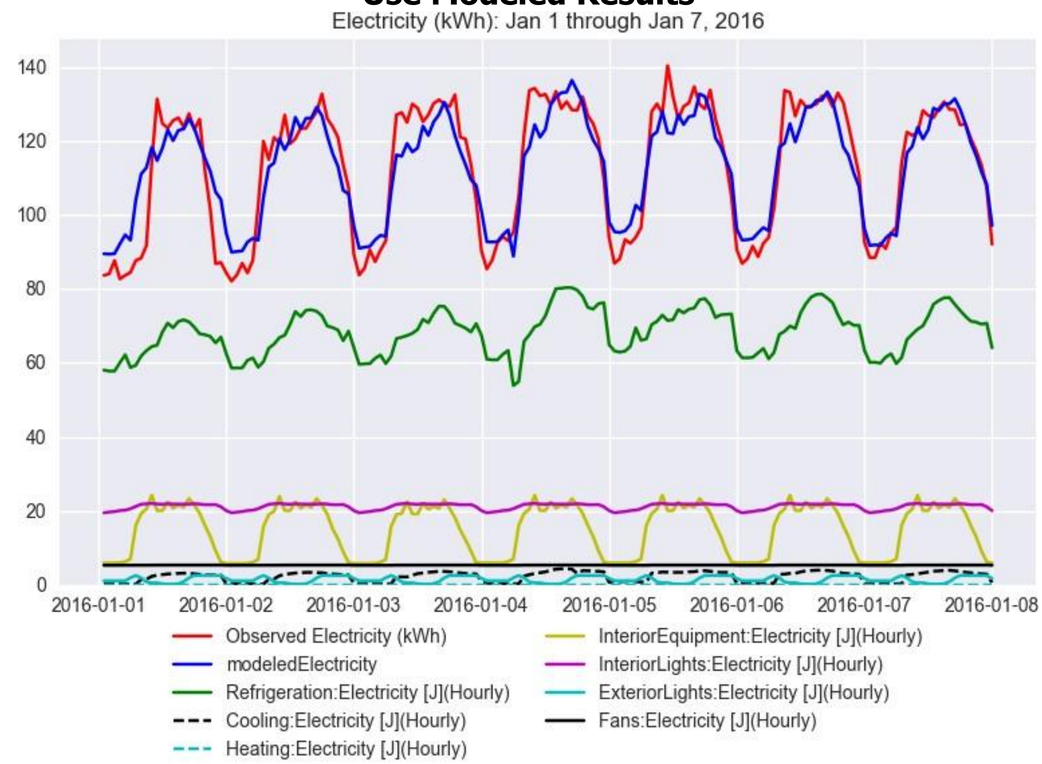


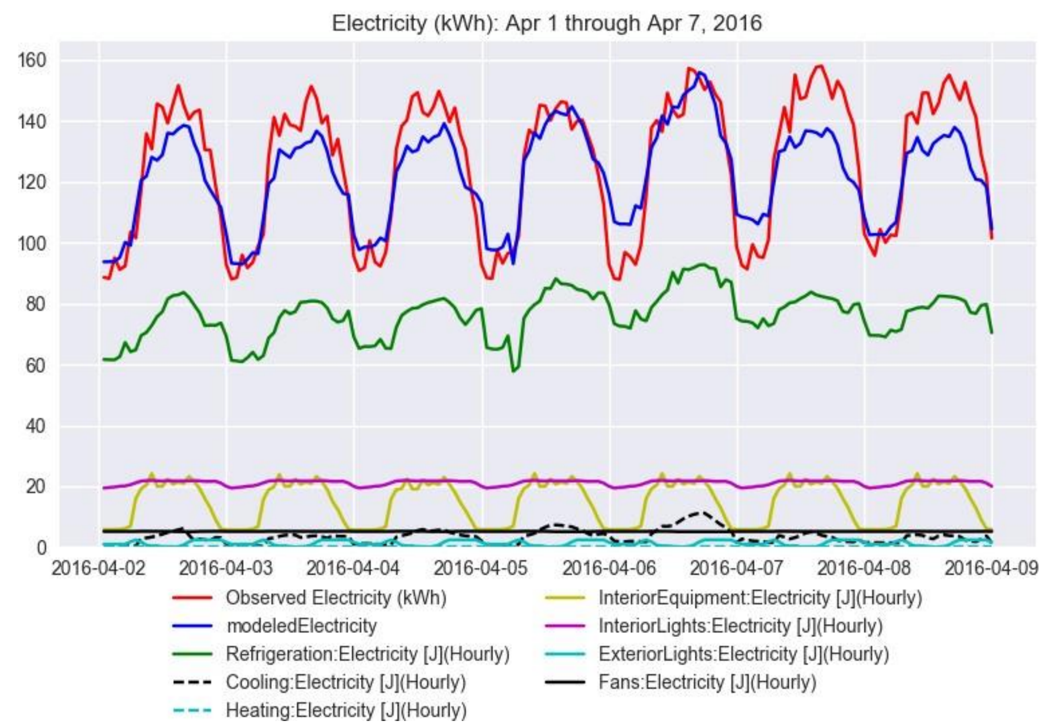
Monthly Gas Use (therms), Jan 2015-Feb 2017
2000
1500
1000
500
0
2014-12
2015-03
2015-06
2015-09
2015-12
2016-03
2016-06
2016-09
2016-12
modeledGas
Observed Gas (therms)

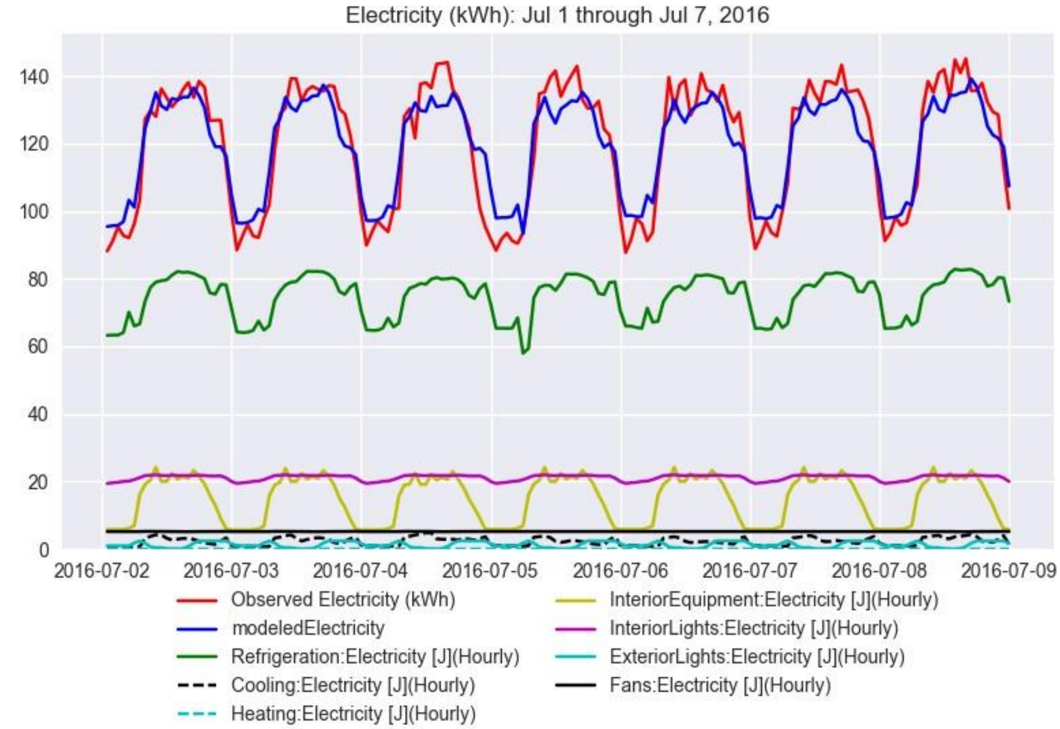

Source: LBNL

Comparisons of modeled end-use loads and total load compared to observed total load for one week in each season are shown in Figure A-3.

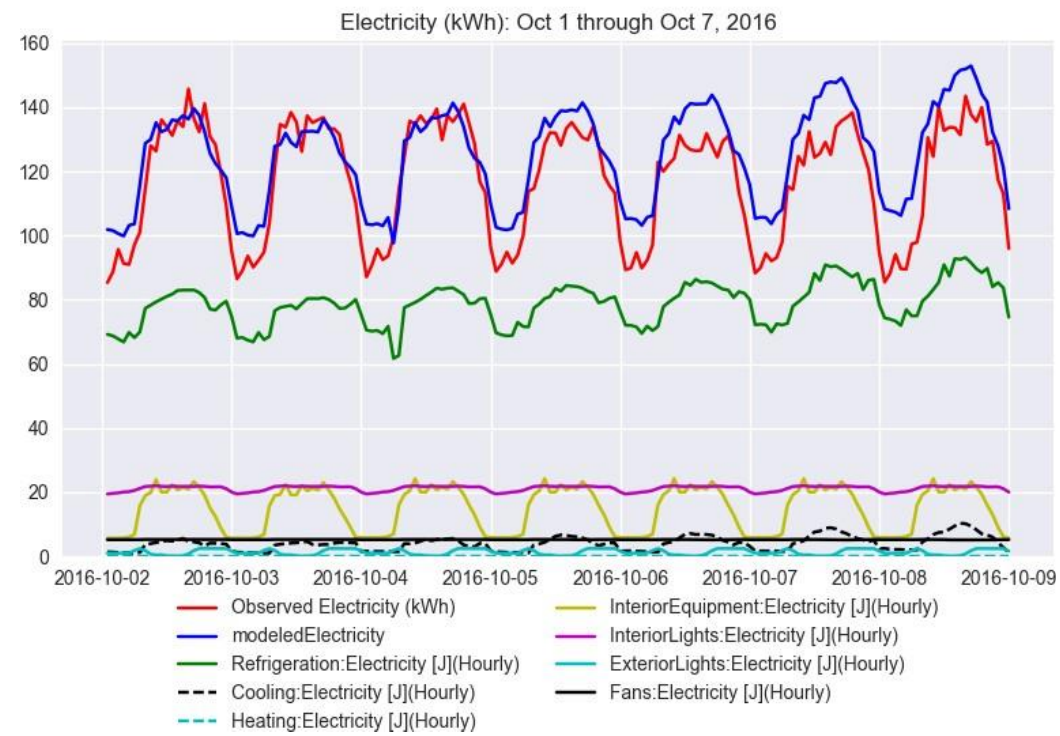
**Figure A-3: Calibrated Electricity Use for Four Weeks in 2016 With Total and End-Use Modeled Results**





Electricity (kWh): Jul 1 through Jul 7, 2016
0
20
40
60
80
100
120
140
2016-07-02
2016-07-03
2016-07-04
2016-07-05
2016-07-06
2016-07-07
2016-07-08
2016-07-09
Observed Electricity (kWh)
modeledElectricity
Refrigeration:Electricity [J](Hourly)
Cooling:Electricity [J](Hourly)
Heating:Electricity [J](Hourly)
InteriorEquipment:Electricity [J](Hourly)
InteriorLights:Electricity [J](Hourly)
ExteriorLights:Electricity [J](Hourly)
Fans:Electricity [J](Hourly)

Electricity (kWh): Oct 1 through Oct 7, 2016
0
20
40
60
80
100
120
140
160
2016-10-02
2016-10-03
2016-10-04
2016-10-05
2016-10-06
2016-10-07
2016-10-08
2016-10-09
Observed Electricity (kWh)
modeledElectricity
Refrigeration:Electricity [J](Hourly)
Cooling:Electricity [J](Hourly)
Heating:Electricity [J](Hourly)
InteriorEquipment:Electricity [J](Hourly)
InteriorLights:Electricity [J](Hourly)
ExteriorLights:Electricity [J](Hourly)
Fans:Electricity [J](Hourly)

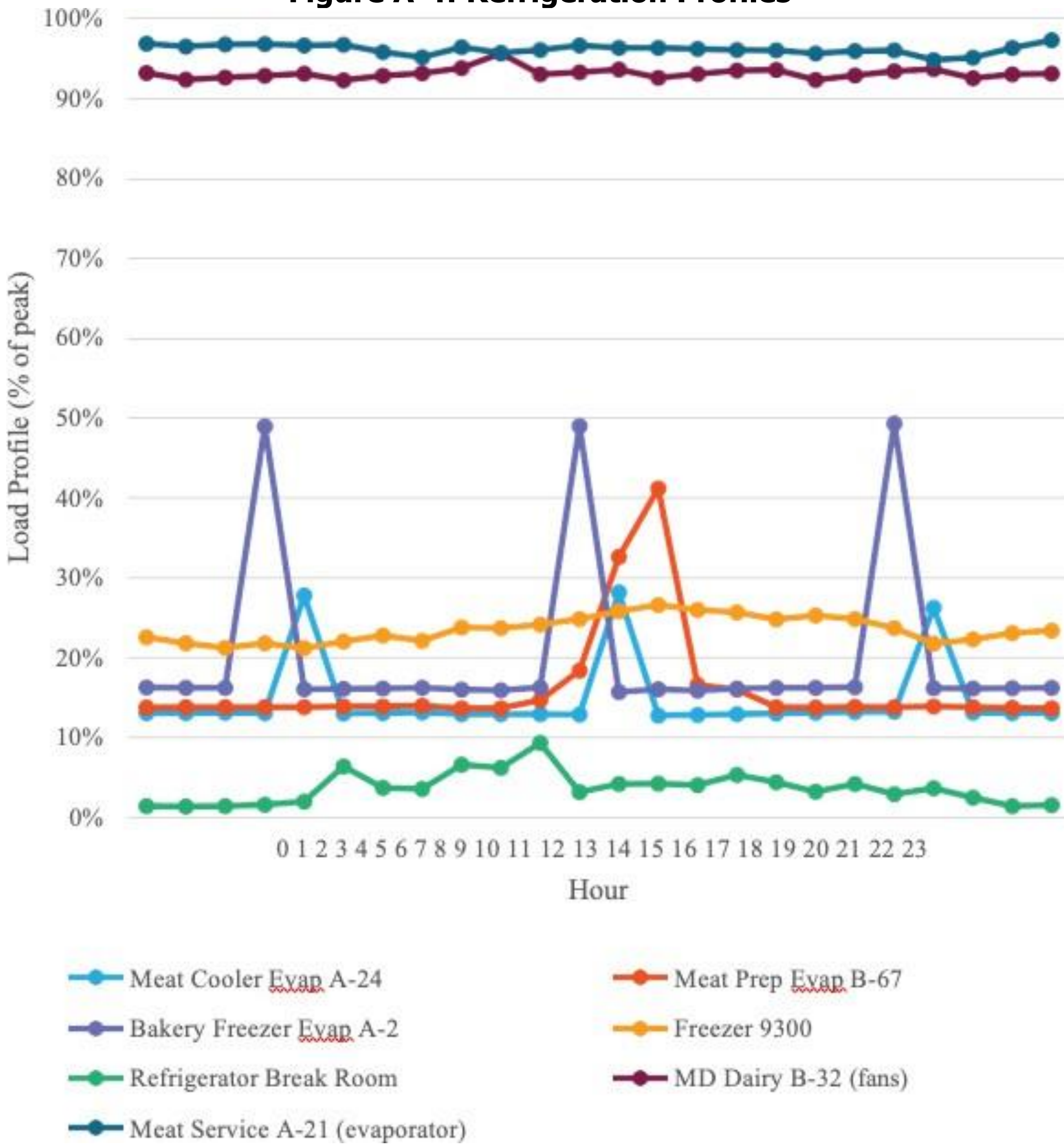

Source: LBNL

# ATTACHMENT A-1: MODEL INPUTS

## A1: Load Profiles

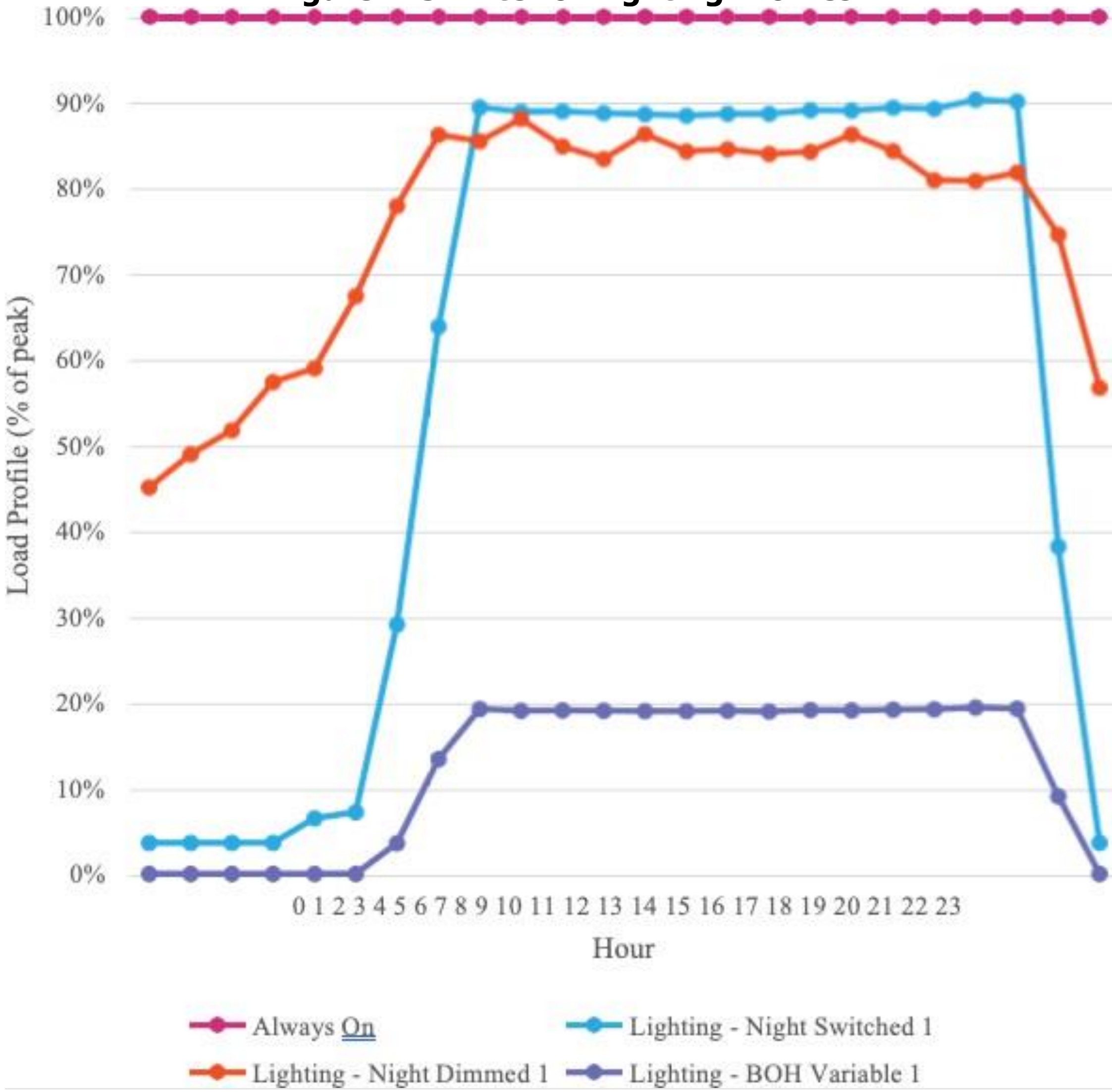
One-week submetering data for lighting and plug-load circuits gathered from the store was statistically analyzed to extract operating schedules for different zones and equipment types where possible. These schedules are shown in Figure A-4, Figure A-5, Figure A-6, Figure A-7, and Figure A-8 .

**Figure A-4: Refrigeration Profiles**



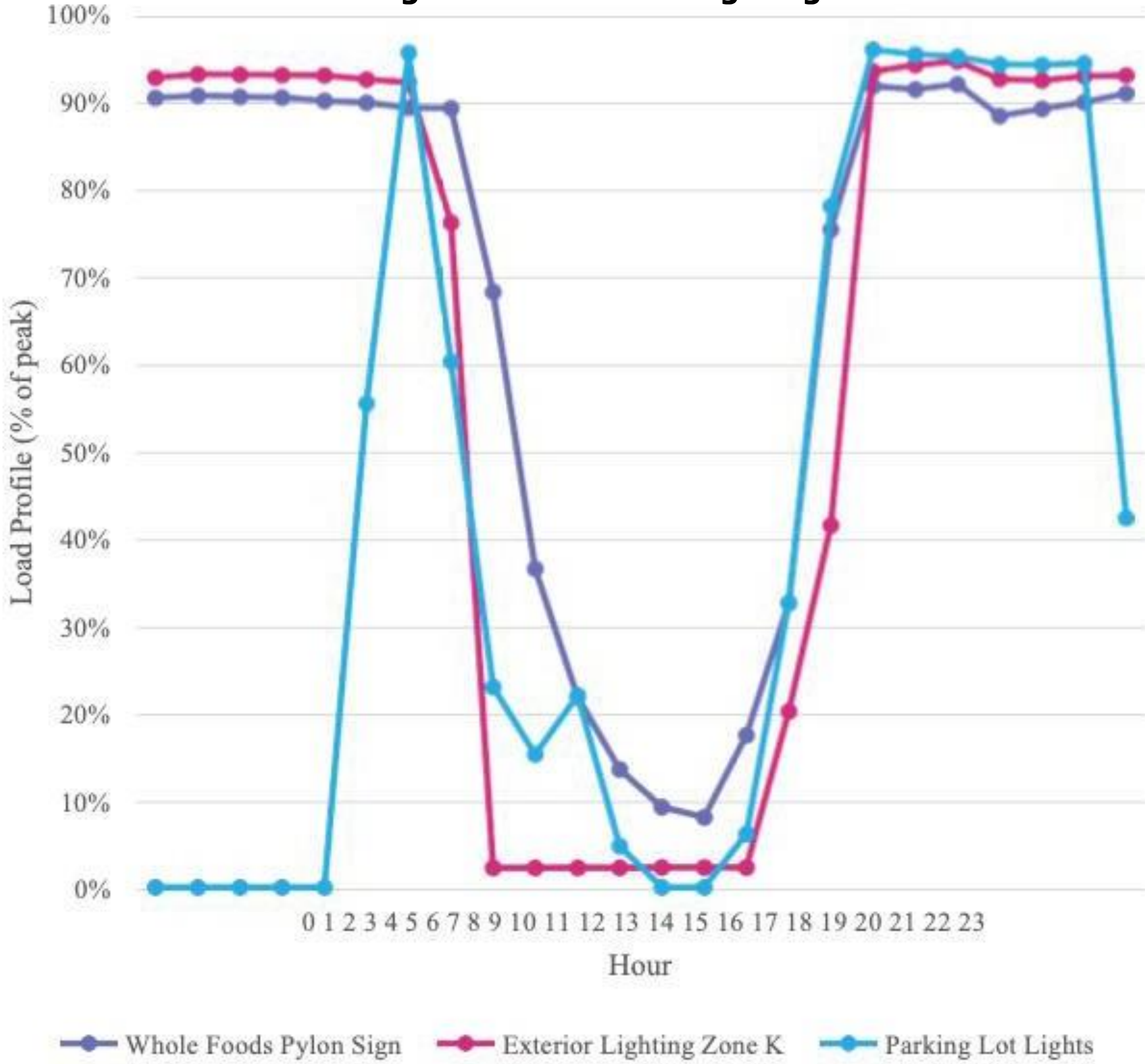

Source: LBNL

**Figure A-5: Interior Lighting Profiles**



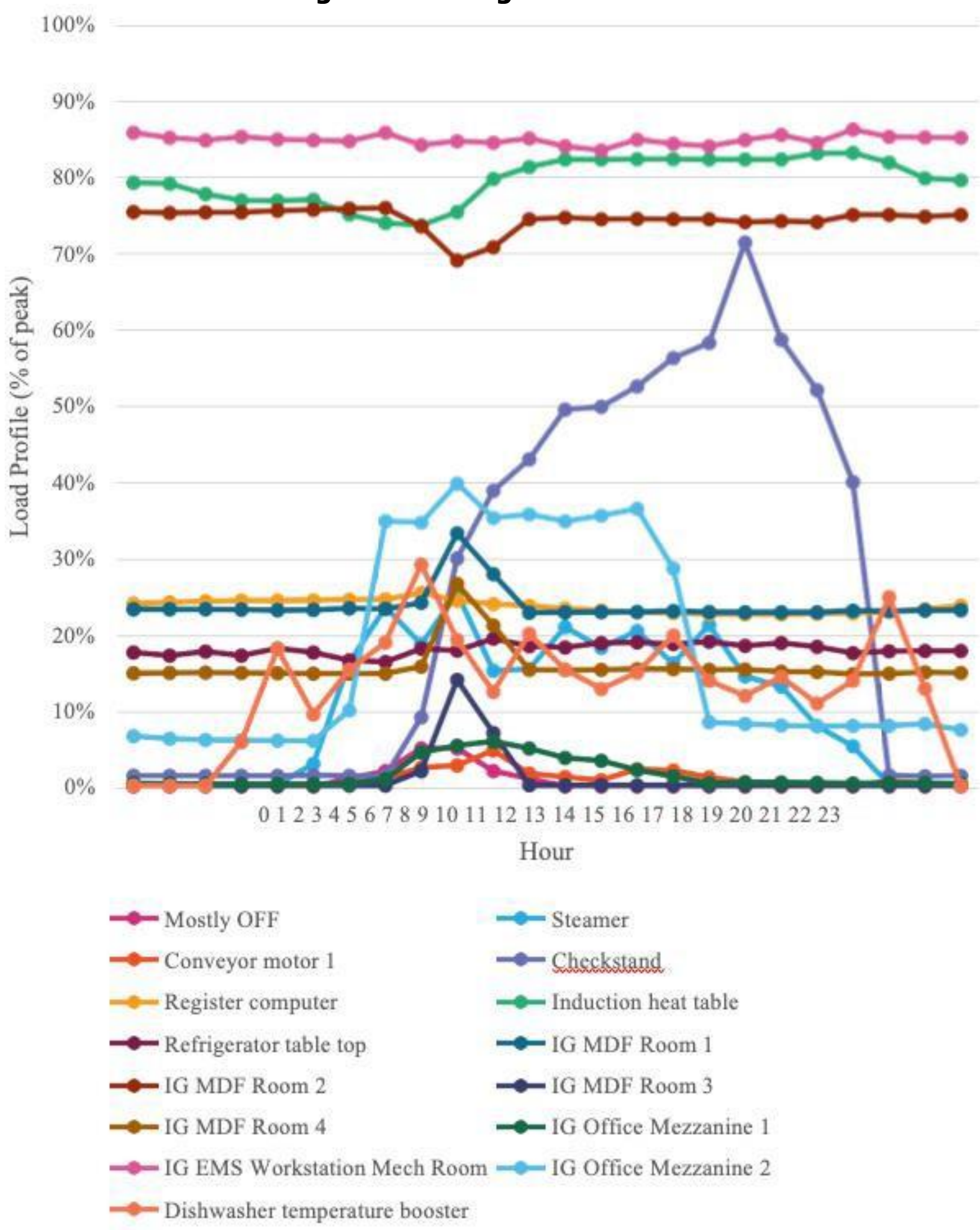

Source: LBNL

**Figure A-6: Exterior Lighting Profiles**



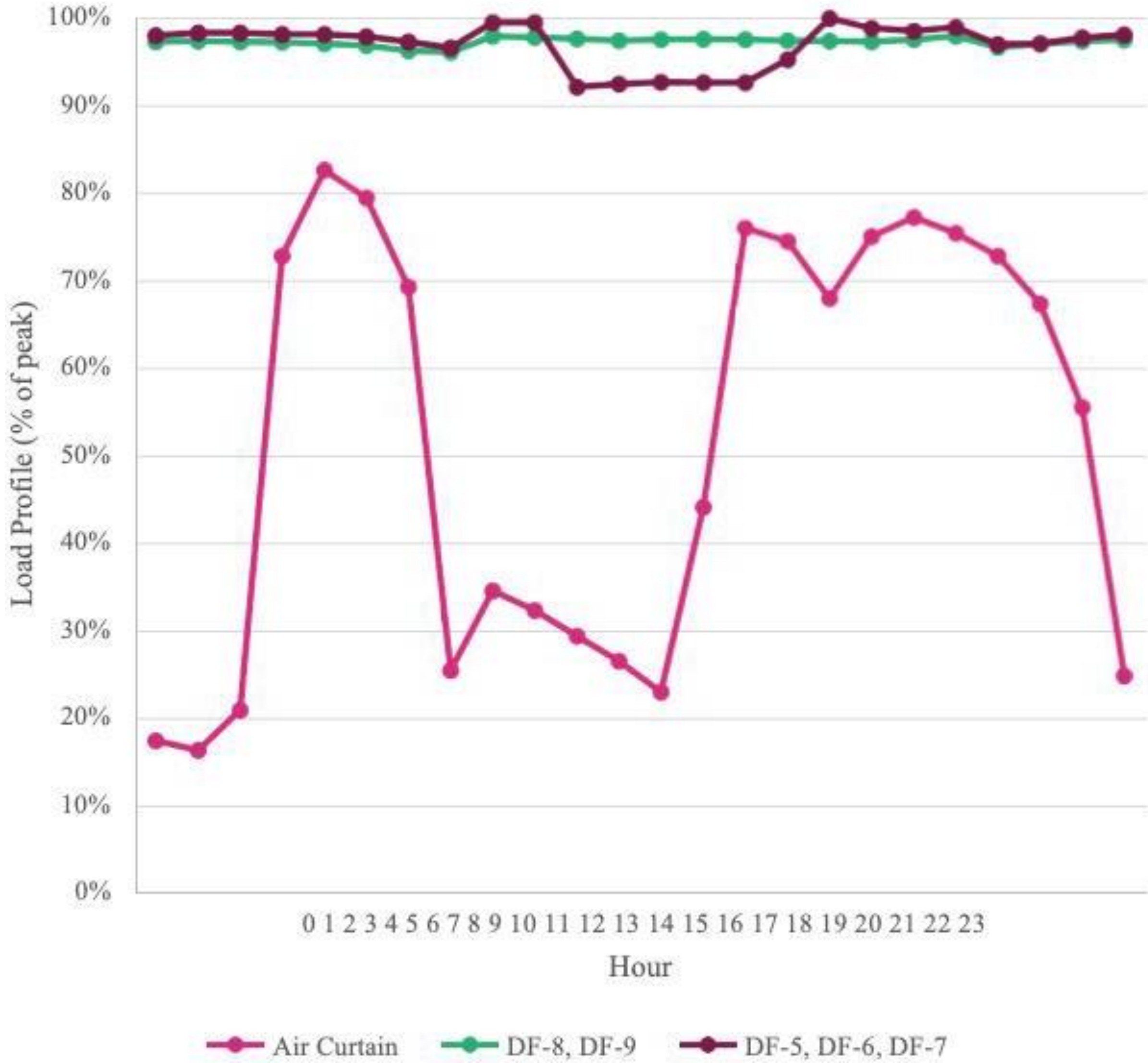

Source: LBNL

**Figure A-7: Plug-Load Profiles**




Source: LBNL

**Figure A-8: Heating, Ventilation, and Air-Conditioning Profiles**




Source: LBNL

# APPENDIX B:
# Noe Valley Whole Foods Energy Conservation Measures Modeling Report

## Summary

The MarketZero project aims to set a Whole Foods Market store in Noe Valley on the path to net-zero energy through a combination of deep energy retrofits and on- site generation that can be implemented while keeping the store operational. This study examines the potential for deep energy savings at the store by modeling a series of energy conservation measures (ECMs). 121 ECMs were considered based on measures proposed by the project team, input from the project Technical Advisory Committee (TAC), and products proposed for application in the store by manufacturers through a Call for Innovation. These ECMs were evaluated by the project team for energy savings potential, feasibility, cost, scalability, innovation, disruption to the store, and reliability. Using this early screening, the total number of ECMs to evaluate more deeply was reduced to 107. Each of these 107 ECMs was modeled individually in EnergyPlus using a calibrated baseline model of the Noe Valley store. Combinations of ECMs were then tested using a genetic algorithm which created packages of ECMs, tested them, and then evolved toward better performing solutions over many successive iterations. In all, 2,448 ECM packages were tested via this approach. Of these, 770 met the required capital cost constraint of $2,000,000. The single lowest energy cost solution reduced energy cost by approximately 70% within the model.

While the genetic algorithm approach efficiently generates solutions that achieve deep energy savings, it does not find a single optimal solution. Given this and the uncertainty in energy modeling, it was decided to evaluate the ECMs common across the 280 solutions with the lowest energy cost. It was discovered that four ECMs were present in all 280 solutions. A much larger number were present in some of the top performing solutions, but not all, indicating that there are multiple pathways to achieve significant energy savings. Using these energy cost results and the qualitative decision factors for each ECM devised by the project team, a preliminary list of ECMs was recommended. These were reviewed by Whole Foods' engineering and operations staff and DC Engineering. From this, a revised list of ECMs that met operational criteria and constructability was devised. This final ECM list provides a 55% reduction in annual energy use in the store at a cost of approximately $1.4 million. An additional set of measures in an optional package could increase energy savings to 59% for an additional $400,000 cost.

The proposed measures and associated costs are shown in Table B-1.

**Table B-1: Proposed Measures and Associated Costs**

| Proposed Measure | Individual ECM Energy Saving Potential | Estimated Cost |
|---|---|---|
| *Base Set of ECMs* | | |
| Refrigeration High Savings Option | 8.96% | $752,545 |
| Lighting Retrofit to LEDs (Interior and Exterior) | 10.43% | $288,440 |
| Insulated Ducts with AHU + VFD | 9.85% | $74,736 |
| Solar Air Preheat | 4.83% | $15,100 |
| Heat Pump Water Heater | 6.48% | $8,900 |
| Increased Ceiling Reflectance + Reduced Ambient Sales Floor Lighting | 7.35% | $42,160 |
| Replace Rotisserie with Combi Oven | 3.66% | $63,400 |
| Insulate Walk-Ins, Replace Lighting and Fans with Higher Efficiency Components | 1.86% | $85,810 |
| Upgrade Computers | 0.93% | $9,300 |
| Behavioral Program for Plug Load Switching | 0.56% | -- |
| Replace Gaskets on Walk- Ins, Add Door Closers | 0.53% | $40,900 |
| Time Clock for Hot Water Recirculation | 0.20% | $6,200 |
| Ice Machine Upgrade | 0.17% | $15,500 |
| Disconnect L2 Cooler 10 Months per Year | 0.97% | -- |
| ***Base Option Total*** | ***56.54%*** | ***$1,402,691*** |
| *Add-On ECMs* | | |
| Occupancy Sensors in Restrooms | 0.08% | $7,730 |
| Occupancy Sensors in the Back of House Spaces | 0.08% | $7,730 |
| DC Lighting Bus | 1.50% | $58,000 |
| Replace Refrigerated/Deli Tables | 0.16% | $61,800 |
| Fit Sinks with 1.15 GPM Spray Valves | 0.10% | $1,550 |
| Increase Insulation on Refrigeration Lines | 0.02% | $211,300 |
| Refrigeration System Hybrid Condenser | 0.65% | $92,700 |
| ***Add-On Subtotal*** | -- | ***$440,810*** |
| ***Base + Add-On Total*** | ***59.35%*** | ***$1,843,501*** |

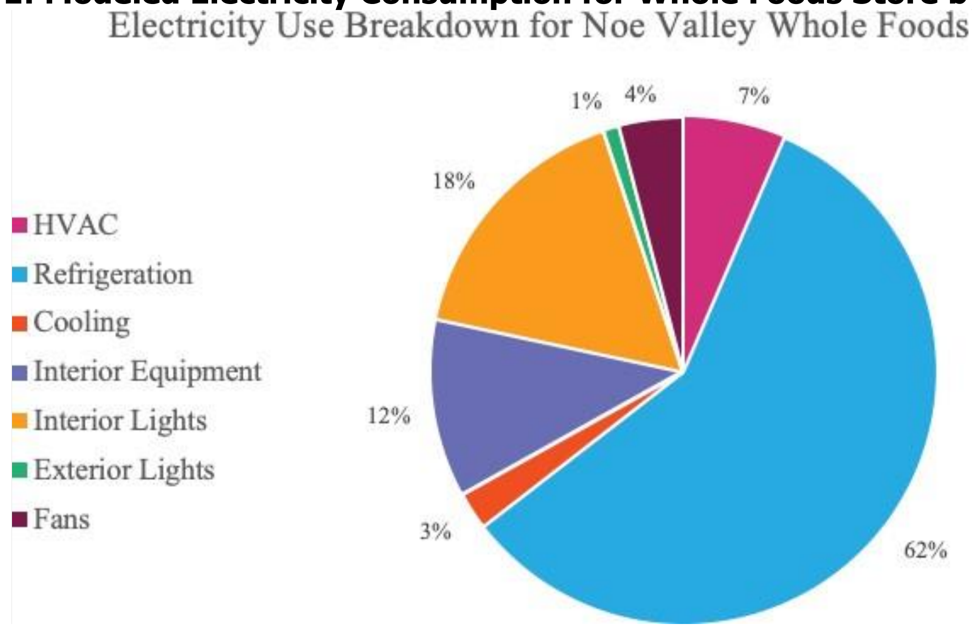
Source: LBNL

## Introduction

The MarketZero project, sponsored by the California Energy Commission through an EPIC grant, aims to set the Noe Valley Whole Foods Market on the path to net- zero energy through deep energy retrofits and on-site renewable energy generation.

Supermarkets are one of the most difficult commercial buildings to attempt net-zero due to the high energy use of store refrigeration, and no known examples of net-zero grocery stores currently exist. The Noe Valley store is no exception. The store has an Energy Use Intensity (EUI) of 228 kBtu/sf/yr, which is slightly higher than the US median grocery store EUI of 215 kBtu/sf/yr.[26] Over half of the energy use in the store is from the refrigeration compressors, cases, and condenser. Interior lighting and plug loads account for the next two major sources of energy use, with HVAC and fans contributing only marginally to total energy consumption. Figure B-1 shows the breakdown of electricity use within the store; Figure B-2 shows the breakdown of gas use. The percentages in the figure are based on a simulation of a calibrated energy model for the store run with actual meteorological data for San Francisco for 2016.

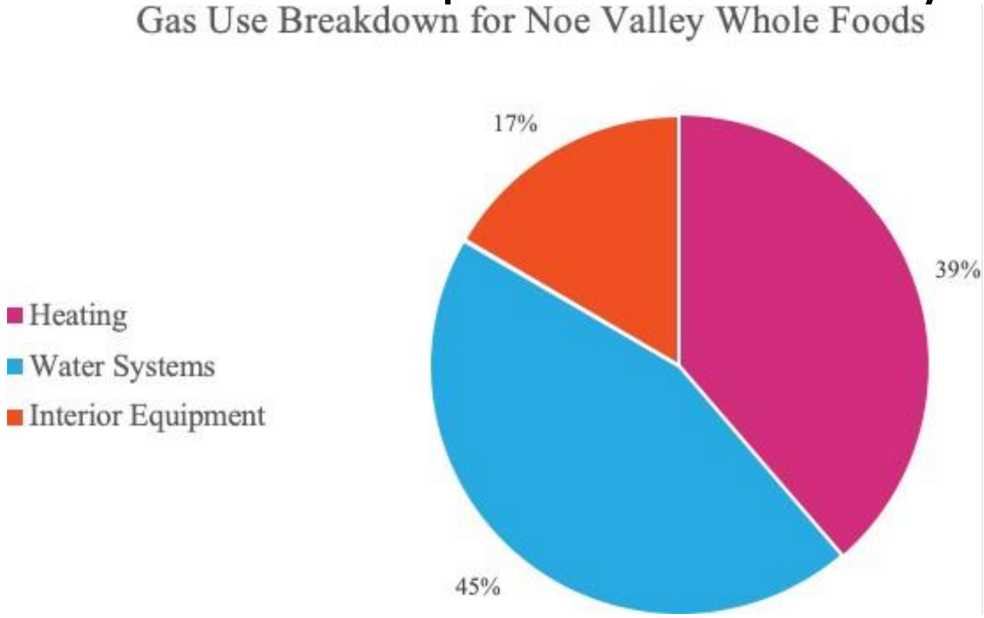
**Figure B-1: Modeled Electricity Consumption for Whole Foods Store by End Use**




Source: LBNL

[26] From the Lawrence Berkeley Lab Building Performance Database (www.bpd.lbl.gov)

**Figure B-2: Modeled Gas Consumption for Whole Foods Store by End Use**



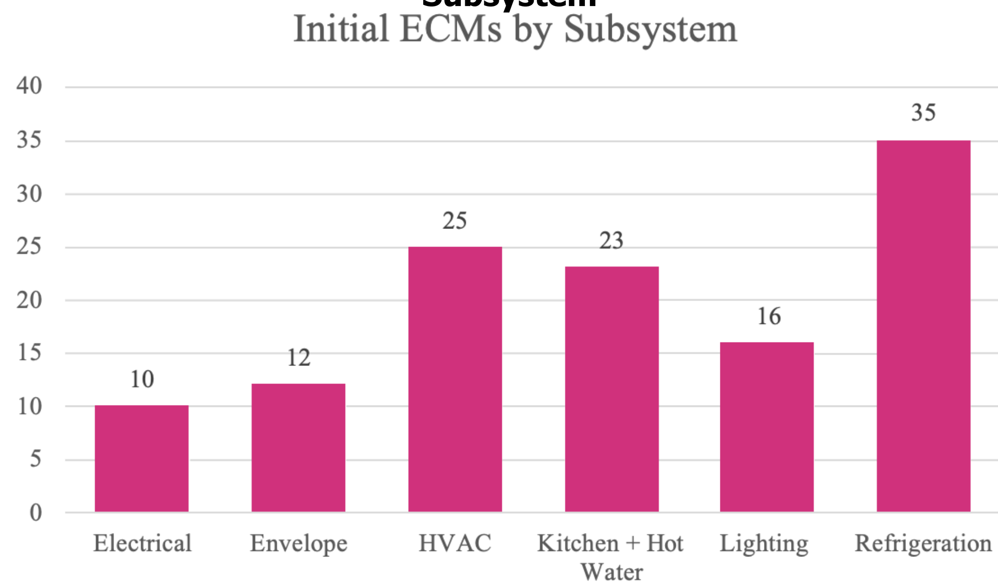

Source: LBNL

To reduce the energy use, a series of energy conservation measures (ECMs) were identified and modeled to examine their impact on the store's performance. The goal was to determine the combination of measures that would have the greatest impact on the store's energy performance within a limited $2 million construction budget.

## Energy Conservation Measures

During 2016, the project team worked with Whole Foods' management, the Technical Advisory Committee (TAC) for the project, and product manufacturers to compile a list of ECMs with the potential to reduce energy consumption in the store. The proposed ECMs had either been documented to save energy in prior grocery store installations or were based on promising technologies that offered better performance than industry equivalents in product or laboratory tests. In total, 121 ECMs were proposed for consideration in the store. Of these, the breakdown of ECMs by store subsystem is shown in Figure B-3.

**Figure B-3: Number of ECMs Tested for Whole Foods Store by Energy-Use Subsystem**




Source: LBNL

Arup reviewed every ECM to evaluate its applicability to the store and identify specific products and technical performance criteria that could be used to quantify the impact of each measure on the store's energy use. In addition, each proposed ECM was ranked qualitatively on six categories:

- Innovation
- Customer experience
- Maintenance
- Disruption
- Integration
- Scalability

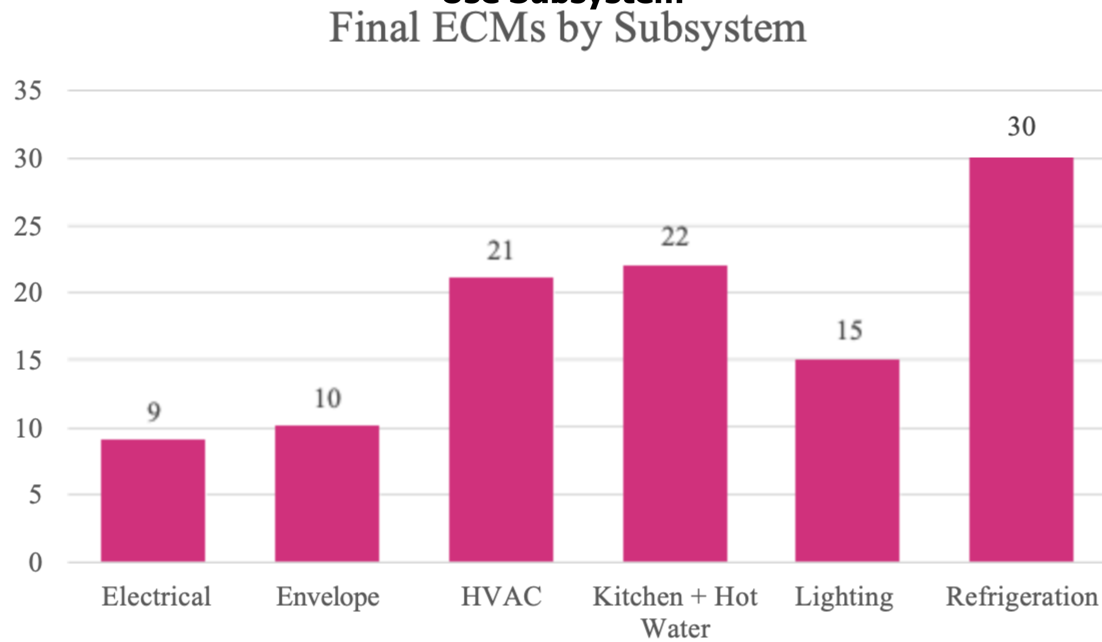
Rankings were devised through conversations with the project team based on experience from past projects and past case studies where the technology had been applied.

The findings of this evaluation were used to pare down the list of prospective ECMs. Those that were discarded from further consideration either:

- Had no discernible record of demonstrable savings, or no technical criteria on which modeling could be based
- Provided load shifting or cost savings but no demonstrable energy savings
- Were inapplicable to the system or construction types found in the Noe Valley store
- Were infeasible to implement while keeping the store open

From this initial analysis, the total number of ECMs was reduced to 107 for modeling. Of these, the breakdown of ECMs by subsystem is given in Figure B-4.

**Figure B-4: Number of ECMs Ultimately Tested for Whole Foods Store by Energy-Use Subsystem**




Source: LBNL

A complete list of the ECMs carried forward into modeling is provided in Appendix A.

To identify the best package of ECMs within the construction budget also required a more detailed understanding of the cost of each ECM carried forward into modeling. Based on the ECM description, the as-built drawings of the Noe Valley store, and the best understanding of the construction work required, a rough order of magnitude (ROM) estimate for ECM construction was compiled by Arup's cost estimating team. Estimates used a combination of industry-wide cost estimations and specific costs from manufacturers where a unique product was proposed. The ROM costs for each of the 107 ECMs are provided in Attachment B-1.

## Modeling Energy Conservation Measures

The remaining 107 ECMs were carried forward into modeling to determine the best combination of measures within the limited construction budget to achieve deep energy savings in the store. The baseline for modeling was a calibrated model of the store created in EnergyPlus using data from January 1, 2015 through February 20, 2017. The calibration of this model is described in the previous Arup Energy Model Calibration Report.

The modeling approach was to create a modification to the calibrated EnergyPlus model for each ECM. Where possible, the modeling strategy used a direct implementation of the exact technology and data from published case studies or product manufacturers to simulate component performance. Where an exact modeling strategy was not available in EnergyPlus, industry best practice for modeling that component was used or the closest analogue was developed. In some cases, multiple variants of a single ECM were tested (e.g., multiple thicknesses of duct and pipe insulation), resulting in a total of 169 variants modeled and simulated. A complete list of the modeled ECMs and the strategies employed in EnergyPlus along with key performance characteristics are provided in Attachment B-1.

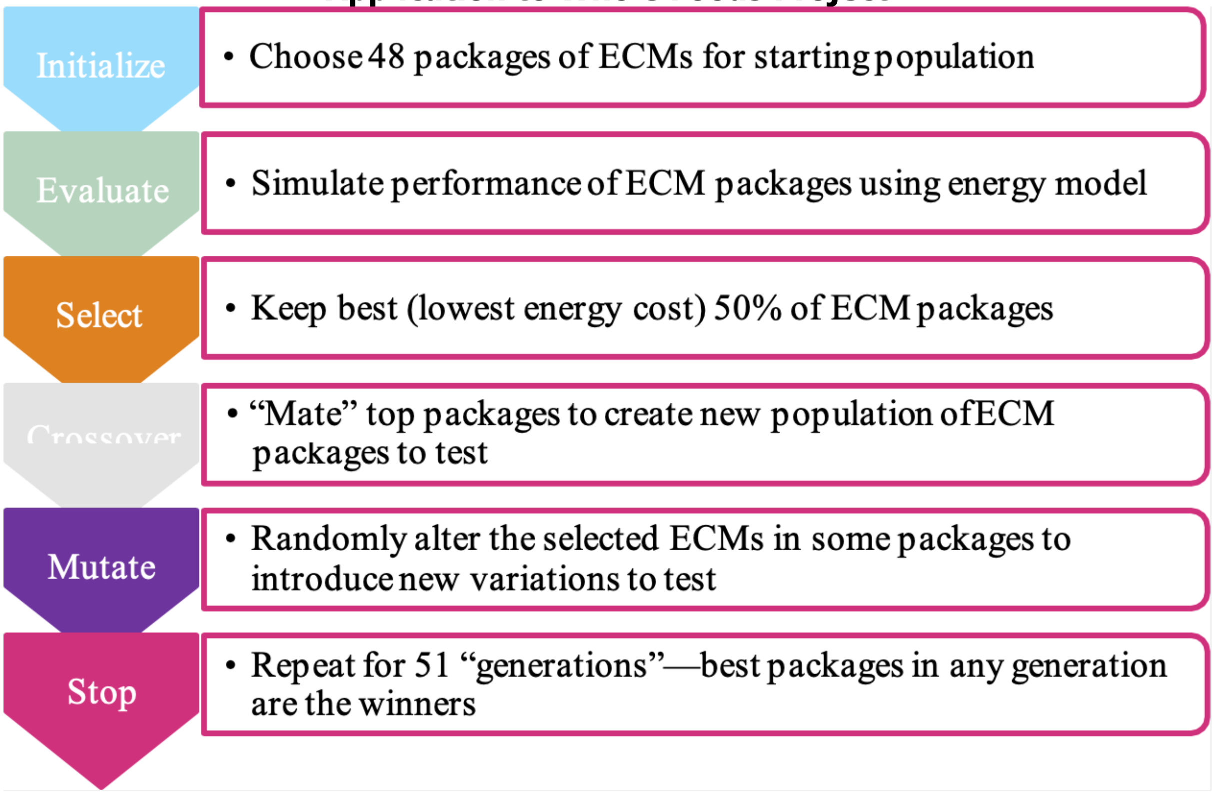
Each ECM was simulated individually as a variant on the calibrated base model to assess the energy savings attributable that measure. The top performing ECMs were found to be (percent energy savings from baseline in parentheses):

- LED lighting for all interior lights (13.3%)
- Convert produce and dairy refrigeration cases to walk-ins (13%)
- Add secondary refrigeration loop for medium temperature cases (10.5%)
- Occupancy sensors for front of house lighting (8.5%)
- Occupancy sensors in refrigeration cases (8.5%)
- Heat pump domestic hot water heater (6.5%)
- Point of use electric water heating (6.5%)
- Reduce front of house lighting and keep accent lighting same (6%)
- Solar air preheat (5%)
- Doors on exposed medium-temperature walk-ins (4.5%)

A full list of the energy savings from each ECM are provided in Attachment B-1. With the large number of ECMs to test and the possibility of combined effects between measures, a strategy was designed using a genetic algorithm to test a large number of

ECM packages and identify the best combination of ECMs to achieve maximum energy savings within the construction cost. Genetic algorithms operate through a simulation of Darwinian evolution. A set of proposed solution sets is randomly generated, the models are tested, energy performance and cost recorded, and then new solution sets are created by combining the characteristics of the best sets that have been tested and adding some variation. These last two steps are similar to the processes of reproduction and mutation that are a typical characteristic of evolution mechanisms. Figure B-5 summarizes this process.

**Figure B-5: Genetic Algorithm Flow Chart Showing Steps in Algorithm and Their Application to Whole Foods Project**




Source: LBNL

The benefit of simulating ECM package performance using a genetic algorithm is that a significantly larger number of solutions are tested, leading to opportunities for integrated ECM packages with higher energy savings to be found. Since the algorithm learns from earlier tests of ECM packages, the probability of finding the best combination of measures is substantially increased. Additionally, by learning from previous model iterations, the genetic algorithm can identify beneficial combinations of solutions that have higher performance than the two measures in isolation. By contrast, combinations that lead to lower than anticipated performance can also be identified.

Typically, too few iterations of ECM selections are simulated to identify unexpected impacts of combined measures.

Therefore, genetic algorithms present a potential large improvement over current energy modeling and energy conservation approaches. This project is among the first to pursue such an avenue, though it is not unique. Parametric modeling and genetic algorithm-based energy modeling have been pursued in academia, but no stable commercial products exist for undertaking genetic optimization in energy modeling currently.

The challenge is that the resulting packages may not entirely be feasible, and the single best solution found by the optimization does not take into account the other objectives of Whole Foods. Given the uncertainty inherent in energy modeling, the single best outcome also cannot be judged to be universally better than a solution with similar performance evaluated by the genetic algorithm. To account for these limitations, the approach for analyzing the results was to evaluate the ECMs present in a number of the best performing solutions produced by the algorithm.

For the genetic algorithm to run, an objective and set of constraints must be defined. The objective of the MarketZero project is to reduce the energy consumption of the store, but this can be expressed in multiple ways. Through consultation with Whole Foods and the project team, the objective that was utilized for the study was energy cost. This was interpreted as the cost of energy only and not demand charges as paid by Whole Foods to the utility, Pacific Gas and Electric (PG&E). Whole Foods currently pays for electricity on the E-19 TOU tariff and gas on the G-NR1 tariff. Both rates vary seasonally, with electricity also varying by time of use and gas varying by consumption in any month, as shown in Table B-2.

**Table B-2: PG&E Electricity and Gas Rates for Whole Foods**

| PG&E E-19 TOU Energy Rates (USD/kWh) | | PG&E G-NR1 Gas Rates (USD/therm) | |
|---|---|---|---|
| Summer Peak | $0.15178 | Summer, First 4,000 therms | $0.97499 |
| Summer Part-Peak | $0.11127 | Summer, Each therm over 4,000 | $0.71967 |
| Summer Off-Peak | $0.08445 | Winter, First 4,000 therms | $1.08585 |
| Winter Part-Peak | $0.10573 | Winter, Each therm over 4,000 | $0.78335 |
| Winter Off-Peak | $0.09111 | Surcharge | $0.04672 |

**Summer is defined as May 1- October 31, and winter is defined as November 1-April 30.**

Source: LBNL

Since the wind turbine and PV ECMs would be procured as a PPA, they were not modeled in the optimization, as the objective of the optimization was to reduce energy cost relative to a capital cost. Decisions on these generation technology strategies were intended to be made after choosing the ECMs and evaluating the remaining need for renewable generation.

Additionally, the qualitative assessments of innovation, customer experience, maintenance, disruption, integration, and scalability were calculated for each option tested by the genetic algorithm. While these were not treated as objectives in the optimization, they were retained for use as decision-making parameters in choosing the final ECMs to implement. To constrain the optimization, the capital cost of all ECMs was specified to be less than or equal to $2 million as specified by Whole Foods.

As was noted, the ECMs were written as modifications to the EnergyPlus model which was calibrated over a 26 month period. This model takes roughly 2 hours to simulate. Therefore, to enable simulation of many ECM options, rapidly learn, and create better packages of ECMs, the model run time was limited to four months, chosen to be representative of the entire year:

- February 2015
- May 2015
- September 2015
- November 2015

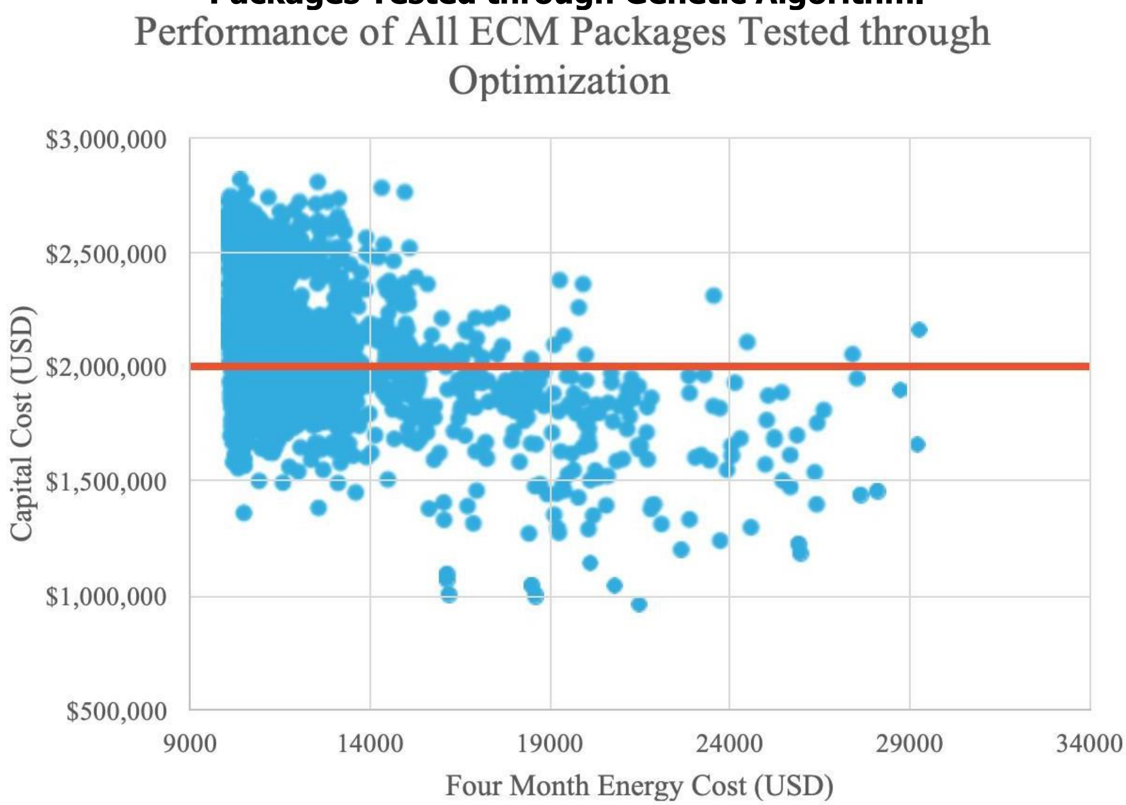
For the simulation to be consistent with the calibration and to reflect the closest weather station to the store, actual data was used rather than typical meteorological year data. A comparison of the store EUI and relative subsystem performance over these four months and over the entire 26 months in the actual weather data found that the relative EUIs adjusted for a full year were within 0.002%, providing a sound basis for using the reduced model in the study.

Reducing run time to four months enabled a single simulation to be completed in 20 minutes.

The algorithm was allowed to run for 51 generations of solution development with each generation comprised of 48 individuals for a total of 2,448 ECM packages explored.

Figure B-6 shows the results of this exploration for all solutions tested graphed as capital cost vs. energy cost for four months. Theoretically, the most ideal solutions are located in the lower left of the graph, with the best solutions being those farthest left on the horizontal and below the line representing the $2 million construction budget.

**Figure B-6: Scatter Plot of Capital Cost vs. Four Month Energy Cost for All ECM Packages Tested through Genetic Algorithm.**




**The orange line denotes the capital cost constraint.**

Source: LBNL

Figure B-6 shows that a number of the solutions tested exceeded the $2 million capital budget and were therefore excluded from further consideration. 770 tested solutions were below the capital cost budget. These varied in energy cost from $10,100 to $31,500. The baseline four month calibrated energy cost for the store was $35,000. Relative to this, the best performing solutions indicate energy cost savings of ~70%.

Of these solutions, 280 had an energy cost between $10,000 and $11,000. These 280 were selected for further study to identify the ECMs which most consistently contributed to high performance.

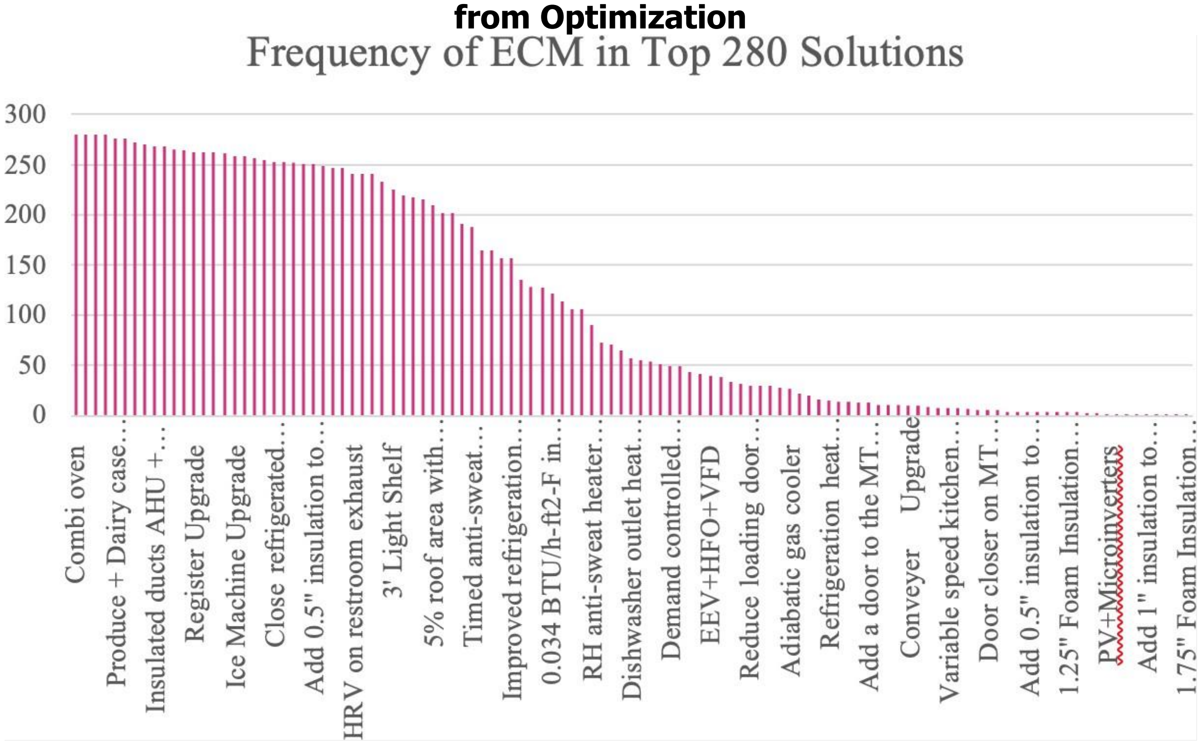
Within these 280 solutions, 114 different variants of ECMs appeared at least once. Table B-2 shows how many ECM variants exist within a given range of occurrences, and Figure B-7 shows a visual interpretation of the data as a histogram of the variant frequency. In this image, each bar represents the number of occurrences for a unique variant of an ECM. Attachment B-2 presents the full list of 114 variants that occurred in the top 280 solutions along with their individual energy cost savings, capital cost, and qualitative performance.

**Table B-2: Number of ECM Variants that Occur with a Specific Frequency in 280 Top Performing Solutions from Optimization**

| Number of Occurrences | Number of ECM Variants |
|---|---|
| 1-10 | 32 |
| 11-50 | 22 |
| 51-100 | 7 |
| 101-150 | 7 |
| 151-200 | 6 |
| 201-250 | 15 |
| 251-270 | 17 |
| >270 | 7 |

Source: LBNL

**Figure B-7: Histogram of ECM Variant Frequency in Top 280 Performing Solutions from Optimization**




Source: LBNL

Several conclusions emerge from this data. First, the long tail of the distribution suggests that a number of ECMs likely have low impact on the overall energy performance, and that the majority of savings are realized through the smaller number of ECMs that occur in the majority of solutions. Second, four ECMs occur in all 280 solutions. Based on the individual performance of these measures, it is likely that these account for roughly 30% of total energy savings realized in any package. Finally, the solutions in the middle of the distribution likely have a significant impact on the performance of the store, but multiple pathways exist to realizing large energy savings. This presents an opportunity for the final ECMs to be chosen based on energy cost and the qualitative indicators previously evaluated by the project team and Whole Foods.

## Limitations and Uncertainty

EnergyPlus is an advanced energy modeling tool capable of simulating a large variety of building conditions, equipment, and system types. However, the software still has several limitations that may impact the ECM modeling findings and recommendations.

Most notably, the EnergyPlus' ability to model refrigeration systems is less fully developed than the HVAC and building equipment modeling capabilities. The interaction of walk-in units and refrigerated cases with the surrounding environment could be improved to more accurately model the convective and conductive transfer of energy from cold environments to warmer regions. This is especially true when incorporating door opening/closing behavior and the presence or absence of additional insulation or openings in these units. On the compressor side of the refrigeration simulation, limitations were encountered in creating accurate representations of different patterns of staging and subcooling the compressors as well as incorporating elements such as electronic expansion valves which do not have a direct implementation in EnergyPlus.

Another limitation noted in the study was the interaction of stratified thermal zones. The design of the store creates a natural thermal stratification of the main sales floor, which is mitigated through destratification fans. Replicating this behavior is challenging in EnergyPlus since the software does not natural allow natural convection between adjacent zones, even when separated by a void or air wall. Creating the necessary air flows requires an understanding of the air transfer balance between zones and is limited in cases where more than one HVAC system serves the same area of a building. The complexity of interaction between multiple HVAC systems and multiple zones in the store led to compromises being required to accurately model thermal comfort and stratification. This also resulted in temperature sensors being located in the occupied zones with HVAC distribution in the stratified zone; the feedback loop between the HVAC system and the thermostat may be questionable as a result given the challenge of connecting across stratified zones. The lack of interaction across the stratified zones also created challenges in simulating daylighting. Positioning the sensors in the occupied zones failed to capture light incident from skylighting above the stratified zones. This is because light does not transfer across air walls adequately in EnergyPlus by default.

Additionally, uncertainty is inherent in energy modeling given both that operating conditions are variable and not fully known and that future weather is not predicted by typical or past weather. In the case of Whole Foods, the greatest uncertainty exists in the occupancy schedules and behavioral patterns of employees and customers. Despite the submetering performed throughout the store, occupancy patterns are not well known and use patterns for some of the interior equipment is unknown. These had to be estimated from observation and typical supermarket operation but may not be representative of the store.

Additionally, stocking patterns and the effects of specific aisle occupancy on refrigerated case performance are unknown and could not be accurately incorporated without a better understanding of customer patterns and use within the store. Finally, as with any energy model, the results have been simulated based on historic weather data which is not representative of any future year. Savings on an annual basis will therefore vary; the savings reported in this document are mean to be treated as average likely savings rather than expectations for any particular year.

Due to the limitations and uncertainties experienced in modeling, there is varying confidence in the ECM savings results. The highest degree of confidence exists for plug loads and lighting, for which use profiles could be well established through sub metering and for which schedule values of power consumption were available.

## Preliminary Energy Conservation Measures Recommendation

Using the energy model results and an evaluation of the qualitative performance of each ECM, three categories of measures are recommended for further study. The first category represents high impact measures that should be included in the final retrofit design on the basis of energy performance. The second include low cost, high-impact and behavioral measures that represent "quick wins" for the store. The final set are measures that occurred numerous times in the best performing simulations that should be evaluated qualitatively with Whole Foods and the Technical Advisory Committee (TAC) for inclusion in the final ECM recommendation. This list represents a preliminary recommendation only subject to review and approval by Whole Foods and the TAC on the basis of the qualitative rankings, priorities, and review of the technical feasibility.

- High Impact Measures
  - Replace rotisserie with combi oven
  - Convert all interior lighting to LED
  - Provide occupancy sensors on all lights in sales/front of house area
  - Provide secondary refrigeration loop for medium temperature cases
  - Replace produce and dairy cases with walk-ins
- Quick, Low-Cost Wins
  - Upgrade computers
  - Behavioral adjustment to turn off registers, computers, and office equipment plug loads at night
  - Turn off L2 cooler
  - Upgrade ice machine
  - Occupancy sensors in restrooms
  - Gaskets and door closers on medium temperature and low temperature walk-ins

    - Refrigeration case occupancy sensors for lighting
    - Time clock for hot water recirculation
- Measures for Additional Consideration
    - DC electrical system for lighting and compressors
    - Provide doors on all refrigerated cases
    - Upgrade fans, lights, and add insulation (0.5” add’l) on walk-ins
    - Electronic expansion valves added to compressors
    - Heat pump domestic hot water heater or point of use water heating
    - Replace RTUs with AHU+VFD or heat pump
    - Adiabatic gas cooling condenser

In addition to these measures, rooftop PV is recommended for investigation and purchase as a PPA to offset additional power consumption. Preliminary analysis shows that covering the lower roof area with PV could provide approximately 200,000 kWh annually based on a preliminary area calculation from PV Watts. This could account for as much as 60-70% of the remaining store load depending on the ECMs implemented.

## Refining the Recommended Energy Conservation Measures List

The preliminary list of recommended ECMs was reviewed with Whole Foods’ engineering and operations staff for feasibility and potential conflicts with Whole Foods’ store operations. In addition, measures which showed energy savings but were not initially recommended were discussed. Some were included for additional analysis on the basis of other benefits provided to the store. Based on their input, the list of ECMs for further study and possible implementation was refined to measures confirmed for implementation based on energy savings potential and cost. The set of data is shown in Table B-3.

**Table B-3: Confirmed ECMs for Final Implementation and Measures Requiring Further Feasibility Analysis**

| Measures Confirmed for Implementation |
|---|
| Convert interior lighting to LED |
| Convert exterior lighting to LED |
| Increase ceiling reflectance and turn down store ambient lighting |
| Replace domestic water boiler with heat pump water heater |
| Enclose medium temperature refrigeration cases with doors |
| Add insulation to walk-ins, and replace fans and lights with more efficient units |
| Upgrade computers |
| Behavioral adjustment to turn off registers, computers, and office equipment plug loads at night |
| Replace gaskets on walk-ins and add door closers to walk-in doors |
| Add time clock for hot water recirculation |

Source: LBNL

For measures requiring further feasibility assessment, four steps were outlined:

1. For refrigeration ECMs, a consultation with DC Engineering, Whole Foods' preferred refrigeration engineer, was scheduled. DC Engineering subsequently reviewed the list of proposed ECMs and walk through the store to identify which opportunities were feasible given the current piping and refrigeration infrastructure. This was paired with a refined cost estimate from Source Refrigeration. Measures from the ECM list ultimately endorsed by DC Engineering would be packaged as the refrigeration component of the final design.
2. For the combi oven, Whole Foods' operations team required further study of the quantity of roasted chickens which could be prepared in a combi oven relative to the current sales in the store. If the combi oven could meet demand, it would be selected as an ECM for implementation. After review by the operations staff, it was determined that the combi oven would be capable of meeting demand, and this measure was confirmed for implementation in the store.
3. Whole Foods' operational and sales staff were also required to provide input on whether the second floor cooler could be turned off. Currently, the cooler is used during the holiday season to manage a surge in inventory. It was determined that this function must remain, but during the additional 10 months of the year the cooler is not required and can be turned off.
4. After revising refrigeration measures, remaining HVAC and electrical measures would be simulated again to determine their impact on the final energy. Those which still showed a positive savings would be included in the final ECM measure list.

DC Engineering performed a walkthrough of the store on July 27, 2017. Following this visit, they proposed two options for refrigeration system improvements that would reduce overall capacity and generate energy savings. These were grouped as medium and high savings potential packages. Each was evaluated for energy savings potential in EnergyPlus and estimated by Source Engineering. Table B-4 describes the components and characteristics of these packages.

**Table B-4: DC Engineering Proposed Refrigeration Package Characteristics**

| Characteristic | Medium Savings Refrigeration Package | High Savings Refrigeration Package |
|---|---|---|
| Package Components | Change refrigerant to R- 448A<br>Add doors to medium temperature cases<br>Adjust suction temperatures<br>Decrease suction temperature for medium temperature loop<br>Compressor VFDs where feasible | Change refrigerant to R- 448A<br>Add doors to medium temperature cases<br>Adjust suction temperatures<br>Decrease suction temperature for medium temperature loop<br>Move all medium temperature loads to Rack B<br>Cascade System<br>Raise suction temperature where feasible<br>3 Suction groups for Rack B<br>Additional compressor VFDs where feasible<br>Reduce compressor horsepower |
| Refrigeration Rack Power (kW) | 68.75 | 59.33 |
| Energy Savings from Calibrated Model | 5.23% | 8.96% |
| Cost | $435,850 | $752,545 |
| Energy Savings (kWh/$) | 0.435 | 0.394 |

Source: LBNL

For these two options, the high savings package maximizes energy saving at a slightly higher cost per kWh saved. Based on the savings potential and the similarity savings per dollar invested, the high savings refrigeration package is recommended for implementation in the store.

## Final Recommended Energy Conservation Measures List

With the final refrigeration package selected, the additional ECMs were simulated to determine the combination which provided the greatest energy reduction within the capital cost target of $2 million. To account for pricing, design, and construction contingency, these measures were further divided into a base set of measures to be further detailed and priced, and an add-on set of measures to be detailed and priced if budget and time allow. The priorities of these two sets reflected the energy savings potential and Whole Foods' priorities. These final recommended sets of ECMs and their associated estimated costs are shown in Table B-5.

Costs for all measures except refrigeration were provided by Arup; refrigeration costs were estimated by Source Engineering.

**Table B-5: Proposed and Add-On ECMs with Cost and Energy Savings Estimates**

| Proposed Measure | Individual ECM Energy Saving Potential | Estimated Cost |
|---|---|---|
| *Base Set of ECMs* | | |
| Refrigeration High Savings Option | 8.96% | $752,545 |
| Lighting Retrofit to LEDs (Interior and Exterior) | 10.43% | $288,440 |
| Insulated Ducts with AHU + VFD | 9.85% | $74,736 |
| Solar Air Preheat | 4.83% | $15,100 |
| Heat Pump Water Heater | 6.48% | $8,900 |
| Increased Ceiling Reflectance + Reduced Ambient Sales Floor Lighting | 7.35% | $42,160 |
| Replace Rotisserie with Combi Oven | 3.66% | $63,400 |
| Insulate Walk-Ins, Replace Lighting and Fans with Higher Efficiency Components | 1.86% | $85,810 |
| Upgrade Computers | 0.93% | $9,300 |
| Behavioral Program for Plug Load Switching | 0.56% | -- |
| Replace Gaskets on Walk-Ins, Add Door Closers | 0.53% | $40,900 |
| Time Clock for Hot Water Recirculation | 0.20% | $6,200 |
| Ice Machine Upgrade | 0.17% | $15,500 |
| Disconnect L2 Cooler 10 Months per Year | 0.97% | -- |
| ***Base Option Total*** | ***56.54%*** | ***$1,402,691*** |
| *Add-On ECMs* | | |
| Occupancy Sensors in Restrooms | 0.08% | $7,730 |

| Proposed Measure | Individual ECM Energy Saving Potential | Estimated Cost |
|---|---|---|
| Occupancy Sensors in the Back of House Spaces | 0.08% | $7,730 |
| DC Lighting Bus | 1.50% | $58,000 |
| Replace Refrigerated/Deli Tables | 0.16% | $61,800 |
| Fit Sinks with 1.15 GPM Spray Valves | 0.10% | $1,550 |
| Increase Insulation on Refrigeration Lines | 0.02% | $211,300 |
| Refrigeration System Hybrid Condenser | 0.65% | $92,700 |
| ***Add-On Subtotal*** | -- | ***$440,810*** |
| ***Base + Add-On Total*** | ***59.35%*** | ***$1,843,501*** |

Source: LBNL

In addition to these measures, rooftop PV is recommended for implementation on the store, but it is assumed that the procurement of rooftop PV will be through a different financing mechanism. With rooftop PV, the total energy of the store can be reduced by an additional 13%, yielding a total reduction in energy from the current baseline of 67%.

# ATTACHMENT B-1: LIST OF MODELED ECMS

Table B-6 provides a full list of the ECMs modeled for the Whole Foods store along with the model implementation, ROM cost, and percent EUI savings for the measure from the calibrated baseline.

**Table B-6: List of Modeled Energy Conservation Measures**

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| **Electrical** | | | | | | | | | |
| PV Panels (Horizontal Roof): 135 kW premium efficiency PV array over 9,700 sf of roof area, central inverter | Simulate using PV object in EnergyPlus with module efficiency of 21.5% | $262,900 | 18% | 4 | 3 | 3 | 4 | 4 | 4 |
| PV Panels (Horizontal Roof)+ Microinverters: 135 kW premium efficiency PV array over 9,700 sf of roof area, one inverter per panel | Simulate using PV object in EnergyPlus with module efficiency of 21.5% and improved inverter curve | $450,700 | 18% | 4 | 3 | 2 | 4 | 4 | 4 |
| Plug Load Switching: Computers, registers, and office equipment on full, 24/7 switched to be on from 8 am to 10 pm, and off (~1% phantom load) from 10 pm to 8 am | New schedules controlling equipment power levels created in EnergyPlus and applied to all plug load and cooking equipment determined to be on full | No Cost Impact | 0.62% | 3 | 2 | 3 | 3 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Upgrade Registers: Replace registers with energy efficient equipment, reducing peak power demand from 400 W to 100W | Change peak power value in EnergyPlus register objects | $36,200 | 0.20% | 4 | 3 | 3 | 3 | 4 | 4 |
| Upgrade Computers: Replace computers laptops, reducing peak power demand from 240W to 40 W | Change peak power value in EnergyPlus computer objects | $9,300 | 0.93% | 4 | 3 | 3 | 3 | 4 | 4 |
| Upgrade Conveyor Belt Motors: Replace conveyor belt motors with more efficient equipment, reducing peak power demand from 400W to 288 W | Change peak power value in EnergyPlus conveyor objects | $8,200 | 0.004% | 2 | 1 | 4 | 4 | 3 | |
| Mid-Voltage DC Bus: Replace lighting with DC light fixtures to reduce energy use | Reduce lighting consumption in every hour by 3%, representing savings from eliminating DC-AC conversion losses | $58,000 | 1.5% | 3 | 2 | 2 | 2 | 3 | 2 |
| **Envelope** | | | | | | | | | |
| Insulate Roof: Install highly reflective roof membranes and Title 24 2016 compliant rigid insulation (0.034 Btu/h-ft2-F) | Create a new roof construction with thicker insulation layer. | $61,800 | 0.69% | 2 | 2 | 4 | 3 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Insulate Walls: Install rigid insulation or fiberglass insulation to meet Title 242016 (0.082 Btu/h-ft2-F) | Create a new wall construction with thicker insulation layer | $13,500 | 0.02% | 2 | 2 | 4 | 2 | 4 | 3 |
| Insulate Storefront Glass: Replace windows with Title 24 2016 compliant glass meeting the storefront standard (0.41 Btu/h-ft2-F,SHGC=0.26) | Create new glass type representing the new standard and replace in window objects | $36,000 | -0.13% | 2 | 2 | 4 | 1 | 4 | 3 |
| Electrochromic Glazing: Provide electrochromic glass for all storefront windows | Create new glass type representing the new product and replace windows | $175,800 | -0.11% | 3 | 4 | 1 | 2 | 4 | 3 |
| Insulate Glass: Replace windows with Title 24 2016 compliant glass meeting the fixed window standard (0.36Btu/h-ft2-F, SHGC=0.25) | Create new glass type representing the new standard and replace in window objects | $40,000 | -0.13% | 2 | 2 | 4 | 1 | 4 | 3 |
| Add Window Film to Storefront: Add a window film to the exterior of the storefront to reduce SHGC t00.26 | Create new glass type representing the existing window+ film and replace in window objects | $7,990 | -0.11% | 3 | 3 | 3 | 3 | 4 | 3 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Extend Front Overhang: Extend existing 6.5' overhang to 10' above storefront glass | Change shading element dimension in model to reflect new overhang depth | $14,900 | 0.002% | 2 | 3 | 3 | 3 | 4 | 3 |
| Shelves: Add 3' light shelves to the interior of the front façade | Add light shelf objects in EnergyPlus | $15,100 | 0.01% | 2 | 3 | 3 | 2 | 4 | 3 |
| Louvers: Add louvers to the exterior of the front façade to provide shading along the entire front of the store | Create new shading objects spanning the width of the façade as new shading objects | $99,900 | 0.001% | 2 | 3 | 3 | 2 | 4 | 3 |
| Improve Loading Dock Doors: Replace leaky loading door with auto closing, gasketed door | educe the infiltration value by 50% or to13.6 CFM for the loading zone | $7,400 | 0.07% | 2 | 2 | 4 | 3 | 3 | 3 |
| **HVAC** | | | | | | | | | |
| Store Setpoints: Widen the store setpoints from 72F constantly to 68F for heating and 75F for cooling with a night setback for heating | Create a new thermostat setpoint schedule and apply to the RTUs with sensing in main store zones | No Cost Impact | 0.00% | 2 | 0 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Server Room Setpoints: Widen the setpoints in the server room from 64F to 50F in heating and 82F in cooling | Create a new thermostat setpoint schedule and apply to the server room AC with sensing in the server room | No Cost Impact | 0.00% | 2 | 0 | 4 | 4 | 4 | 4 |
| Demand Control Ventilation: Convert from constant volume ventilation to demand controlled ventilation based on occupancy | Create new ventilation control scheme tied to the occupancy schedule and apply to outside air for main store | $84,400 | 0.00% | 2 | 3 | 4 | 3 | 3 | 4 |
| Replace Office AC with VRF System: Switch from existing through-wall air conditioners (EER=10) to variable refrigerant flow split system(EER=11.0) | Create new system type and connect to existing air supply and return nodes in office zones | $27,700 | 0.07% | 4 | 2 | 2 | 4 | 4 | 1 |
| Replace Office AC with Heat Pumps: Switch from existing through-wall air conditioners (EER=10) to split system heat pumps (EER=11.2) | Create new system type and connect to existing air supply and return nodes in office zones | $9,700 | 0.08% | 2 | 1 | 4 | 4 | 4 | 1 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Heat Recovery Ventilator on Restroom Exhaust: Add an HRV to restroom exhaust to preheat supply air to the store | Create an HRV object and connect to exhaust node of restroom and supply node of RTUs | $2,500 | 0.00% | 2 | 3 | 3 | 3 | 4 | 4 |
| Heat Recovery Ventilator on Kitchen Exhaust: Add an HRV to kitchen exhaust to preheat supply air to the store | Create an HRV object and connect to exhaust node of kitchen and supply node of RTUs | $9,300 | 0.00% | 2 | 3 | 3 | 3 | 4 | 4 |
| Natural Ventilation: Utilize skylights and front façade to cool the store when temperatures outside are low enough and cooling is demanded. | Eliminate cooling energy in the model when temperature is between 55 and 72F | $38,900 | 0.50% | 3 | 4 | 3 | 2 | 2 | 4 |
| Replace RTUs with Heat Pump: Replace the two existing RTUs with heat pumps for conditioning and lower volume fans for outside air to improve efficiency and reduce overventilation | Create two heat pumps and connect to inlet and outlet nodes of existing duct networks serving sales floor, COP=3.5,EER=12.3 | $57,100 | 8.24% | 3 | 1 | 3 | 2 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Replace RTUs with AHU with VFD: Replace the two existing RTUs with an air handler and variable frequency drive, heating and cooling coils, with an economizer | Create two air handler objects and DX cooling and heating coils and connect to existing duct networks serving sales floor, EER=12.2 | $31,700 | 9.85% | 2 | 1 | 2 | 2 | 3 | 4 |
| Replace RTUs with Lezeti DC Split System AC: Replace the two existing RTUs with DC split air Conditioners feeding the sales space directly | Reduce air flow on existing RTUs, add electric resistance heating coil, and improve efficiency of RTUs to mimic DC performance | $48,700 | -4.95% | 4 | 1 | 2 | 2 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Radiant Heating: Provide radiant heating in the floor of the sales floor with 30 Btuh/sf capacity and a 10 F delta T | Create radiant ceiling objects in EnergyPlus and pumps to circulate fluid with heat pump on roof for conditioning; air handler for ventilation connected to existing duct network | $247,300 | 0.00% | 3 | 4 | 1 | 2 | 3 | 4 |
| Variable Speed Evaporator Fans on Existing RTUs: Equip variable speed drives on evaporator fans with a10% decrease in power draw | Switch constant fans to variable speed fans and replace in RTU objects | $9,300 | 0.10% | 2 | 2 | 3 | 2 | 2 | 4 |
| Efficient RTUs: Replace existing RTUs with new rooftop units with higher EER | Change EER value in RTU objects in EnergyPlus | $51,800 | 0.31% | 2 | 1 | 3 | 2 | 3 | 4 |
| Insulate Ducts: Add insulation to the ducts running through the store | Increase efficiency in the RTU units by 3% | $53,600 | 0.57% | 3 | 3 | 0 | 0 | 4 | 3 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Move Destratification Fans: Operationalize destratification fans and relocate them within the store to improve efficacy | Change schedules and encompassing zones of destratification fans | $6,960 | -0.03% | 2 | 1 | 4 | 2 | 3 | 4 |
| Solar Air Preheating: Install solar air preheat panels on the vertical south façade of level 2 to heat air prior to entering the RTUs | Create solar air preheat panels and connect the outlet to the inlet of the RTUs | $15,100 | 4.83% | 3 | 4 | 2 | 2 | 4 | 4 |
| mprover Server Room Air Conditioning: Change from the existing ductless air conditioner to a split system with an auto sized split system with SEER=15.5 | Change the capacity of the unit to be auto sized and change the efficiency of the existing modeled AC unit | $5,600 | 0.00% | 2 | 0 | 3 | 3 | 3 | 4 |
| **Kitchen + Hot Water** | | | | | | | | | |
| Low-Flow Spray Valves: Replace existing 1.42, 2, and 3.5 gpm sprayers with 1.15gpm sprayers | Reduce peak water use in end-uses of water equipment in EnergyPlus model | $1,550 | 0.10% | 2 | 1 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Consolidate Kitchen Uses: Move the bakery and produce sinks to the same location to reduce hot water pipe losses on longer runs | Relocate the water use equipment to the same or adjacent zones | No Cost Impact | 0.00% | 2 | 1 | 2 | 1 | 2 | 4 |
| Variable Speed Kitchen Exhaust Fan: Add a variable speed drive to the existing kitchen exhaust fan | Replace existing constant volume fan with a variable speed fan object and schedule related to expected kitchen use | $5,400 | 0.0002 % | 2 | 1 | 4 | 4 | 3 | 4 |
| Optimize the Kitchen Hood: Adding fins, seals, and streamlining air flow to the hood reduces the amount of air required to vent the space and reduces cooling load | Reduce the peak power draw of the kitchen exhaust hood by 41% | $7,700 | 0.0002 % | 2 | 1 | 4 | 4 | 3 | 4 |
| Replace Dipper Well: Replace existing once-through dipper well running 24/7 at 0.25 gpm with a heated utensil holder using 436 kWh/yr | Change the dipper well water use flow schedule, electric peak power draw, and dipper well electric power draw schedule | $1,400 | 0.23% | 2 | 1 | 4 | 4 | 3 | 3 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Replace Rotisserie: Replace gas-fired rotisserie operating 12 hours per day with an efficient electric combi oven running only 6 hours per day | Remove the gas-fired rotisserie and add an electric oven; modify the use schedule to reduce the time of operation | $63,400 | 3.66% | 2 | 1 | 4 | 4 | 3 | 4 |
| Enclose Warming Cases: Provide covers for the open hot food bar to reduce energy loss through insulation of warming trays and food | Change schedule governing hot food bar energy consumption | $12,400 | 0.07% | 2 | 2 | 4 | 4 | 1 | 4 |
| Place Bread Bins Over Refrigerated Tables When Not Used: Provide covers for refrigerated table tops to reduce energy loss through insulation of refrigerated areas | Change schedule governing refrigerated table top energy consumption | No Cost Impact | 0.14% | 2 | 1 | 4 | 4 | 3 | 2 |
| Recover Heat from Dishwasher Drain: Provide heat recovery from drain feed to preheat the cold water feed to the dishwasher | Enable heat recovery from the dishwasher branch of hot water use and connect to inlet node at 65% efficiency | $4,700 | 0.0003 % | 2 | 2 | 3 | 3 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Recover Heat from Dishwasher Condensate: Provide heat recovery from dishwasher condensate to preheat the cold water feed to the dishwasher | Enable heat recovery from the dishwasher branch of hot water use and connect to inlet node at 65% efficiency | $5,100 | 0.0003 % | 2 | 2 | 3 | 3 | 4 | 4 |
| Heat Pump Water Heater: Convert existing gas-fired water heater to an electric heat pump water heater | Change water heater object to heat pump with electric fuel, and add a resistance coil with COP = 2.758 | $8,900 | 6.48% | 3 | 1 | 3 | 3 | 2 | 4 |
| Heat Pump Water Heater with CO2 Refrigeration: Convert existing gas-fired water heater to an electric heat pump water heater withCO2 refrigerant | Change water heater object to heat pump with electric fuel, and add a resistance coil with COP = 3.2 | $10,400 | 6.48% | 3 | 1 | 2 | 3 | 2 | 4 |
| Point-of-Use Water Heating: Remove water heater and add electric instantaneous heaters at each fixture | Change fuel type in water heater object to electric, eliminate tank capacity, and change efficiency to99% | $2,700 | 6.46% | 3 | 2 | 3 | 3 | 2 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Horizontal Solar Hot Water Heating: Provide evacuated tube solar hot water heating on the horizontal plane of the level 2 roof | Create solar hot water heater objects and solar hot water heating loop and expansion tank as preheater to existing water heater | $18,500 | -4.58% | 3 | 3 | 2 | 2 | 4 | 4 |
| Vertical Solar Hot Water Heating: Provide evacuated tube solar hot water heating on the vertical south-facing façade of the level 2 roof | Create solar hot water heater objects and solar hot water heating loop and expansion tank as preheater to existing water heater | $19,600 | -3.40% | 3 | 3 | 2 | 2 | 4 | 4 |
| Replace Refrigerated Tables: Replace existing eight 660 W refrigerated tables with 530W models | Change peak power draw of refrigerated table objects in EnergyPlus | $61,800 | 0.16% | 2 | 1 | 2 | 4 | 3 | 2 |
| Timed Hot Water Recirculation: Current recirculation is constant, replace with timed control to shut off when store is closed | Change hot water pump schedule to on/off and turn off from 11 pm to 7 am | $6,200 | 0.20% | 2 | 0 | 2 | 3 | 2 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Temperature-Based Hot Water Recirculation: Control recirculation based on temperature in hot water return line | Change hot water pump to variable speed and control based on schedule related to water use | $6,200 | 0.00% | 2 | 0 | 2 | 3 | 2 | 4 |
| **Lighting** | | | | | | | | | |
| LED Lighting: Replace all lighting in the front of house with LED (currently CFL, fluorescent strips, and metal halides) | Reduce peak power on all lighting objects in the store | $127,500 | 10.43% | 2 | 4 | 4 | 4 | 4 | 4 |
| Exterior LED Lighting: Convert existing exterior fluorescent lighting to LED | Change peak power value in lighting objects | $5,100 | 0.21% | 2 | 4 | 4 | 4 | 4 | 4 |
| Occupancy Sensor on Restroom Lights: Control restroom lighting via an occupancy sensor | Change restroom lighting control from "Always On" to a schedule based on store occupancy | $7,730 | 0.08% | 3 | 3 | 4 | 4 | 3 | 4 |
| Occupancy Sensor on Refrigeration Case Lighting: Control display lighting in shelves of refrigeration cases via an occupancy sensor | Create new lighting schedules for cases that reflect store occupancy | $43,800 | 8.61% | 3 | 4 | 4 | 4 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Occupancy Sensor on Sales Floor/Front of House Lights: Control overhead lighting via an occupancy sensor | Change lighting control from "Always On" to a schedule based on store occupancy with minimum lighting levels | $7,730 | 8.62% | 3 | 4 | 4 | 4 | 3 | 4 |
| Reduced Lighting in Stocking Shelves: Switch lights on one aisle at a time during stocking of shelves to reduce lighting power consumption | Alter lighting schedule from 10-11 pm to be 1/10 of maximum overhead lighting power | No Cost Impact | 4.13% | 3 | 3 | 4 | 4 | 3 | 4 |
| Reduced Overhead Lighting: Reduce overhead sales lighting by 30% and do not change accent lighting power density | Create new schedule for overhead lighting with 30% power reduction | $460 | 6.15% | 2 | 4 | 4 | 4 | 4 | 4 |
| Daylight Dimming: Dynamic daylight-integrated dimming (0- 100% control) on all fixtures in front of house with 20 fc ambient levels | Add daylight sensors to the sales aisles and daylight control objects to overhead sales lighting | $16,200 | 0.00% | 2 | 4 | 4 | 3 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Occupancy Sensor on Back of House Lights: Control office, storage, and backstock lighting via an occupancy sensor | Change lighting control from "Always On" to a schedule based on store occupancy with minimum lighting levels | $7,730 | 0.91% | 3 | 3 | 4 | 4 | 3 | 4 |
| Install Additional Skylights: Increase number of skylights to meet 5% of roof area maximum defined by Title 24 | Add new skylight objects in roof plane of model using existing skylight parameters | $52,600 | -0.14% | 3 | 4 | 4 | 4 | 4 | 4 |
| Daylighting on Second Floor: Add windows to 40% WWR on second floor to capture natural light | Create Title 24 compliant glazing objects and windows in northern wall of second level | $187,020 | -0.01% | 3 | 2 | 4 | 4 | 4 | 4 |
| Maximize daylighting on Second Floor: Add windows to 90% WWR on second floor to capture natural light | Create Title 24 compliant glazing objects and windows in northern wall of second level | $411,440 | -0.01% | 3 | 2 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| **Refrigeration** | | | | | | | | | |
| Insulate Walk-In Refrigeration Cases: Add 0.5- 2” of insulation to low/medium temperature walk-ins | Increase U-value on insulation in walk-in case objects | $81,400 | 1.20% | 2 | 2 | 4 | 4 | 4 | 4 |
| Dual-Speed Q Sync Evaporator Fans: Upgrade evaporator fans in walk-in cases to high efficiency, dual- speed evaporator fans | Reduce peak power value on evaporator fans in all walk-ins to½ hp per fan (3 total for small coolers, 6 for large) | $1,210 | 0.96% | 1 | 1 | 2 | 3 | 4 | 4 |
| Walk-in LED Lighting: Convert lighting in walk-in cases to LEDS from existing fluorescents | Reduce peak power value for all lighting objects in walk-in refrigerators | $3,200 | 0.81% | 2 | 4 | 4 | 4 | 4 | 4 |
| Add Doors to Medium- Temperature Cases: Add doors to cases which are currently unenclosed | Change case sensible load schedule to values reflecting door insulation with opening | $7,400 | 4.59% | 2 | 2 | 4 | 3 | 4 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Add Better Night Curtains to Medium-Temperature cases: Upgrade night curtains for cases | Change case sensible load schedule to values reflecting improved nighttime insulation | $88,100 | 1.89% | 2 | 2 | 4 | 4 | 4 | 4 |
| Add Strip Curtains to Medium-Temperature Cases: Add strip curtains to cases which are currently unenclosed | Change case sensible load schedule to values reflecting strip curtains | $52,860 | 4.32% | 2 | 2 | 4 | 3 | 4 | 4 |
| Automatic Door Closers on Walk-Ins: Add automatic door closers to low and medium temperature walk-ins | Change door opening fraction on walk-in objects | $22,700 | 0.17% | 2 | 2 | 4 | 3 | 4 | 4 |
| Improve Gaskets on Walk- In Doors: Gasket upgrades can save up to 20% in walk-in energy consumption | Change door opening fraction in walk-in objects | $8,000 | 0.17% | 3 | 1 | 4 | 3 | 3 | 3 |
| Add Doors to Produce Walk- In: No doors currently exist on produce walk-ins (only strip curtains) | Change door opening fraction and door U-value on produce walk- in | $3,700 | 0.07% | 3 | 1 | 4 | 3 | 3 | 3 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Electronic Expansion Valves: Replace thermal expansion valves with electronic expansion valves to control superheat | Alter compressor curves to reflect 30% potential savings identified in Title 24 report | $40,200 | 3.41% | 2 | 1 | 2 | 3 | 4 | 4 |
| Compressor Digital Unloaders: Limited compressor modulation currently which can be changed to variable modulation with an unloader | Alter compressor curves to reflect 10% potential savings identified in ASHRAE report | $10,300 | 1.31% | 2 | 1 | 3 | 3 | 4 | 4 |
| DC Compressors: Convert compressor motors to DC connected to PV or grid-rectifier | 3% savings in energy use captured through change in compressor curve | $8,000 | 0.39% | 2 | 0 | 3 | 3 | 4 | 4 |
| HFO Refrigerant: Swap R404a to HFO refrigerant (low temp COP=2.19, medium temp COP=3.06) | Change working fluid properties in EnergyPlus and alter compressor curves to reflect modified COP | $61,800 | 0.65% | 2 | 2 | 0 | 1 | 3 | 1 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| $CO_2$ Refrigerant: Swap R404a to $CO_2$ refrigerant (COP=1.7) | Change working fluid properties in EnergyPlus and alter compressor curves to reflect modified COP | $61,800 | -1.39% | 2 | 2 | 0 | 1 | 3 | 1 |
| Secondary Loop: Provide a secondary loop for medium temperature cases and walk- ins | Model a cascade condenser to transfer load between low and medium temperature loops | $5,400 | 11.06% | 1 | 2 | 1 | 0 | 3 | 1 |
| Refrigeration Floating Suction Pressure: Control the condenser operation based on float saturated condensing temperature | Change compressor control object to control based on suction temperature | No Cost Impact | 0.22% | 2 | 1 | 2 | 3 | 3 | 4 |
| Mechanical Subcooler: After the load is condensed, cool liquid refrigerant for low- temperature system using medium-temperature capacity | Enable subcooling in compressor control object | $68,800 | -0.35% | 2 | 1 | 0 | 1 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Pipe Insulation: Insulate with 1-2.5" of foam insulation on the medium and low temperature refrigeration piping | Change value for distribution loss (in W) in EnergyPlus refrigeration system object | $211,300 | 0.03% | 2 | 1 | 4 | 4 | 4 | 4 |
| Demand-Based Defrost: Change from scheduled defrost to demand-based defrost in walk-in freezers | Alter defrost schedule for walk-ins to reduce frequency | $7,700 | 0.01% | 2 | 1 | 2 | 3 | 3 | 3 |
| More Efficient Heat Recovery: Replace heat exchanger from refrigeration to DHW to improve efficiency | Change efficiency in desuper-heater coil object | $68,800 | 0.24% | 2 | 3 | 2 | 1 | 3 | 4 |
| Heat Pump Heat Recovery: CO2 heat pump with COP=3.4 for DHW | Change efficiency of desuper-heater coil object | $13,100 | -3.31% | 2 | 3 | 2 | 1 | 3 | 4 |
| Efficient Heat Recovery for Space Heating: Heat recovery from refrigeration loop to heating hot water | Change efficiency in desuperheater coil object and connect to heating nodes | $68,800 | -0.67% | 2 | 3 | 2 | 1 | 3 | 4 |
| Heat Pump Heat Recovery for Space Heating: CO2 heat pump with COP=3.4 for heating hot water | Change efficiency of desuperheater coil object and connect to heating nodes | $13,100 | -0.67% | 2 | 3 | 2 | 1 | 3 | 4 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Dewpoint Anti-Sweat Heater Control: Control anti-sweat heaters based on ambient dewpoint temperature | Change mode of anti-sweat heater control in case objects to dewpoint with a minimum 50% power draw | $37,560 | 0.09% | 2 | 1 | 2 | 3 | 2 | 3 |
| Relative Humidity Anti- Sweat Heater Control: Control anti-sweat heaters based on relative humidity | Change mode of anti-sweat heater control in case objects to relative humidity with a minimum 50% power draw | $37,560 | 0.0% | 2 | 1 | 2 | 3 | 2 | 3 |
| Timed Anti-Sweat Heater Control: Reduce time of anti- sweat heater operation to 50% of current energy use | Change energy of anti-sweat heater operation to be 50% of baseline | $37,560 | -0.10% | 2 | 1 | 2 | 3 | 2 | 3 |
| Air-Cooled Condenser: Replace evaporative condenser with air- cooled condenser | Add air-cooled condenser object and connect to refrigeration system | $80,400 | -12.10% | 2 | 0 | 3 | 1 | 4 | 2 |
| Hybrid Condenser: Replace evaporative condenser with hybrid condenser | Change performance of evaporative condenser object | $92,700 | 0.65% | 2 | 0 | 3 | 1 | 4 | 2 |

| Energy Conservation Measure | Modeling Strategy | ROM Cost | Energy Cost Savings (+/-) | Innovation Score | Customer Experience Score | Maintenance Score | Disruption Score | Integration Score | Scalability Score |
|---|---|---|---|---|---|---|---|---|---|
| Adiabatic Gas Cooler: Replace evaporative condenser with adiabatic gas cooler | Operate as more efficient condenser | $95,050 | 1.09% | 1 | 1 | 1 | 1 | 4 | 2 |
| Turn Off Walk-In Cooler in L2: No cooling in dry storage L2 cooler | Remove walk-in from case list | No Cost Impact | 0.97% | 2 | 1 | 4 | 0 | 4 | 2 |
| Convert Dairy and Produce Cases to Walk- Ins: Replace open cases with walk-in refrigeration | Remove case objects from case list and add two walk-in objects, add to case list | $220,100 | 13.18% | 2 | 0 | 4 | 0 | 4 | 2 |
| Replace Ice Machines: Replace existing 811 W and 690 W ice machines with EnergyStar self- contained units. | Change peak power value in EnergyPlus ice machine objects. | $15,500 | 0.17% | 2 | 2 | 3 | 3 | 3 | 4 |

Source: LBNL

# ATTACHMENT B-2: RESULTS OCCURRING IN TOP OPTIMIZATION SOLUTIONS

**Table B-7: Results in Top Optimization Solutions**

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Combi oven | 280 | -3.66% | 2 | 1 | 4 | 4 | 3 | 4 |
| Interior LED Lighting | 280 | -10.43% | 2 | 4 | 4 | 4 | 4 | 4 |
| Sales occupancy sensors | 280 | -8.70% | 3 | 4 | 4 | 4 | 3 | 4 |
| Medium temperature cases on secondary loop. | 280 | -11.06% | 1 | 2 | 1 | 0 | 3 | 1 |
| Produce + Dairy case walk-in | 277 | -13.18% | 2 | 0 | 4 | 0 | 4 | 2 |
| Computer Upgrade | 276 | -0.93% | 4 | 3 | 3 | 3 | 4 | 4 |
| HRV on kitchen exhaust | 273 | 0.00% | 2 | 3 | 3 | 3 | 4 | 4 |
| Restroom occupancy sensors | 270 | -0.08% | 2 | 4 | 4 | 3 | 3 | 4 |
| Insulated ducts AHU + VFD | 268 | -9.85% | 2 | 1 | 2 | 2 | 3 | 4 |
| Mechanical subcooler | 268 | 0.35% | 2 | 1 | 0 | 1 | 3 | 4 |
| Wind Turbines | 265 | 0.00% | 4 | 3 | 1 | 1 | 2 | 2 |
| Better night curtains on dairy cases | 265 | -0.05% | 2 | 2 | 4 | 4 | 4 | 4 |
| Register Upgrade | 263 | -0.20% | 4 | 3 | 3 | 3 | 4 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Enclosed hot food bar | 263 | -0.07% | 2 | 2 | 4 | 4 | 1 | 4 |
| Plug Load Switching | 262 | -0.56% | 3 | 2 | 3 | 3 | 4 | 4 |
| DC Bus for Lighting, Refrigeration | 261 | -1.50% | 3 | 2 | 2 | 2 | 3 | 2 |
| Ice Machine Upgrade | 258 | -0.17% | 2 | 2 | 3 | 3 | 3 | 4 |
| Turn off walk-in cooler on L2 | 258 | -0.97% | 2 | 1 | 4 | 0 | 4 | 2 |
| Replace refrigerated/deli tables | 257 | -0.16% | 2 | 1 | 2 | 4 | 3 | 2 |
| Ceiling reflectance + Reduce sales T8s by 30%, leave accent lighting | 254 | -7.35% | 2 | 4 | 4 | 4 | 4 | 4 |
| Close refrigerated tables when not used | 252 | -0.14% | 2 | 1 | 4 | 4 | 3 | 2 |
| Hybrid condenser | 252 | -0.65% | 2 | 0 | 3 | 1 | 4 | 2 |
| Window Film | 251 | 0.13% | 3 | 3 | 3 | 3 | 4 | 3 |
| Optimize kitchen hood | 251 | 0.00% | 2 | 1 | 4 | 4 | 3 | 4 |
| Add 0.5" insulation to walk ins, efficient fans, LEDs | 250 | -0.84% | 2 | 2 | 4 | 4 | 4 | 4 |
| Change server room setpoint | 249 | 0.00% | 2 | 0 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Timeclock Hot Water Recirc | 247 | -0.20% | 2 | 0 | 2 | 3 | 2 | 4 |
| Door closers on LT walk ins | 247 | -0.14% | 2 | 2 | 4 | 3 | 4 | 4 |
| HRV on restroom exhaust | 241 | 0.00% | 2 | 3 | 3 | 3 | 4 | 4 |
| Load-based defrost | 241 | -0.01% | 2 | 1 | 2 | 3 | 3 | 3 |
| EEV+DC+HFO+VFD | 240 | -4.99% | 2 | 1 | 2 | 3 | 4 | 4 |
| Second floor North windows to WWR=40% | 232 | 0.01% | 3 | 2 | 4 | 4 | 4 | 4 |
| 3' Light Shelf | 224 | -0.01% | 2 | 3 | 3 | 2 | 4 | 3 |
| Consolidated Kitchen Uses | 220 | 0.00% | 2 | 1 | 2 | 1 | 2 | 4 |
| BOH with VRF, COP=3.3, EER=11.0 | 218 | -0.07% | 4 | 2 | 2 | 4 | 4 | 1 |
| Dishwasher drain heat recovery | 216 | 0.00% | 2 | 2 | 3 | 3 | 4 | 4 |
| 5% roof area with skylights | 209 | 0.14% | 3 | 4 | 4 | 4 | 4 | 4 |
| Efficient server AC | 202 | 0.00% | 2 | 0 | 3 | 3 | 3 | 4 |
| 2.752 COP HP DHW Heater | 202 | -6.48% | 3 | 1 | 3 | 3 | 2 | 4 |
| LT Saturated condensing temp float controller | 191 | -0.13% | 2 | 1 | 2 | 3 | 3 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Timed anti-sweat heater control | 188 | -0.10% | 2 | 1 | 2 | 3 | 2 | 3 |
| Second floor North windows to WWR=90% | 165 | 0.01% | 3 | 2 | 4 | 4 | 4 | 4 |
| Gaskets + Door closers on MT with new door | 165 | -0.22% | 2 | 2 | 4 | 3 | 4 | 4 |
| 1.75" Foam Insulation on MT lines | 157 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |
| Improved refrigeration heat recovery | 156 | 0.67% | 2 | 3 | 2 | 1 | 3 | 4 |
| 2.25" Foam Insulation on LT lines | 135 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |
| MT Saturated condensing temp float controller | 128 | -0.09% | 2 | 1 | 2 | 3 | 3 | 4 |
| Gaskets + Door closers on MT walk ins | 127 | -0.06% | 3 | 1 | 4 | 3 | 3 | 3 |
| 0.034 BTU/h-ft2-F in walls | 121 | -0.69% | 2 | 2 | 4 | 2 | 4 | 3 |
| 1.5" Foam Insulation on MT lines | 113 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |
| Electronic expansion valves | 106 | -3.41% | 2 | 1 | 2 | 3 | 4 | 4 |
| 2" Foam Insulation on LT lines | 106 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| RH anti-sweat heater control | 90 | 0.00% | 2 | 1 | 2 | 3 | 2 | 3 |
| Reduce loading door infiltration | 72 | -0.07% | 2 | 2 | 4 | 3 | 3 | 3 |
| Refrigeration case occupancy sensors | 70 | -8.61% | 3 | 4 | 4 | 4 | 3 | 4 |
| Add 0.5" insulation to walk ins | 64 | -0.03% | 2 | 2 | 4 | 4 | 4 | 4 |
| Dishwasher outlet heat recovery | 56 | 0.00% | 2 | 2 | 3 | 3 | 4 | 4 |
| BOH heat pump, COP=3.3, EER=11.2 | 54 | -0.08% | 2 | 1 | 4 | 4 | 4 | 1 |
| Natural Ventilation | 53 | 0.00% | 3 | 4 | 3 | 2 | 2 | 4 |
| Efficient sprayers and consolidated kitchen use | 50 | -0.10% | 2 | 1 | 4 | 4 | 4 | 4 |
| Demand controlled ventilation | 48 | 0.00% | 2 | 3 | 4 | 3 | 3 | 4 |
| Point of use water heating | 48 | -6.46% | 3 | 2 | 3 | 3 | 2 | 4 |
| Louvers on Façade | 43 | 0.00% | 2 | 3 | 3 | 2 | 4 | 3 |
| Heated utensil holder | 41 | -0.23% | 2 | 1 | 4 | 4 | 3 | 3 |
| EEV+HFO+VFD | 39 | -4.73% | 2 | 1 | 2 | 3 | 4 | 4 |
| Change store setpoint | 38 | 0.00% | 2 | 0 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Change destratification fans | 33 | 0.03% | 2 | 1 | 4 | 2 | 3 | 4 |
| PV | 31 | 0.00% | 4 | 3 | 3 | 4 | 4 | 4 |
| Reduce loading door infiltration to 13.6 CFM | 30 | -0.01% | 2 | 2 | 4 | 3 | 3 | 3 |
| 3.4 COP HP DHW Heater | 30 | -6.48% | 3 | 1 | 2 | 3 | 2 | 4 |
| 2.5" Foam Insulation on LT lines | 30 | -0.02% | 2 | 1 | 4 | 4 | 4 | 4 |
| 0.082 BTU/h-ft2-F in walls | 27 | -0.02% | 2 | 2 | 4 | 2 | 4 | 3 |
| Adiabatic gas cooler | 26 | -1.09% | 1 | 1 | 1 | 1 | 4 | 2 |
| Ceiling reflectance + Light switching 10pm to 11 pm. | 22 | -5.70% | 2 | 3 | 3 | 4 | 4 | 4 |
| Recirculation by temperature gauge | 19 | 0.00% | 2 | 0 | 2 | 3 | 2 | 4 |
| Enclose medium temperature cases with doors | 15 | -4.59% | 2 | 2 | 4 | 3 | 4 | 4 |
| Refrigeration heat recovery for space heating | 14 | 3.31% | 2 | 3 | 2 | 1 | 3 | 4 |
| Improved gaskets on LT walk ins | 13 | -0.14% | 3 | 1 | 4 | 3 | 3 | 3 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Improved gaskets on MT walk ins | 13 | -0.03% | 3 | 1 | 4 | 3 | 3 | 3 |
| Replace RTU with AHU + VFD, EER=11.2. | 12 | -9.85% | 2 | 1 | 2 | 2 | 3 | 4 |
| Add a door to the MT without a door | 12 | -0.07% | 2 | 2 | 4 | 3 | 4 | 4 |
| Windows to 0.41 [Btu/h-ft2-F], SHGC=0.26 | 10 | 0.13% | 2 | 2 | 4 | 1 | 4 | 3 |
| Electrochromic Glazing | 10 | 0.13% | 3 | 4 | 1 | 2 | 4 | 3 |
| Strip curtains on display cases | 10 | -4.32% | 2 | 2 | 4 | 3 | 4 | 4 |
| Conveyer Upgrade | 9 | 0.00% | 2 | 1 | 4 | 4 | 3 | 1 |
| 10' Overhang | 9 | 0.00% | 2 | 3 | 3 | 3 | 4 | 3 |
| Four 1.15 gpm spray valves | 8 | -0.10% | 2 | 1 | 4 | 4 | 4 | 4 |
| Solar air preheat | 7 | -4.83% | 3 | 4 | 2 | 2 | 4 | 4 |
| Variable speed kitchen exhaust fan | 7 | 0.00% | 2 | 1 | 4 | 4 | 3 | 4 |
| 2" Foam Insulation on MT lines | 7 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |
| 1.5" Foam Insulation on LT lines | 6 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Add 1" insulation to walk ins, efficient fans, LEDs | 5 | -0.06% | 2 | 4 | 4 | 4 | 4 | 4 |
| Door closer on MT with a new door | 5 | -0.18% | 2 | 2 | 4 | 3 | 4 | 4 |
| CO2 heat pump for refrigeration heat recovery to space heating | 5 | 0.67% | 2 | 3 | 2 | 1 | 3 | 4 |
| Windows to 0.36 [Btu/h-ft2-F], SHGC=0.25 | 3 | 0.13% | 2 | 2 | 4 | 1 | 4 | 3 |
| Ceiling reflectance + daylight dimming | 3 | -2.16% | 2 | 4 | 4 | 3 | 3 | 4 |
| Add 0.5" insulation to walk ins, LEDs | 3 | -0.84% | 2 | 4 | 4 | 4 | 4 | 4 |
| Better night curtains | 3 | -1.89% | 2 | 2 | 4 | 4 | 4 | 4 |
| Gaskets + Door closers on LT walk ins | 3 | -0.31% | 3 | 1 | 4 | 3 | 3 | 3 |
| Efficient gaskets on MT with new door | 3 | -0.22% | 3 | 1 | 4 | 3 | 3 | 3 |
| 1.25" Foam Insulation on MT lines | 3 | 0.00% | 2 | 1 | 4 | 4 | 4 | 4 |
| Dairy case walk-in | 3 | -5.79% | 2 | 0 | 4 | 0 | 4 | 2 |

| Energy Conservation Measure | Frequency of ECM in Top 280 Solutions | Individual ECM Energy Savings | Innovation | Customer Experience | Maintenance | Disruption | Integration | Scalability |
|---|---|---|---|---|---|---|---|---|
| Add 2" insulation to walk ins, LEDs | 2 | -0.90% | 2 | 4 | 4 | 4 | 4 | 4 |
| Dewpoint anti-sweat heater control | 2 | -0.09% | 2 | 1 | 2 | 3 | 2 | 3 |
| PV+Microinverters | 1 | 0.00% | 4 | 3 | 2 | 4 | 4 | 4 |
| Reduce front of house T8s by 30%,leave accent lighting | 1 | -6.15% | 2 | 4 | 4 | 4 | 4 | 4 |
| Add 2" insulation to walk ins, efficient fans | 1 | -1.08% | 2 | 4 | 4 | 4 | 4 | 4 |
| Lighting in Walk-ins converted to LEDs | 1 | -0.81% | 2 | 4 | 4 | 4 | 4 | 4 |
| Add 1" insulation to walk-ins, LEDs | 1 | -0.86% | 2 | 4 | 4 | 4 | 4 | 4 |
| Add 1.5" insulation to walk-ins, LEDs | 1 | -0.88% | 2 | 4 | 4 | 4 | 4 | 4 |
| Add 1.5" insulation to walk-ins, efficient fans, LEDs | 1 | -1.86% | 2 | 4 | 4 | 4 | 4 | 4 |
| EEV+HFO | 1 | -3.86% | 2 | 1 | 2 | 3 | 4 | 4 |
| 1.75" Foam Insulation on LT lines | 1 | -0.01% | 2 | 1 | 4 | 4 | 4 | 4 |

Source: LBNL

# APPENDIX C: Schematic Design Report, Deliverable 2.3.3

## Introduction

### 1.1 Project Goal

The MarketZero project, sponsored by the California Energy Commission through an EPIC grant, aims to set the Noe Valley Whole Foods Market on the path to net- zero energy through deep energy retrofits and on-site renewable energy generation.

Supermarkets are one of the most difficult commercial building types to attempt net- zero due to the high energy use of store refrigeration, and no known examples of net- zero grocery stores currently exist. The Noe Valley store has an Energy Use Intensity (EUI) of 228 kBtu/sf/yr, which is slightly higher than the US median grocery store EUI of 215 kBtu/sf/yr.[27]

Over half of the energy use in the store is from the refrigeration compressors, cases, and condenser. Interior lighting and plug loads are the next two major consumers of energy, with HVAC and fans contributing only marginally to total energy consumption.

This document presents the schematic design concepts to reduce the store's energy consumption based upon the agreed Energy Conservation Measures (ECMs) presented in the ECM report.

### 1.2 Energy Saving Opportunities

During 2016, the project team worked with Whole Foods' management, the Technical Advisory Committee (TAC), and product manufacturers to compile a list of ECMs with the potential to reduce energy consumption in the store. The proposed ECMs, 107 in total, were either documented to save energy in prior grocery store installations or were based on promising technologies that offered better performance than industry equivalents in product or laboratory tests.

Each of these 107 ECMs was modeled individually in EnergyPlus using a calibrated baseline model of the Noe Valley store. Combinations of ECMs were then tested using a genetic algorithm which created packages of ECMs, tested them, and then evolved toward better performing solutions over many successive iterations. In all, 2,448 ECM packages were tested via this approach.

These ECMs were evaluated by the project team for energy savings potential, feasibility, cost, scalability, innovation, disruption to the store, and reliability. The final ECM list reduces annual energy use by 55% at a cost of approximately $1.4 million.

An additional set of measures in an optional package could increase energy savings to 59% for an additional $400,000 cost. Both the base ECMs and additional ECMs are included in this document.

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[27] From the Lawrence Berkeley Lab Building Performance Database (www.bpd.lbl.gov)

The proposed measures and associated costs are shown in Table C-1.

**Table C-1: Final ECM Measures**

| Proposed Measure | Individual ECM Energy Saving Potential | Estimated Cost |
|---|---|---|
| *Base Set of ECMs* | | |
| Refrigeration High Savings Option | 8.96% | $752,545 |
| Lighting Retrofit to LEDs (Interior and Exterior) | 10.43% | $288,440 |
| Insulated Ducts with AHU + VFD | 9.85% | $74,736 |
| Solar Air Preheat | 4.83% | $15,100 |
| Heat Pump Water Heater | 6.48% | $8,900 |
| Increased Ceiling Reflectance<br>+ Reduced Ambient Sales Floor Lighting | 7.35% | $42,160 |
| Replace Rotisserie with Combi Oven | 3.66% | $63,400 |
| Insulate Walk-Ins, Replace Lighting and Fans with Higher Efficiency Components | 1.86% | $85,810 |
| Upgrade Computers | 0.93% | $9,300 |
| Behavioral Program for Plug Load Switching | 0.56% | -- |
| Replace Gaskets on Walk- Ins, Add Door Closers | 0.53% | $40,900 |
| Time Clock for Hot Water Recirculation | 0.20% | $6,200 |
| Ice Machine Upgrade | 0.17% | $15,500 |
| Disconnect L2 Cooler 10 Months per Year | 0.97% | -- |
| *Base Option Total* | *56.54%* | *$1,402,691* |
| *Add-On ECM* | | |
| Occupancy Sensors in Restrooms | 0.08% | $7,730 |

| Proposed Measure | Individual ECM Energy Saving Potential | Estimated Cost |
|---|---|---|
| Occupancy Sensors in the Back of House Spaces | 0.08% | $7,730 |
| DC Lighting Bus | 1.50% | $58,000 |
| Replace Refrigerated/Deli Tables | 0.16% | $61,800 |
| Fit Sinks with 1.15 GPM Spray Valves | 0.10% | $1,550 |
| Increase Insulation on Refrigeration Lines | 0.02% | $211,300 |
| Refrigeration System Hybrid Condenser | 0.65% | $92,700 |
| *Add-On Subtotal* | -- | *$440,810* |
| *Base + Add-On Total* | *59.35%* | *$1,843,501* |

Source: LBNL

## 1.3 Schematic Design

This schematic design document identifies the design strategy to implement each of the ECM's documented in Section 1.2

The design team consists of the following team members:

- Mechanical Engineer: Arup
- Refrigeration Engineer: DC Engineering
- Electrical Engineer: Arup
- Lighting Consulting: Arup
- Plumbing Engineer: Arup

## 1.4 Design Schedule

Schematic design represents the first step in the design process. Table C-2 shows the design schedule.

**Table C-2: Design Milestones**

| Task Name | Duration | Start | Finish |
|---|---|---|---|
| Schematic Design | 4 weeks | Tue 10/3/17 | Mon 10/30/17 |
| Design Development | 6 weeks | Tue 11/7/17 | Mon 12/18/17 |
| Construction Design | 8 weeks | Tue 1/2/18 | Mon 2/26/18 |

Source: LBNL

### 1.5 Further Reading

A site assessment of the existing building conditions was carried out in September 2017. This document is located in Attachment C-2. The full ECM report, along with the recommended measures and costs is available in Appendix B of this report.

## References, Codes and Standards

It is anticipated that the project will comply with the 2016 version of Title 24 under the performance compliance path. As part of the Design Development and Construction Documents effort we will be performing code compliance modeling and documentation to demonstrate that the projected energy consumption of the proposed design is less than the energy consumption of a standard reference model representing the "baseline" version of the project which meets minimum prescriptive code requirements.

The applicable codes for the project are the following:

- The 2016 San Francisco Building Code (SFBC)
- The 2016 California Building Code (CBC) with San Francisco amendments
- The 2016 California Fire Code (CFC) with San Francisco amendments
- The 2016 California Plumbing Code (CPC)
- The 2016 California Mechanical Code (CMC)
- The 2016 California Electrical Code (CEC) [based on the 2014 National Electrical Code (NEC or NFPA 70)] with San Francisco amendments
- The 2016 California Energy Code (CECC)
- The 2016 California Green Building Standards Code (CALGreen)
- The 2016 California Administrative Code
- 2015 ASHRAE Handbook
- ASHRAE Standard 15 – Safety Standard for Refrigeration Systems
- ASME B31.5 – ASME Code for Pressure Piping
- SMACNA, Duct Construction Standards
- SMACNA Seismic Restraint Guidelines for Mechanical Systems
- ASHRAE Standards: ASHRAE 55-2004, 62.1-2010, and 90.1-2013

## Mechanical Engineering

### 3.1 General

#### 3.1.1 Outdoor Design Criteria

ASHRAE Handbook for Climate Data - San Francisco International Airport (0.4% / 99.6%)

- Summer: 82.6 º F DB / 62.7º F MCWB
- Summer Evaporation: 65.6º F WB / 77.5º F MCDB
- Winter: 39.5º F D

### 3.1.2 Indoor Design Criteria

Indoor design criteria are based on ASHRAE 55-2004, ASHRAE 62.1-2010, and the 2016 California Mechanical Code.

According to BMS data, the current temperature setpoints in the store were reset to 76º F in occupied and unoccupied mode. The final ECM package model resets these setpoints to the original BMS intent. In heating mode, the setpoints are 70º F unoccupied and 72º F occupied. In cooling mode, the setpoints are 79º F unoccupied and 75º F occupied. Hours of occupancy are assumed to be 7am to 11pm.

**Table C-3: Mechanical Design Setpoints**

| Space Type | Cooling Set-point (Summer) | Heating Set-point (Winter) | Humidity | Supply Ventilation Air | Exhaust Air |
|---|---|---|---|---|---|
| Sales Floor | 75º F DB | 70 º F DB | 35-50% | 0.3 cubic feet per minute/sf (CFM/SF) | |
| Front End and Customer Service | 75º F DB | 70 º F DB | 35-50% | 0.15 CFM/SF | |
| Back of House Offices | 75º F DB | 70 º F DB | 35-50% | 21 CFM/SF | Per existing exhaust fans |
| Food Prep Areas | 75º F DB | 70 º F DB | 35-50% | Minimum 85% of exhaust air rate | Per existing exhaust fans |
| Mechanical / Electrical and other Utility Rooms | 78º F DB | 68 º F DB | 35-50% | 0.06 CFM/SF | Per existing exhaust fans |

Source: LBNL

Per the ASHRAE design criteria, space heating and cooling loads are calculated with the Proposed System Configuration and Equipment. The cooling capacity of the proposed equipment shall take credit for the refrigeration cases on the sales floor.

### 3.1.3 Duct Sizing Criteria

- Supply / Return / Exhaust ducts installed indoors overhead or exposed shall be sized for maximum 1500 feet per minute (fpm) and maximum static pressure loss of 0.1 inches water column per 100 feet of duct.
- Supply / Return / Exhaust duct risers enclosed in a shaft or ducts installed in mechanical spaces may be sized for maximum velocity of 2000 fpm and maximum static pressure loss of 0.1 inches water column per 100 feet of duct.
- Where possible, ductwork shall be sized for a lower velocity to promote fan power savings.
- Branch ducts serving individual air outlets will be same size as diffuser neck or maximum 600 feet per minute.

## 3.2 Existing Systems

### 3.2.1 Sales Floor

The sales floor is currently provided with heating, cooling, and ventilation by two packaged rooftop units (RTU-1 and 2). The RTUs have DX air cooled compressors for cooling and natural gas for heating. Minimum outside air is provided by intakes at the RTUs and distributed to the store aisles via uninsulated ductwork. At least one space served by the RTUs has a variable air volume (VAV) diffuser to modulate the airflow delivered to the space. However, the RTUs are unable to modulate airflow based on HVAC load.

### 3.2.2 Front End and Customer Service

The front end and customer service area is currently provided with heating, cooling, and ventilation by RTU-1 and RTU-2.

Existing air door units (AD-1 and AD-2) are provided at the main customer entrances and shall remain.

In addition, exhaust is provided by the following existing-to-remain fan:

- EF-7; Public toilet: 200 CFM

### 3.2.3 Back of House Offices

Back of house offices each have a DX in-wall AC unit for cooling. The heat from these air cooled AC units is rejected into the store above the mezzanine. Heating and ventilation is provided by a natural gas furnace that is ducted to each office.

In addition, exhaust is provided by the following existing-to-remain fans:

- EF-5; Mezzanine toilet: 150 CFM
- EF-6; Mezzanine toilet: 150 CFM

### 3.2.4 Food Prep Areas

The existing exhaust fans shall remain:

- EF-1; Kitchen Hood: 2025 CFM
- EF-8; Coffee Service: 300 CFM

Makeup air for the kitchen and coffee area is provided by transferred and supplied outside air from the RTUs. Heating and cooling for all the food prep and food storage areas is provided the RTUs.

### 3.2.5 Mechanical and Electrical Rooms

The MDF room is served by a ductless split air conditioning unit. The unit’s outdoor condenser is on the roof. This DAC-1 unit shall remain.

Existing air door units (AD-3 to AD-6) are provided at the receiving and loading dock doors and shall remain.

In addition, exhaust is provided by the following existing-to-remain fans:

- EF-2; Receiving: 150 CFM
- EF-3; Mezzanine storage: 515 CFM

### 3.2.6 Building Management System

The existing Building Management System (BMS) shall be optimized to provide automatic control and monitoring of the existing-to-remain and new MEP equipment. The BMS shall monitor analog and digital points to provide system alerts and record usage data.

## 3.3 Energy Conservation Measures

### 3.3.1 Variable Air Volume Air Handling Unit

The existing RTUs will be demolished and replaced with a VAV air handling unit (AHU) that will serve the store and back of house areas. Existing ductwork from RTUs shall be demolished and replaced with insulated supply ductwork sized to serve new VAV box zone airflow.

This new AHU-01 will consist of:

- Filters
- Airside Economizer Section
- 30 nominal ton DX Cooling Coil
- Air-cooled Variable Speed Compressors
- 360,000 btu/h output DX Natural Gas-fired Heating Coil
- 12,000 CFM Supply Fan(s) with Variable Frequency Drive (VFD)
- Packaged Unit Controller

Ventilation air will be supplied to the spaces via VAV boxes at a zone level. Zones shall be sized to meet heating and cooling demand based on external and internal loads calculated per ASHRAE standards. Return air shall be transferred and ducted back to AHU-01. VAV boxes serving perimeter zones will provide electric heating coils.

The existing air conditioning wall units and furnace serving the back of house offices will also be demolished, and AHU-01 will serve these rooms as a single zone.

The new VAV system shall have direct digital controls (DDC) capable of providing setpoint reset of static pressure and supply air temperature per the California Energy Code (Title 24) 2016 clause 140.4(d).

The coils in AHU-01 shall be sized with a face area not to exceed 450 fpm at design airflow.

### 3.3.2 Solar Air Preheat

New solar air preheat panels shall be installed on the vertical south façade of level 2 (between the main roof and high roof) to preheat outside air prior to entering AHU-01. Insulated rooftop ductwork shall connect the combined outlet of the solar air preheat panels to the inlet of AHU-01. The design team shall evaluate during the next design phase if additional energy can be saved by creating additional solar air preheat panels on the roof. This will be coordinated with any PV installation.

### 3.3.3 Heat Pump Water Heater

The kitchen and prep rooms use relatively little domestic hot water since the Whole Foods store has low cooking loads. Domestic hot water for the kitchen, coffee service area, restrooms, and prep rooms is generated using a 250 kBtu/hr AO Smith gas-fired boiler. This boiler is 96% efficient and set to 140 °F supply temperature. Boiler energy is partially offset by domestic water preheat using heat recovered off of the medium- temperature refrigeration rack with a Therm-Stor TS-II120-1 refrigerant heat recovery system. This system will be replaced with a DHW heat pump water heater, with a 2.752 energy factor, preheated with heat recovery off refrigeration loop. This heat pump will be sized in the next design phase.

### 3.3.4 Low Flow Spray Valves

The current arrangement in the store has the following items:

- Two 1.42 gpm sprayers used 30 minutes per day.
- One 2 gpm sprayer used 1 hour per day.
- One 3.5 gpm sprayer used 1 hour per day.

This design proposes to replace the valves with four 1.15 gpm spray valves. Two sprayers will be used 30 minutes per day and the remaining two will be used 1 hour per day.

### 3.3.5 Technologies from Technology Workshop

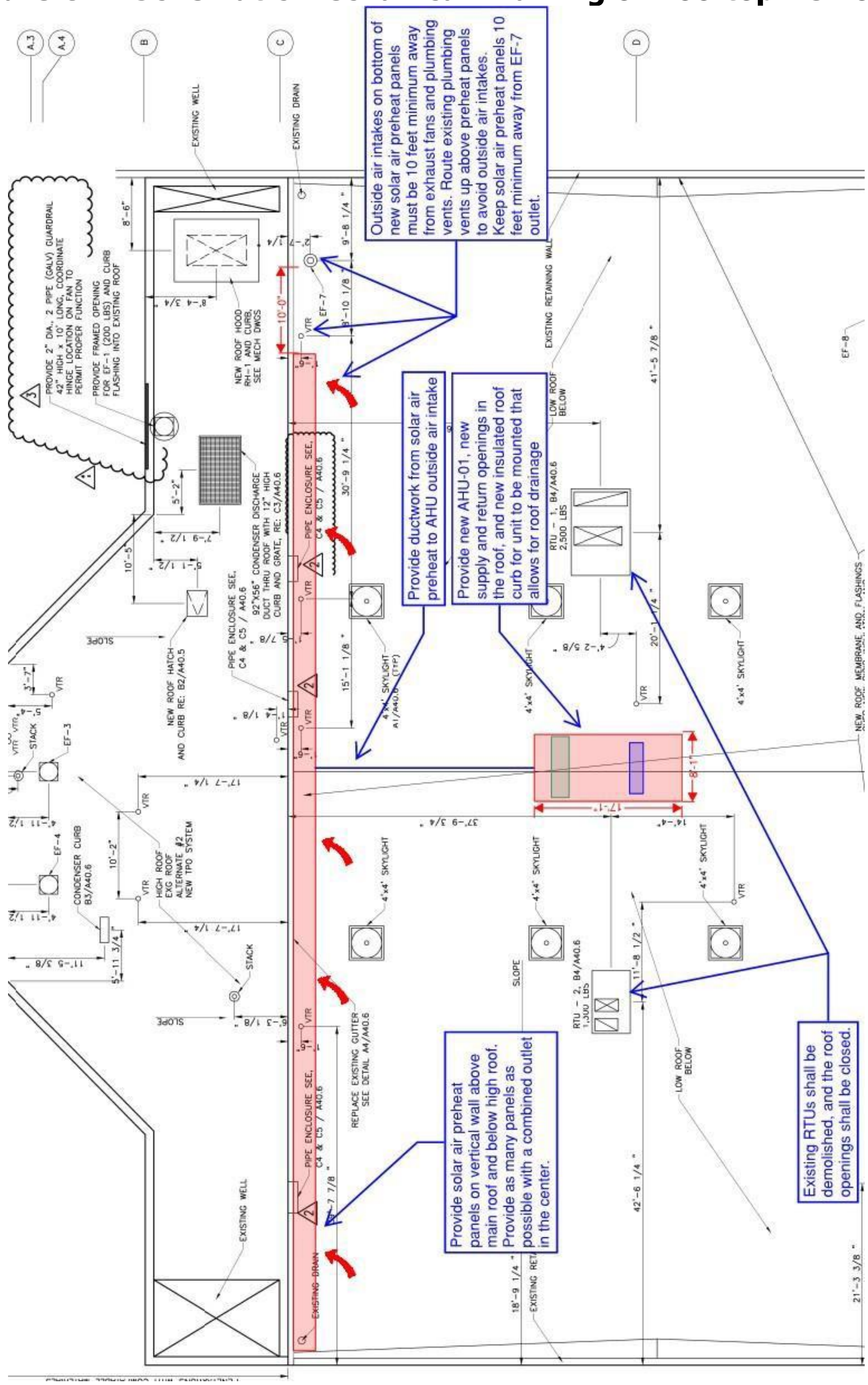
Two technologies were identified during earlier phases of the project that may provide energy savings to the store. These two technologies will be further assessed during the next design phase.

Because refrigeration accounts for a majority of the store's electrical load, thermal phase change material is a promising method for 'storing' small amounts of excess energy. Thermal storage allows refrigeration compressors to run less often when energy costs are high (and energy production is low) and to run more often and store thermal energy when energy costs are low (and there is excess generation). This reduces cycling of the compressors and refrigeration energy cost. Phase change materials are passive and do not require additional electrical connections. Adjustments would need to be made to the sequence of operations for the refrigeration control system. The technology under consideration is manufactured by Viking Cold Solutions.

A manufacturer called Nelumbo is commercializing a new materials system to increase sustainability in the built environment. Their materials leverage extreme water- repellency – particularly during the condensation process – to keep surfaces running clean and dry in harsh environments. The product under consideration for this project is their Ice-Nein coating which will be applied to existing equipment in the store. This coating reduces frost build, improving cooling coils for refrigeration equipment and reducing equipment downtime for defrost.

## 3.4 Mechanical Schematic Drawings

### Figure C-1: Schematic Mechanical Drawing of Rooftop Remodel




Source: LBNL

# 4.0 Refrigeration Engineering

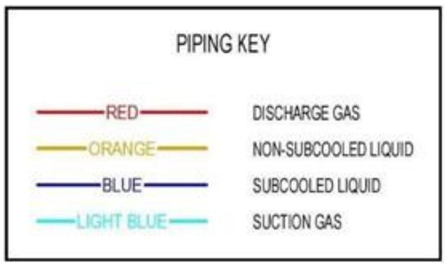
## 4.1 General

### 4.1.1 Outdoor Design Criteria
See section 3.1.1.

### 4.1.2 Indoor Design Criteria
See section 3.1.2.

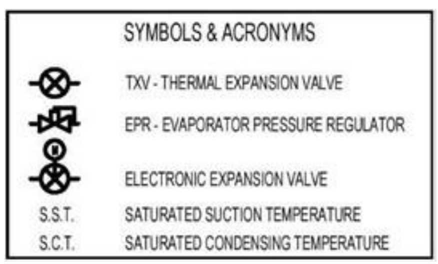
### 4.1.3 Pipe Sizing Criteria
Accumulated pressure drop per suction group will be maintained at an equivalent saturation temperature change of less than 3 degrees. Minimum riser velocity will be 1200 fpm to prevent oil accumulation in the piping.

## 4.2 Mechanical Sketch Styles

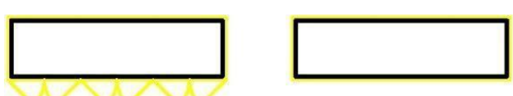
### 4.2.1 Piping



The following key will apply to refrigeration system schematics.

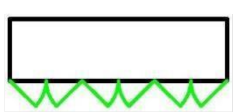
### 4.2.2 Legend
The following symbols and definitions will apply to refrigeration system schematics.




### 4.2.3 Sales Floor Fixture Changes
The following style is used to represent refrigerated fixture replacements and the addition of display doors to existing fixtures.



**New Fixture – with and without doors**



**Display door addition to existing fixture**

## 4.3 Sales Floor Fixture Changes

The following changes shall be made to increase fixture operating suction pressure and reduce refrigeration load:

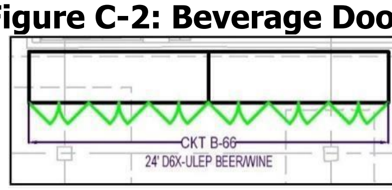
- Add display doors to existing open multi-deck fixtures.
- Replace poorly operating fixtures with more efficient, new fixtures.
- Ensure all evaporator fans motors are electronically commutated (ECM) and replace if not.
- Replace all thermal expansion valves with electronic expansion valves to minimize refrigerant flow cycling and improve fixture efficiency.
- Replace gaskets on walk-ins and add door closures.
- Increase insulation on refrigeration lines.
- Replace all fixture fluorescent lighting with LED lighting to reduce electrical and refrigeration loads.

**Table C-4: Refrigeration Load Reduction**

| Fixture Changes | Department | Suct Group | Compressor Suct Temp | Load (MBH) | Load Reduction |
|---|---|---|---|---|---|
| Current Refrigeration Load | PRODUCE B41-B44 | B | +15 | 136.6 | 65% Refrigeration load reduction of the fixtures replaced or doors added. |
| | DAIRY B31-B35 | B | +15 | 116.6 | |
| | PREP FOODS B50, B56-B59 | B | +15 | 121.7 | |
| | BEVERAGE B66 | B | +15 | 41.8 | |
| | | | Total | 416.7 | |
| Fixture Revisions | PRODUCE B41-B44 | B2 | +22 | 76.1 | |
| | DAIRY B31-B35 | B2 | +22 | 21.5 | |
| | PREP FOODS B50, B56-B59 | B2 | +22 | 36.6 | |
| | BEVERAGE B66 | B2 | +22 | 12.5 | |
| | | | Total | 146.7 | |

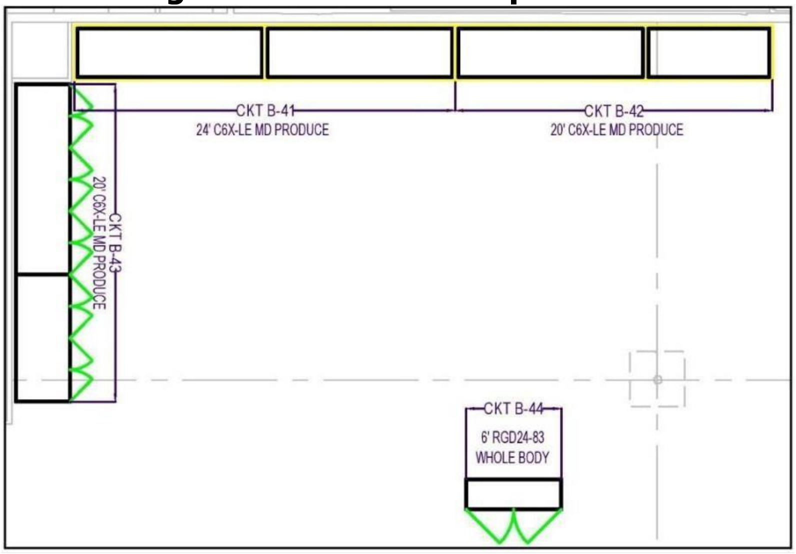
Source: LBNL

**Figure C-2: Beverage Doors**



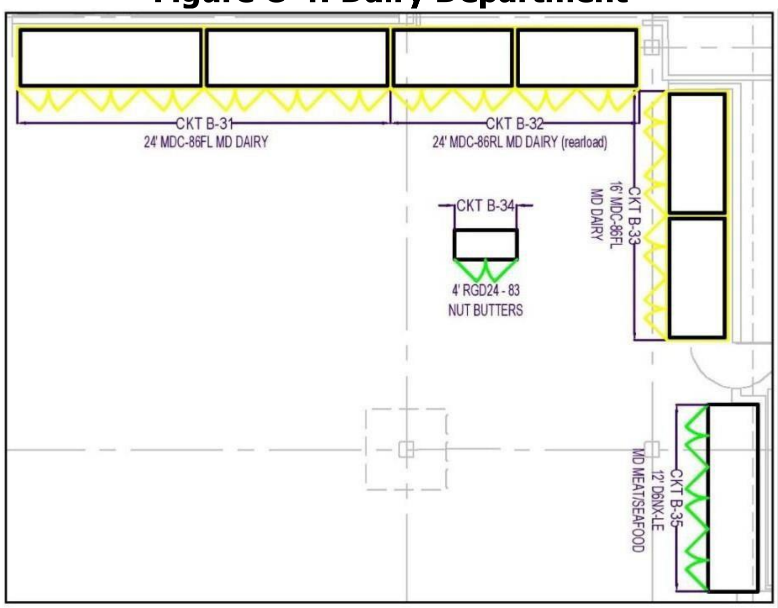

Source: LBNL

**Figure C-3: Produce Department**



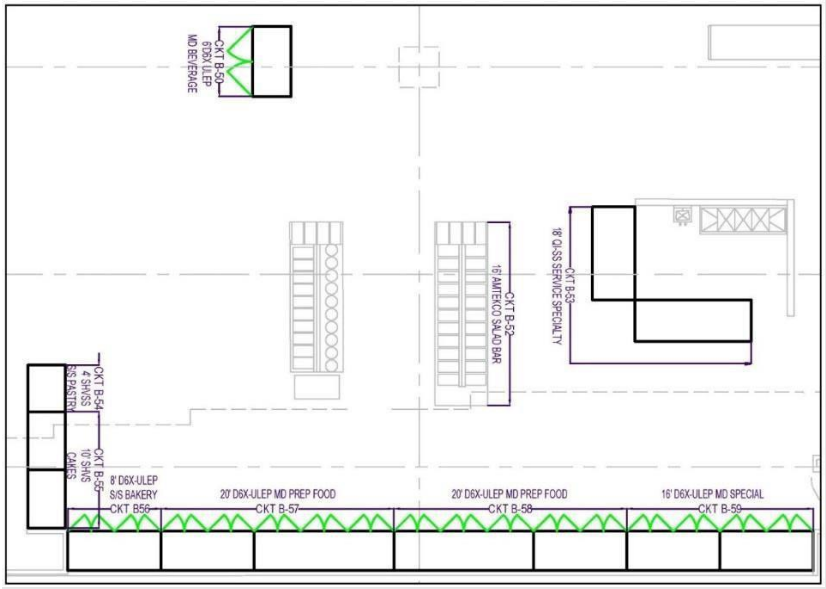

Source: LBNL

**Figure C-4: Dairy Department**




Source: LBNL

**Figure C-5: Prepared Foods and Specialty Department**




Source: LBNL

## 4.4 Refrigeration System Changes

The following changes shall be made to reduce energy consumption by increasing suction pressures and decreasing head pressures where possible.

- Install a cascade system to operate the low temperature system, System A, at low head pressure.
- Connect the medium temperature compressors currently on the low temperature rack, System A, to the medium temperature rack, System B.
- Create three medium temperature suction groups on System B to operate compressors at highest suction pressure possible.
- Configure rack controllers of both systems to float the suction pressures up while maintaining the required fixture discharge temperatures.
- Subcool liquid refrigerant for the System B +18°F and +22°F compressor groups.
- Install variable frequency drives on all lead compressors of each suction group to minimize compressor cycling.

The aforementioned changes result in downsizing several compressors.

Note: Current refrigerant R-404A (GWP 3900) will be replaced with R-448A (GWP 1273) for compliance with future phase-out of high GWP refrigerants. The change is incidental to this energy reduction project.

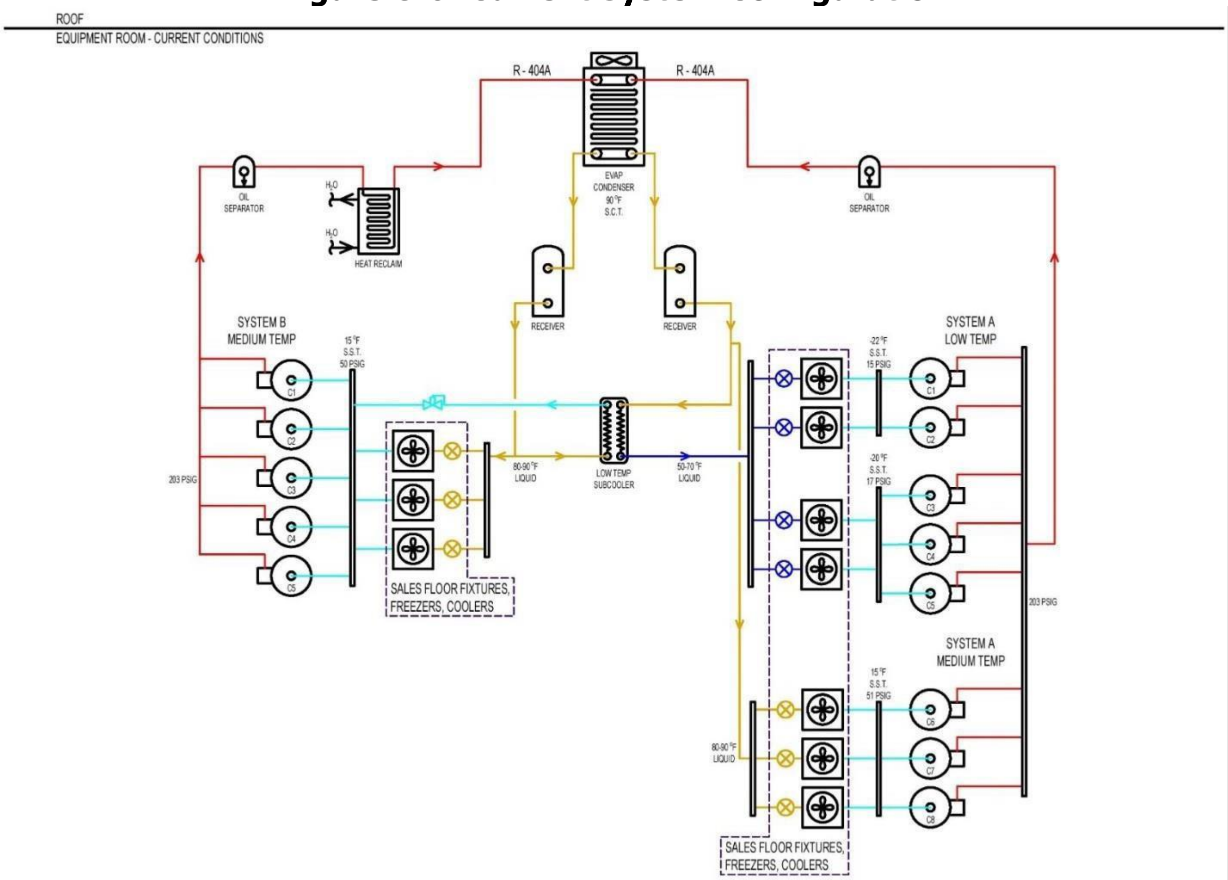
**Table C-5: System Reconfigured for Energy Reduction.**

| System Schematics | | Suct Group | Comp Suct | Cond Temp | Load (MBH) | Evap Cap | Power (kW) | Group EER | Rack THR | Rack Power | Rack EER (MBH/ kW) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CURRENT SYSTEM FIGURE C-5 | R-404A | A1 | -22 | 90 | 25 | 42.5 | 6.37 | 6.7 | 261 | 23.53 | 8.13 |
| | | A2 | -18 | 90 | 69.8 | 86.5 | 12.01 | 7.2 | | | |
| | (GWP 3900) | A3 | +18 | 90 | 32.5 | 62.27 | 5.15 | 12.1 | | | |
| | | B | +15 | 90 | 593 | 670.6 | | | 821 | 55.39 | 12.1 |
| | | | | | | | | TOTAL POWER | | 78.92 | |
| NEW SYSTEM FIGURE C-6 | R-448A | A1 | -25 | 55 | 25 | 26.05 | 3.01 | 8.7 | | | |
| | | A2 | -18 | 55 | 69.8 | 77.54 | 7.42 | 10.5 | 134 | 10.43 | 9.93 |
| | (GWP 1273) | | | | | | | | | | |
| | | B1 | +18 | 90 | 52.4 | 63.5 | 5.26 | 12.1 | | | |
| | | B2 | +22 | 90 | 251.6 | 292.6 | 19.97 | 14.7 | | | |
| | | B3 | +28 | 90 | 228.9 | 276.3 | 19.54 | 14.1 | 732.3 | 44.77 | 14.13 |
| | | | | | | | | TOTAL | POWE R | 55.2 | |

Source: LBNL

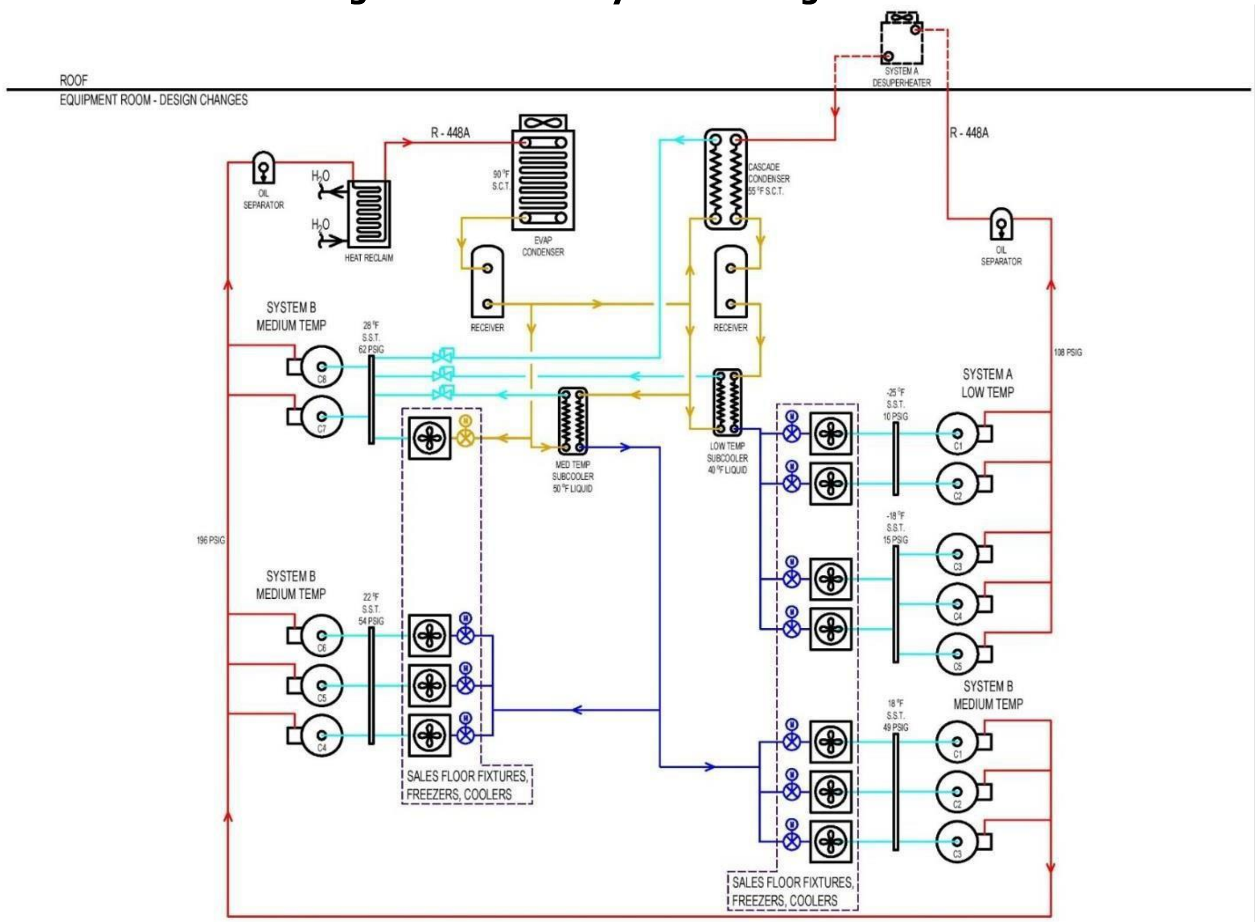
## 4.5 Refrigeration System Drawing

**Figure C-6: Current System Configuration**




Source: LBNL

**Figure C-7: New System Configuration**




Source: LBNL

# 5.0 Electrical Engineering

## 5.1 General

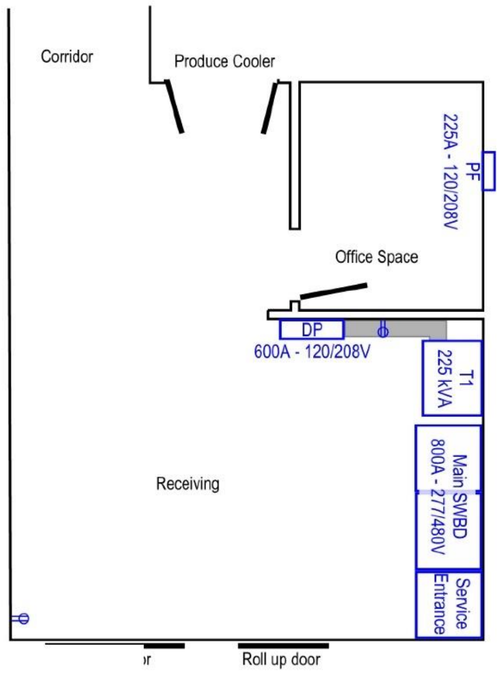
The narrative below outlines the basis of design for new and retrofit electrical systems that will be installed as part of this project. The proposed systems are based on best practices, the specific building architecture, and local codes with the aim to increase overall building efficiency. As previously stated, the overarching goal of this project is to strive towards net zero energy. Moving away from gas loads to electrical loads, upgrading high energy use equipment and fixtures, and the addition of distributed energy resources are some of the measures that are being pursued in this design process.

## 5.2 Electrical Services

### 5.2.1 Utility Power

The incoming utility feed from Pacific Gas & Electric is a 480V, 3 phase, 4 wire system landing on an 800A circuit breaker in the main switchboard. This service allows for a maximum of 530 kW after factoring in the 80% rating of the circuit breaker. Current building electrical load is metered and tops out near 170 kW, with the average daytime load ranging between 120 and 130 kW. Despite moving some gas services to the electrical service, none of the existing electrical equipment should need to be replaced due to the efficiency measures being implemented and existing overhead. Figure C-8 shows the layout of the receiving area which includes the main electrical service.

**Figure C-8: Main Electrical Service Layout**




Source: LBNL

### 5.2.2 Emergency Power

There are no plans to change the emergency power systems in the building. Currently, the only system with backup power is the egress lighting system. This is accomplished with batteries integral to emergency bug-eye luminaires.

Connections to the existing fire alarm system will not be changed.

## 5.3 Building Refit

As with all projects, many of the systems that affect electrical load are led by other disciplines. The electrical design is contingent on the upgrades and optimizations that are completed by other systems designers. The major electrical loads in this building are refrigeration, lighting, and plug/kitchen loads. This section will outline changes to electrical systems but will refer to the other chapters for details involving other disciplines. Power savings estimations were developed from a calibrated load model that was created in a previous phase of this project.

### 5.3.1 Refrigeration Upgrades

Refrigeration accounts for the largest portion of electrical load in the building (as is expected from a grocery store). A full explanation of the upgrades to the refrigeration systems can be found in section 4. A partial list includes upgrading the main refrigeration racks, upgrading the insulation of walk-in coolers, replacing the ice machine, enclosing the medium temperature reach-ins, replacement of inefficient reach-ins and refrigerated tables, and installing a valve to turn off the walk in freezer (2nd floor) outside of the holiday season. All of this equipment will need to be disconnected and reconnected by the electrician.

### 5.3.2 Lighting Refit

The lighting load is the second largest load in the building. The current system was installed in 2009 and includes inefficient metal halide, high-pressure sodium (outdoors), and fluorescent lighting. The main efficiency measure for the lighting system is the replacement of all fixtures with LED luminaires. Additional controls (including occupancy sensors and daylighting) in both the sales floor and back-of- house will be incorporated into the system. A full explanation of the lighting and controls upgrades can be found in section 6 and Appendix A. Currently, the lighting systems are fed from several panels.

This represents an opportunity to consolidate the lighting systems onto one panel (LP- 1). Case lighting will remain on a separate panel (RL).

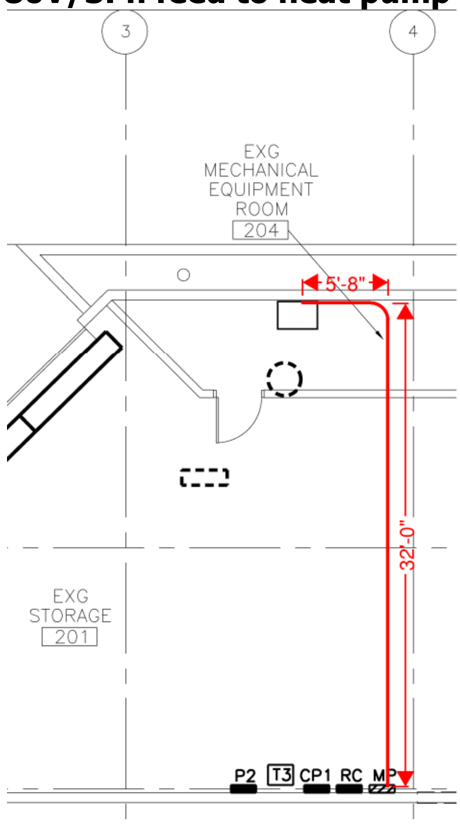
### 5.3.3 HVAC Upgrades

The HVAC system requires some of the most extensive changes as it is currently a piecemeal aggregation of equipment serving different areas. The system includes two rooftop units, a split system serving the IDF room, and several in- wall AC units that exhaust air into the mezzanine space. The HVAC upgrade will consolidate these disparate systems into one rooftop unit. The new unit will be fed from panel MP on the second floor (MP has a 150 kW capacity and feeds the existing RTUs). A full explanation of the upgrades to the HVAC system can be found in section 3.

### 5.3.4 Hot Water System Upgrade

The existing natural gas boiler will be replaced with an electric heat pump water heater. The water heater is located on the 2$^{nd}$ floor of the building. The preferred method of feeding power to it requires running a 480V/3Ph feed from panel MP. The approximate conduit run is shown in Figure C-9. The feeder size will be determined once the power requirements of the water heater have been finalized in the next design stage.

**Figure C-9: 480V/3Ph feed to heat pump water heater**




Source: LBNL

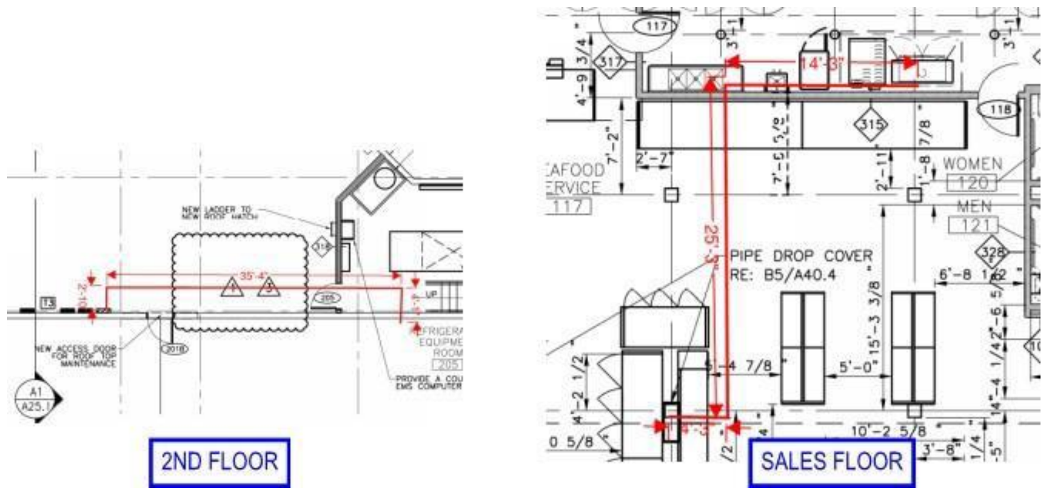
Along with the upgraded water heater, a new control system will be implemented that uses a time-clock water recirculation pump to reduce afterhours energy consumption. Although there will be increased electrical loads from transferring the energy from natural gas to electrical, overall system energy efficiency is estimated to increase by 6.6%.

A solar pre-heat system is being considered for placement on the vertical wall between the main and upper roof areas.

### 5.3.5 Gas Rotisserie Replacement

The current rotisserie uses a natural gas heating element. To move towards a net zero energy system, it was determined that the existing rotisserie could be replaced with an electric combi-oven capable of meeting the chicken throughput requirements of the existing system. This replacement requires extending a 480V circuit from panel MP downstairs into the kitchen area. The current gas line will be cut and capped. Figure C-10 shows the conduit path for the feeder to the new combi-oven. This equipment change will result in an additional estimated 9 kW load on the electrical system but is estimated to decrease energy usage by 3.6%.

**Figure C-10: Conduit run from Panel MP to the new combi-oven**



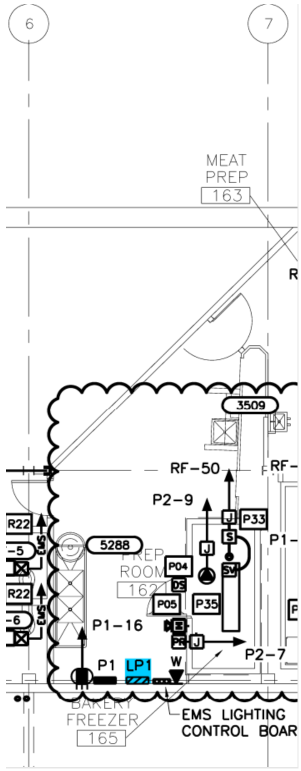

Source: LBNL

### 5.3.6 DC Load Bus

The installation of a DC load bus for lighting (and the future expansion of the refrigeration system) is also being considered. This re-work of the electrical distribution system would help integrate solar PV and battery storage systems more efficiently. This portion of the project is being explored in conjunction with equipment manufacturers and will be refined during the next design stage. Its deployment depends on if a battery system is installed and if the installation of solar and battery storage (most likely purchased on separate PPAs) can be completed together on a DC network. Any necessary equipment could be located in the receiving area near the main distribution equipment.

Because lighting power would be the primary system served by the DC load bus, the existing lighting panels would need to be replaced with DC rated panels and circuit breakers. This may include panels LP-1 in the mezzanine level Prep Room and panel RL in the level 1 Backstock area which are shown in Figure C-11. Panel LP-1 serves a majority of the house lighting and panel RL serves the case lighting. Some lighting circuits are not fed from these panels and will likely need to be re- circuited to amend this. All conduits and wiring from LP-1 and RL shall remain in place and be reused for the DC loads pending insulation tests as necessary.

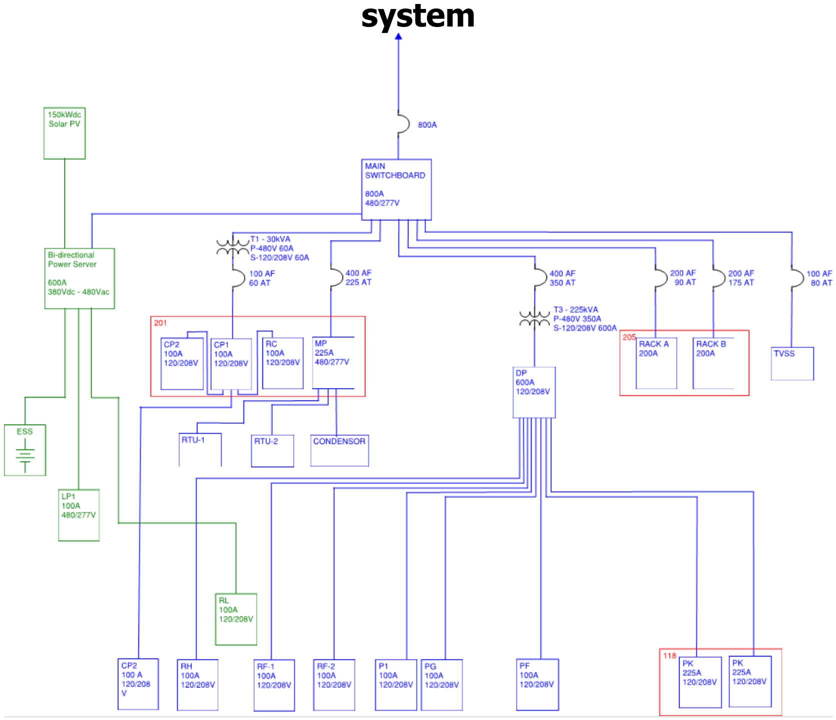
**Figure C-11: Panel LP-1 in the mezzanine Prep Room (above) and Panel RL in the main level Backstock area (right)**




Source: LBNL

Figure C-12 shows a proposed single line diagram for a DC connected PV, battery, and lighting system.

**Figure C-12: Single Line Diagram showing DC systems in green and existing AC system**




Source: LBNL

## 5.4 On-Site Power Generation

One of the critical aspects of a net-zero energy building is the integration of distributed energy resources, including wind, solar, and battery storage. Due to nearby tall buildings and limited space, the site was deemed unsuitable for small scale wind turbines. However, there is ample room on the main rooftop, and a small amount of room on the upper roof, for solar PV. A battery storage system is being considered for storage any excess energy produced by the PV, as well as for aiding in peak load reduction, system resiliency, and demand response.

The interconnection of these systems is planned to be on the DC side of a bidirectional inverter that feeds into the main switchboard (assuming that a DC load bus is not part of the system configuration). The inverter could be located in the loading dock near the main switchboard or on the 2$^{nd}$ level stock area near the electrical panels and roof access door (preferred) depending on final dimensions and space requirements.

### 5.4.1 Solar Photovoltaic

There are about 10,000 square feet of roof space above the main sales floor and 2,000 square feet of roof space above the 2$^{nd}$ floor stock area. Accounting for shading and shared space for mechanical equipment, it is estimated that 150 kWdc of solar can be installed on site. Area over the parking lot was ruled out as an option due to the lack of space in the parking lot to build a support structure for a PV system. The vertical wall space between the roofs will more likely be used for a solar hot water pre-heat system instead of addition solar PV panels.

Either module level (preferred to decrease shading losses though more expensive) or string level MPPTs will be used to convert the power to a nominal DC voltage before it is aggregated and fed into the inverter. The preferred location of the inverter is adjacent to the existing 2$^{nd}$ floor electrical equipment, with the receiving area (across from the main electrical equipment) as a secondary siting location. A conduit will be run between the bi-directional inverter and the main switchboard.

Purchase and installation of the PV system will likely be completed through a Power Purchase Agreement (PPA).

### 5.4.2 Energy Storage Systems

Energy storage systems are important for reducing peak demand and storing excess energy produced by any renewable generation systems. This project site is on a small area and it is unlikely that much excess energy will be produced.

The addition of such a battery storage system will add to the building’s resiliency in the case of an outage as well as enable participate in load shifting and demand response which may provide an economic value stream. The battery system will likely also be provided under a PPA (separate from the solar PV PPA).

## 5.5 Metering

Currently, the electrical service has submetering on a small selection of the systems, including the main lighting panel, the rooftop HVAC units, and the two refrigeration racks. The existing submetering accounts for about 2/3 of the building load. To better understand building energy use, metering shall be expanded with the addition of three new submeters.

Submetering will be installed in the two main distribution panels (the 480V switchboard and the 208V distribution panel). As necessary, circuits in these panels will be metered to obtain sufficient delineation of the energy use data. Additionally, metering will be installed on the PV feeds and battery system (if installed) to monitor energy production.

Data monitoring will measure voltage, current, and power factor averaged into 15 minute intervals. Energy data will be stored for a minimum of 1 year and will be remotely accessible.

# 6.0 Lighting

## 6.1 General

The lighting design approach to energy saving looks at the performance of the entire system as a whole. This takes into account not only the efficiency of the luminaires, but how they work in the space; reflectance/perception of brightness, visual cues, contrast, and glare all contribute to the performance of the lighting system. Improvement in all these areas can improve how people utilize the space and reduce fixture quantities and light levels.

- Existing lighting hardware consists of various fluorescent, compact fluorescent and metal halide sources. Advances in lighting technology since the installation of the current lighting system allow for significant energy savings without sacrificing quality. We recommend overhauling the current lighting system and install fixtures that are not only more energy efficient, but also of higher quality and capable of more sophisticated controls. The goal of the updated lighting scheme is to: Provide a balanced, high-quality, luminous environment
- Reduce energy costs relative to current operation
- Provide a resilient lighting strategy that can be adapted as technology improves

## 6.2 Lighting Solutions

Refer to Attachment C-1 for the results of a site walkthrough, suggestions for lighting improvement per area, and precedents for improved lighting and energy performance for retail areas.

## 6.3 Target Lighting Power Density

The following tables are an excerpt from Title 24 2016, table 140.6 for interior lighting and table 140.7-A and 140.7B for exterior lighting.

**Figure C-13: Excerpt from Title 24**

*TABLE 140.6-C AREA CATEGORY METHOD - LIGHTING POWER DENSITY VALUES (WATTS/FT²)*

| PRIMARY FUNCTION AREA | | ALLOWED LIGHTING POWER DENSITY ($W/ft^2$) |
|---|---|---|
| Commercial and Industrial Storage Areas (conditioned and unconditioned) | | 0.60 |
| Commercial and Industrial Storage Areas (refrigerated) | | 0.7 |
| Corridor, Restroom, Stair, and Support Areas | | 0.60 |
| Grocery Sales Area | | 1.2 [6 and 7] |
| Office Area | > 250 square feet | 0.75 |
| | ≤ 250 square feet | 1.0 |

*TABLE 140.7-A GENERAL HARDSCAPE LIGHTING POWER ALLOWANCE*

| Type of Power Allowance | Lighting Zone 4 |
|---|---|
| Area Wattage Allowance (AWA) | 0.050 $W/ft^2$ |
| Linear Wattage Allowance (LWA) | 0.45 W/lf |
| Initial Wattage Allowance (IWA) | 640 W |

*TABLE 140.7-B ADDITIONAL LIGHTING POWER ALLOWANCE FOR SPECIFIC APPLICATION*

*All area and distance measurements in plan view unless otherwise noted.*

| Lighting Application | Lighting Zone 4 |
|---|---|
| WATTAGE ALLOWANCE PER APPLICATION. Use all that apply as appropriate. | |
| Building **Entrances or Exits.** Allowance per door. Luminaires qualifying for this allowance shall be within 20 feet of the door. | 45 watts |

Source: LBNL

The goal is to provide further reductions to the Title 24 requirements, relative to the impact on the system performance.

## 6.4 Controls

A project-wide lighting control system shall be provided to meet California Energy Code requirements and Brand Standard guidance. The lighting shall be on a centralized control system, with manual overrides in specific areas, such as offices. To comply with Title 24 2016, we have considered the technologies listed in the sections below.

### 6.4.1 Time-switch controls

Daytime and nighttime lighting scenes shall be created to reduce contrast and provide even ambient illumination. During the day, lighting in the deeper spaces within the building shall be balanced with the areas that have access to daylight. At night, the levels shall reduce overall, so there is less need for adaptation from the relatively dark exterior. The daytime and nighttime scenes shall be controlled via astronomical timeclock.

### 6.4.2 Daylight controls

The checkout area, freestanding displays, and aisle areas have daylight access from a full height south-facing glazed façade and six skylights. Fixtures in these areas shall be controlled separately via daylight sensing controls (for example, a photocell) to reduce energy consumption during times where there is useful daylight. Architectural accent lighting in these areas shall also be off, except on very cloudy days.

### 6.4.3 Dimming

Fixtures in front of house spaces, and all spaces with access to daylight, with the exception of inbuilt shelf lighting, are to be dimmable. The lighting system shall be capable of dimming continuously from 100% down to 20%.

#### 6.4.4 Occupant sensing controls

Lighting equipment in restrooms, offices, stairwells, and storage/shelving spaces shall be controlled using occupancy sensors or a combination of manual control with absence detection.

### 6.5 Additional Options

#### 6.5.1 Networked Individual Control

Some digital control systems allow for individual control of each light fixture. This becomes a time and material saving measure if the store is reorganized in the future and control areas need to be re-zoned.

#### 6.5.2 Intelligent Lighting

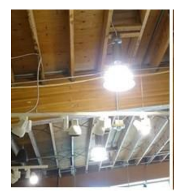
Some fixtures on the market also have the capability to collect and record data. For example, occupancy sensors in fixtures above the aisles can be useful to understand usage patterns in stores, without collecting personal information about the customers.

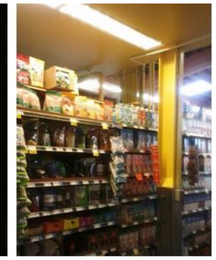
#### 6.5.3 Lighting Control

The lighting control system shall be commissioned to ensure that control devices, components, and equipment are calibrated, adjusted and operate in accordance with the final sequence of operations. Commissioning of the lighting control system shall meet all requirements of the California Energy Code (Title 24).

# ATTACHMENT C-1: LIGHTING SITE WALK THROUGH

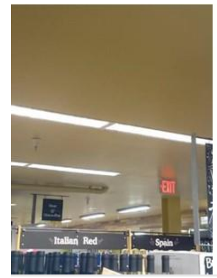
**Table C-1-1**

| Area | Description | Potential improvements | Images of current situation |
|---|---|---|---|
| Entrance/ Facade Zone | Metal halide direct/indirect pendants at circulation.<br><br>Suspended metal halide track accent lights at flowers.<br><br>Suspended linear fluorescent fixtures with specular louvers above checkout.<br><br>Lane numbers light up.<br><br>Fixtures do not contribute much during bright daylight hours but are not currently being switched off and most likely cannot be dimmed. | Use dimmable LED fixtures to be off during daylit hours. Replace suspended fluorescent fixtures with linear<br><br>LED, to match daylight levels, dimmed in the evening. Lane marker lighting appears to be LED already; no action needed.<br><br>Shading system may be needed to shield glare. |    |
| Freestanding Produce/ Specialty or Premade goods | Metal halide pendants with some up light Suspended metal halide track spotlights.<br><br>Much of the product seems to be at end of life; considerable color shift/broken/ burnt out fixtures. Track lighting is not<br><br>optimally aimed, causing glare and wasted light. MEP elements and other light fixtures block light. Ambient light on ceiling from pendants provides pleasant ambient light. | Replace pendant and track systems with a consolidated fixture family to provide accent light and ambient up light.<br><br>Consider high quality light sources with good color rendition and temperature. Fixture placement, mounting height, and coordination with MEP systems to minimize light blockage. |     |

| Area | Description | Potential improvements | Images of current situation |
|---|---|---|---|
| Aisles | Suspended double-row continuous fluorescent pendants with specular louvers at aisles.<br><br>Recessed linear fluorescents at aisles with lowered ceiling.<br><br>Daylight is provided by 6 skylights.<br><br>Some fixtures are at end of life; not optimal beam distribution for shelves. Fixtures do not respond to daylight.<br><br>Linear fixtures are mounted directly below the skylights, blocking some of the light. | Measure to minimize the amount of light blocked from the skylight - smaller fixture profiles, non-linear fixtures, non-rectilinear fixture arrangement. |     |

Source: LBNL

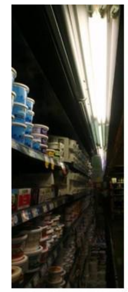
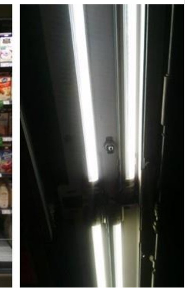
**Table C-1-2**

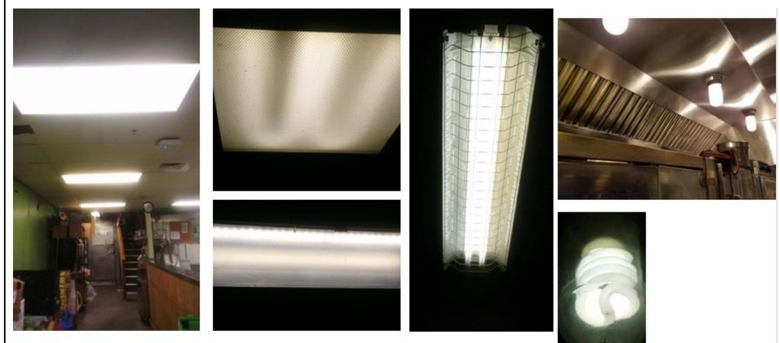
| Area | Description | Potential improvements | Images of Current Situation |
|---|---|---|---|
| Prepared foods/ meat/fish Lowered ceiling area | Recessed linear fluorescents<br>Compact fluorescent ambient downlights Surface-mounted linear prismatic fluorescent fixtures<br>Accent downlights built into work areas. Surface-mounted track lights aimed at end caps.<br>There are many fixture types with different colors and optics. Track at endcaps are a glare source, and some seem to be at end of life. Compact fluorescent lights provide inadequate color rendering. | Use recessed fixtures if possible<br>and consolidate fixture types for visual consistency (this allows us to lower light levels without a perceived feeling of darkness)<br>Alternate solution to endcap lighting: adjustable recessed accent light<br>Use updated LED technology for better color rendering and visual acuity. |      |
| Wall washing | Wall washing throughout the store is done with either track or partially recessed metal halide lights.<br>Some lights were switched off (unclear if this was for a daylight strategy), some not optimally aimed, some burnt out. Fixtures were at end of life. Metal halide fixtures cannot be dimmed for day/night scenarios. | Replace fixture with LED washer.<br>Use monopoint mounting instead of track.<br>Fixtures in skylight area dimmed based on daylight availability.<br>Fixtures in corner areas can be dimmed based on desired daytime and nighttime levels. |      |

| Area | Description | Potential improvements | Images of Current Situation |
|---|---|---|---|
| Soffit accent lighting | Linear fluorescent strips behind produce signage provide accent lighting to the cavity behind the shelves. The effect is subtle and adds the feeling of brightness to the store. Some fixtures seem to be at the end of life, due to color shift and some broken fixtures. | Keep the effect, replace TL with LED.<br><br>Possibly create day/night dimming levels if the energy savings outweigh the cost/complexity of controls. |    |

Source: LBNL

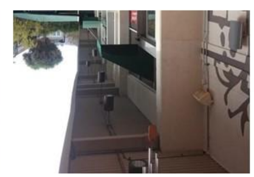
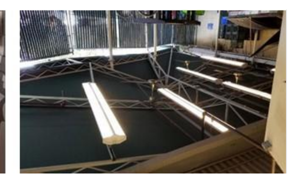
**Table C-1-3**

| Area | Description | Potential improvements | Images of Current Situation |
|---|---|---|---|
| In-built Shelf lighting | Mostly linear T5 or T8 fluorescent fixtures, varying from 1x profile to 2 or 3x profile.<br><br>Some areas (produce vertical display on the bakery side, and freezers) already utilize LED fixtures.<br><br>Some fluorescents would benefit from a higher degree of protection from splashing/ heat/cold to ensure best performance.<br><br>Inconsistent lighting in some places makes the middle of some shelves appear dark. | Replace with wet/damp rated LED fixtures that can be easily cleaned.<br><br>Cases that already include LEDs to eventually be upgraded with a higher output fixture with better optics, so that it isn't necessary to use a double profile.<br><br>An LED strip at the bottom row of the shelving (where applicable) is also recommended to increase the uniformity of brightness. |     |

| Area | Description | Potential improvements | Images of Current Situation |
|---|---|---|---|
| First Floor Storage/ Back of House Lighting | Recessed fluorescent troffers with a prismatic cover<br><br>Surface mounted industrial batten fixtures with a protective grille<br><br>Special high protection LED fixtures in walk-in freezers<br><br>Compact fluorescent E27 base lamps built in to warming unit.<br><br>The prismatic lenses are yellowing and some of lamps look like they are at end of life. | Replace troffers and industrial fixtures with LED products.<br><br>Use lighter finishes on the walls and ceilings to increase the feeling of brightness and reduce need for higher output fixtures.<br><br>Use fixtures that can be easily cleaned in areas where food is being prepared/heated to reduce dirt buildup.<br><br>The LED fixtures in the freezer could be replaced with more efficient LEDs, but it is not a high priority for the initial investment. |  |

Source: LBNL

**Table C-1-4**

| Area | Description | Potential improvements | Images of Current Situation |
|---|---|---|---|
| Offices/ Third Floor storage | Surface-mounted bare lamp fluorescent batten fixtures<br>Surface-mounted fluorescent fixture with a prismatic cover.<br>Some fixtures are using obsolete lamp types (T12) that may be difficult to find on the market later. The office lighting does not follow best practice in terms of glare, color quality, and visual comfort. We did not measure light levels, but it is doubtful that it complies with code. | For the offices, replace fluorescents with updated LED technology (or updated T5 technology if budget constraints do not allow LED).<br>Use fixture with a low UGR rating (<19 for offices), with optics that provide both direct task lighting and ambient lighting.<br>For storage areas, restrooms, and other spaces<br>that are not continuously occupied, fixtures to be controlled with occupancy sensors. |   |
| Exterior lighting | Surface mounted pendants at canopy, retrofitted with LED module<br>Linear fluorescent lights suspended at loading area.<br>We did not observe the exterior pendants in the<br>evening and can’t comment on the<br>light quality. We noticed that the fluorescent fixtures were on during the daytime. | Ensure that the lighting is on a daylight control system so that they are not on during the day. |    |

| Area | Description | Potential improvements | Images of Current Situation |
| --- | --- | --- | --- |
| Parking lot lighting | HPS or metal halide floodlights mounted to poles.<br>We did not observe these lights in the evening and can't comment on the light quality, or control strategy (i.e., are they on for the entire night or just during store opening hours) | Upgrade to more energy efficient lighting that can be on a dimming system for different times of peak traffic during the evening and night.<br>Use proper glare shielding to ensure safety of drivers and pedestrians.<br>New mounting locations may need to be studied to reduce light blockage from trees. |   |

Source: LBNL

**Table C-1-5**

| Description | Images |
|---|---|
| Precedents<br>Light-colored finishes on the ceilings and soffits increase internal reflections and balances contrast levels, allows for reduction in light fixture quantities |     |
| Accent spotlights placed in a structure or mounted above the datum line of the wooden slats keep a clean visual appearance and reduce glare.<br>Although track spotlights are shown in these images, monopoint fixtures could be used for Title 24 compliance. |    |
| Pendants and linear fixtures in an asymmetric grid layout could be considered to avoid blocking the skylights located directly above the aisles. |    |

Source: LBNL

# ATTACHMENT C-2: SITE INVESTIGATION REPORT, DELIVERABLE 2.2.1

## Summary

The four-year "Market Zero" project will design and execute the retrofit of an existing Whole Foods Market in the Noe Valley Neighborhood of San Francisco to achieve net-zero energy utilization with a focus on energy efficiency. To better understand opportunities for energy efficiency upgrades, Arup investigated the existing building components – including façade, kitchen, HVAC, lighting, electrical, plumbing, and refrigeration – at the Whole Foods Market store.

This report summarizes the site investigation findings and is based on the information available at the time of writing:

- Energy use data from 1/1/15 to 6/25/16
- Energy bill data from April 2013 to March 2016
- Sub-metered energy use data from 10/29/16 to 6/16/16
- Site visits on 6/24, 7/21/16, and 8/4/16
- As-built drawings from 2009

### Building Overview

The Whole Foods Market in Noe Valley is located at 3950 24th Street in San Francisco, CA. Originally constructed in 1968, Whole Foods renovated the building in 2009 immediately prior to taking over the lease. The split-level building consists of a single story for the front of house plus a mezzanine and second level for offices, storage, food preparation and equipment.

## Façade

The façade is largely uninsulated, allowing significant thermal bridging through the roof and solar gains through the front entry glazed façade. Possible energy improvements include adding roof insulation and reducing solar gains via window films or shading devices.

## HVAC

HVAC is provided to the front of house through two packaged DX RTUs with gas furnace. The back of house is served by several smaller systems including a packaged furnace and through-the- wall DX units. Current submeter energy data indicates that HVAC uses only <10% of building total energy, but it is likely that this number is artificially low as some HVAC energy is not currently submetered. Possible energy saving measures include replacing the RTUs with higher efficiency units, removing the wall units serving the back of house, and employing energy recovery on exhaust air.

## Electrical

Electricity is provided by PG&E at 480V through an 800A main breaker (total capacity is 665kVA). Properly sized, premium efficiency transformers could reduce the entire store's energy usage by 5%. Additional savings could be realized using a DC microgrid that minimizes AC/DC conversion losses between solar PV, batteries, LED lighting, refrigeration compressors, and HVAC. To determine further energy conservation opportunities, electrical base load needs to be explored further using more detailed submetering.

### Lighting

Lighting fixtures consist mainly of linear T5 and T8 fluorescent fixtures. The front of house also uses compact fluorescent downlights and metal halide pendants for accent and display lighting. To reduce energy use (lighting is the second largest energy end-use in the store according to submetered data), fluorescent and metal halide fixtures can be upgraded to high-efficiency LEDs. Additional savings are available via daylight-integrated dimming and lighting controls.

### Refrigeration

Refrigeration consists of open medium and closed low temperature display cases in the front of house and open medium and closed low temperature walk-in coolers in the back of house. Two R410a compressor racks separately serve low-temperature and medium-temperature loops. Heat rejection is accomplished with a VFD controlled closed evaporative condenser. Refrigeration uses by far the most energy and is a constant 24/7 load. Energy conservation opportunities include adding controls, upgrading evaporator fan motors, retrofitting case lighting, enclosing refrigeration cases and installing high-efficiency compressors.

### Kitchen

The kitchen uses relatively little domestic hot water since this Whole Foods store has low cooking loads. Domestic hot water for the kitchen, coffee service area, restrooms, and prep rooms is generated using a 96% efficient gas-fired boiler. Boiler energy is partially offset by domestic water preheat using heat recovered off of the medium-temperature refrigeration rack. Point of use water heating and reorganization of spaces into hot and cold areas could reduce hot water use. Plug-in kitchen equipment could be upgraded to premium efficiency units and better controlled.

## 1.0 Introduction

Existing grocery stores in urban settings present one of the most challenging sectors for a zero- net energy (ZNE) California. With EPIC grant funding from the California Energy Commission, the four-year "Market Zero" project will design and execute the retrofit of an existing Whole Foods Market in the Noe Valley Neighborhood of San Francisco to achieve net-zero energy utilization with a focus on energy efficiency. The project team includes Prospect Silicon Valley, Arup, Whole Foods Market, and Lawrence Berkeley National Laboratory (LBNL).

To better understand opportunities for energy efficiency upgrades, Arup investigated the existing building components – including façade, kitchen, HVAC, lighting, electrical, plumbing, and refrigeration – at the Whole Foods Market. This report summarizes the site investigation findings.

### Basis of Assessment

This report is based on the information available at the time of writing:

- Energy use data from 1/1/15 to 6/25/16
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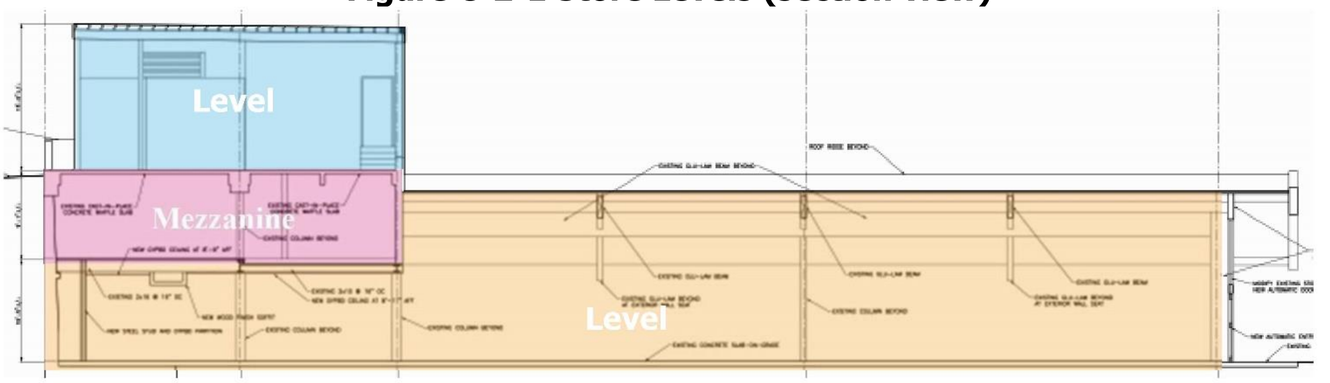
## Building Overview

The Whole Foods Market in Noe Valley is located at 3950 24th Street in San Francisco, CA. Originally constructed in 1968, Whole Foods renovated the building in 2009 immediately prior to taking over the lease.

The split-level building consists of a single story for the front of house plus a mezzanine and second level for offices, storage, food preparation and equipment (Figure 1). Characteristics by level are summarized in Table C-2-1.

**Figure C-2-1 Store Levels (section view)**




Source: LBNL

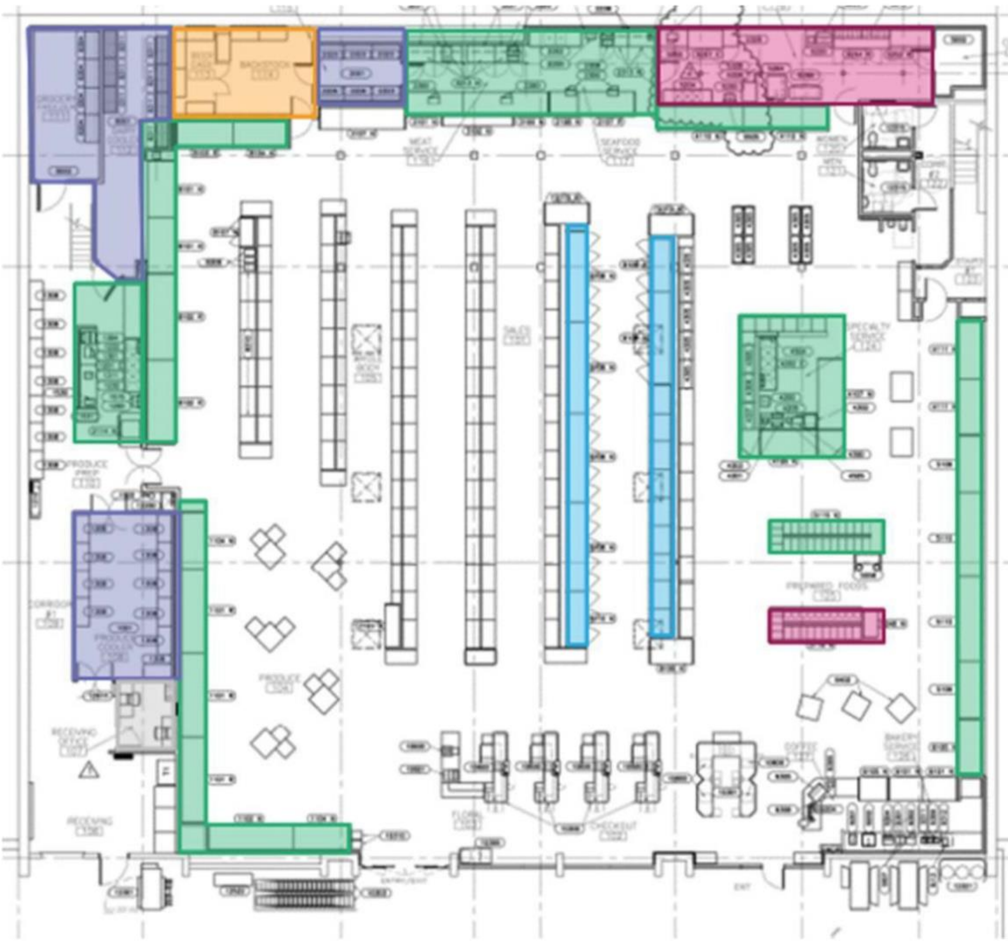
**Table C-2-1 Building Characteristics by Level**

| Level | Main Functions | Area (ft) | Height |
|---|---|---|---|
| Parking lot 1 | Parking, receiving, trash | 15,000 | N/A |
| | Retail, receiving | 16,812 | Sloped ceiling from 8'10" to 15'1" |
| Mezzanine 2 | Office and food preparation | 5,085 | 9'1" |
| | Storage and refrigeration | 3,290 | 15'0" |

Source: LBNL

Store layouts by level with color coding by space use are shown on the next two pages in Figure C-2-2. In front of the building's south façade is a 15,000 sqft parking lot. In addition to parking spaces, the parking lot houses large trash dumpsters and the receiving area.

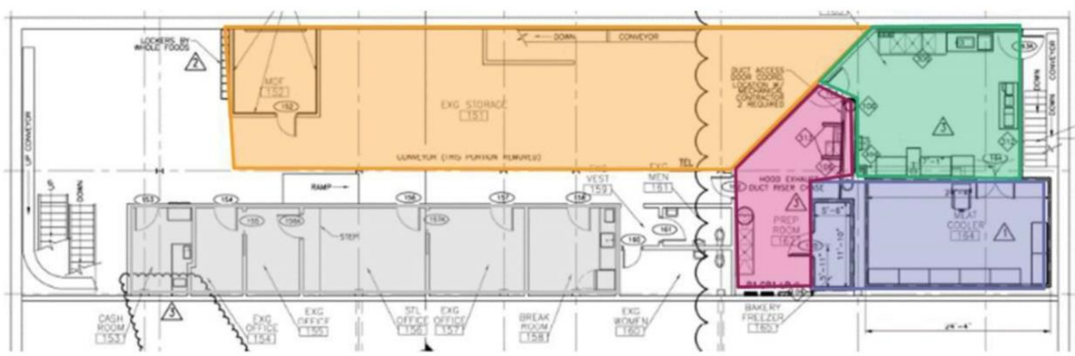
**Figure C-2-2: Space use in Level 1 (top), mezzanine (middle), and level 2 (bottom). Plan view**



**Level 1**

Storage/equipment
Enclosed freezers
Enclosed coolers
Open coolers/prep
Hot prep/display
Office

**Mezzanine**



**Level 2**

Storage/equipment

Enclosed freezers

Enclosed coolers

Open coolers/prep

Hot prep/display

Office

Source: LBNL

## 2.0 Facade

### Walls

The exterior walls are made of pre-cast concrete. The interior columns are steel. Interior walls consist of uninsulated steel frame and gypsum board.

## Roof

Both the lower and upper roofs are glu-lam timber construction.

The 12,000 sqft lower roof covers the front of house. The roof is a minimally insulated with a highly reflective external roof membrane that was installed in 2009 when Whole Foods took over the lease (Figure 4). The lower roof contains six skylights and two air handling roof top units (RTUs). It is shaded by a large tree on the west side, adjacent buildings on the east and west sides, and Level 2 on the north side. Using thermal imaging, heat loss/gain via thermal bridging is visible through the lower roof (Figure C-2-3). The 5,000 sqft upper roof covers the storage and equipment rooms. This roof has a standard tar and gravel surface (Figure C-2-4). The roof includes an exhaust area for the fluid cooler located on Level 2, a gravity vent, and some small exhaust fans.

## Glazing

Glazing consists of a curtain wall on the south entry façade and six skylights in the roof (Figure C-2-5).

The curtain wall is coated with a film to reduce solar heat gain (SHGC = 0.50). Although the curtain wall is fitted with manually-operated roll down shades, glare still poses a problem at the checkout area.

The six skylights each measure 4’ x 4’ and are slightly raised off of the sloping roof. Mirrors inside the skylights track the sun to reflect low-angle light into the store (Figure 5).

**Figure C-2-3: Thermal Bridging through Lower Roof**


**Heat from the outside of the roof (top right) travels through the poorly insulated roof, heating up the inside roof (bottom right) and increasing the amount of heat that the packaged rooftop units must remove.**

Source: LBNL

## Floors

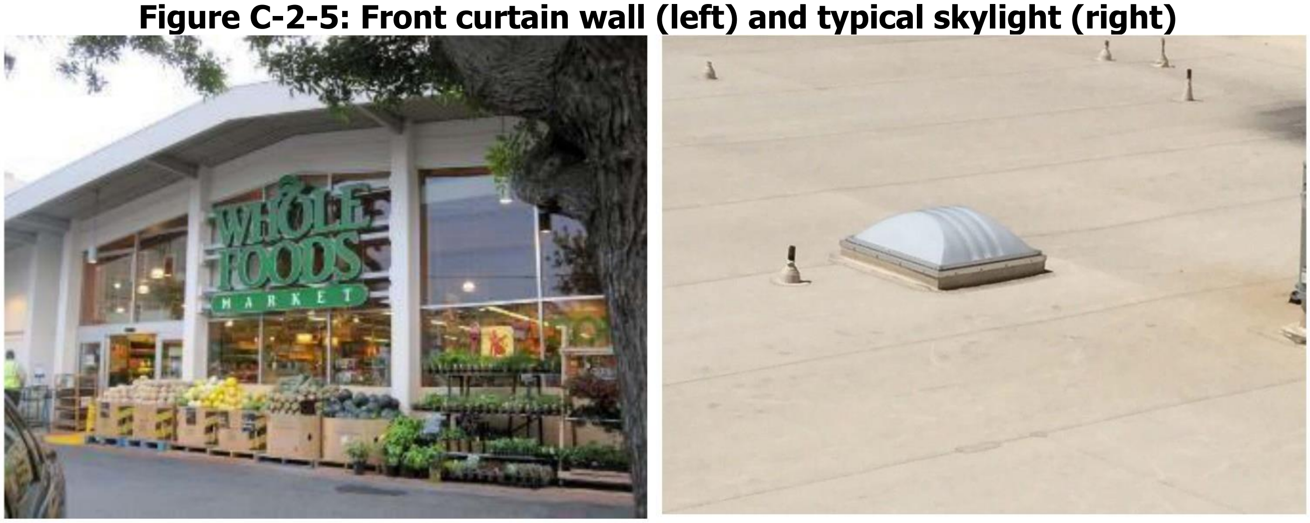
The floors are concrete slab construction. It is not known whether the slab includes any insulation at the perimeter of the building.

The HVAC, lighting, and refrigeration systems are controlled by a Microthermo direct digital controls (DDC) system. A desktop interface to the Microthermo system is located in the compressor room on Level 2. Additionally, remote access is available through a secure website. Generally, site staff do not interact with the Microthermo system. If alarms are generated for the refrigeration system, site staff engage a local refrigeration contractor who uses the Microthermo system.

**Figure C-2-4: Upper roof (left) and lower roof (right)**

Source: LBNL

**Figure C-2-5: Front curtain wall (left) and typical skylight (right)**




Source: LBNL

# 4.0 HVAC

## Conditioning

The front of house is served by two packaged units RTU-1 and RTU-2 that provide air cooled direct expansion (DX) cooling and gas furnace heating. The rooftop units are ASHRAE 90.1-2010 compliant. Due to limited misting in the store, the building does not have a high latent load, so the units do not serve latent load. RTU-1 serves the east side of the Level 1 sales area while RTU- 2 serves the west side of the store.

The back of house is served by several small systems. The offices are served by through-the-wall air conditioning units that exhaust and condense directly into the mezzanine storage area. Small 80% efficient unit heaters hung from the ceiling at the receiving doors on level 1 (UH-1) and level 2 (UH-2). A gas furnace provides heating to the mezzanine area and interior offices. Ductless split air conditioner DAC-1 serves the server closet, though it was not functioning during Arup's site visit in June.

Equipment capacities are summarized in Table C-2-2. Equipment photos are shown in Figure C-2-6.

**Table C-2-2: HVAC Equipment**

| Unit | Description | Location | Area Served | Heating Capacity (kBtu/hr) | Cooling Capacity (kBtu/hr) | Supply Air (cfm) | Outside Air (cfm) | Effi-ciency |
|---|---|---|---|---|---|---|---|---|
| RTU-1 | Packaged rooftop DX unit with gas furnace | Lower roof | Front of house | 350 | 170 | 5,000 | 1,700 | 12.0 EER<br><br>81% heat |
| RTU-2 | Packaged rooftop DX unit with gas furnace | Lower roof | Front of house | 200 | 121 | 4,000 | 1,300 | 10.6 EER<br><br>81% heat |
| DAC-1 | Ductless split air conditioner | MDF room | MDF room | 0 | N/A | 840 | 0 | N/A |
| UH-1 | Unit heater | Level 1 receiving door | Level 1 receiving | 30 | 0 | N/A | 0 | N/A |
| UH-2 | Unit heater | Level 2 receiving door | Level 2 receiving | 30 | 0 | N/A | 0 | N/A |

Source: LBNL

**Figure C-2-6: Heating and cooling equipment**

RTU-1

RTU-2

DAC-1


UH-1

Through-the-wall AC unit

Source: LBNL

## Fans

The front of house is fitted with 7 destratification fans DF-1 through DF-7. Nearly all destratification fans were unplugged and not operational during site visits, due to perceived and actual impacts on customers and grocery products. Thermal imaging indicates that some thermal stratification occurs in the front of house (Figure C-2-7).

**Figure C-2-7 Stratification in the front of house (left). Unplugged destratification fan (right)**


Source: LBNL

Exhaust fans serve the restrooms, storage, seafood service, coffee service, and electrical spaces (Table C-2-3).

**Table C-2-3: Exhaust fan capacities and locations**

| Fan | Location | Area Served | Exhaust Air (cfm) |
|---|---|---|---|
| EF-1 | Upper roof | Kitchen hood | 2025 |
| EF-2 | Upper roof | Electrical room | 1000 |
| EF-3 | Upper roof | Mezzanine storage | 515 |
| EF-4 | Upper roof | Seafood service | 600 |
| EF-5 | Mezzanine toilet room 161 | Mezzanine toilet room 161 | 150 |
| EF-6 | Mezzanine toilet room 160 | Mezzanine toilet room 160 | 150 |

Source: LBNL

## Air Curtains

Air curtains AD-1 through AD-6 are present at the two entrances and at the receiving doors on levels 1 and 2 (Table C-2-4 and Table C-2-5). Units AD-5 and AD-6 operate together as one unit.

**Table C-2-4: Air curtain airflows and locations (AD-1 to AD-6)**

| Unit | Location | Airflow (cfm) |
|---|---|---|
| AD-1 | Exit area | 3054 |
| AD -2 | Entry/exit area | 3054 |
| AD -3 | Level 1 receiving | 5050 |
| AD -4 | Level 1 receiving | 6766 |
| AD-5 and AD-6 | Level 2 receiving | 9108 |

Source: LBNL

**Table C-2-5: Air curtain airflows and locations (EF-1 to EF-8)**

| Fan | Location | Area Served | Exhaust Air (cfm) |
|---|---|---|---|
| EF-1 | Upper roof | Kitchen hood | 2025 |
| EF-2 | Upper roof | Electrical room | 1000 |
| EF-3 | Upper roof | Mezzanine storage | 515 |
| EF-4 | Upper roof | Seafood service | 600 |
| EF-5 | Mezzanine toilet room 161 | Mezzanine toilet room 161 | 150 |
| EF-6 | Mezzanine toilet room 160 | Mezzanine toilet room 160 | 150 |
| EF-7 | Level 1 east stair | Public toilet rooms | 200 |
| EF-8 | Lower roof | Coffee service | 300 |

Source: LBNL

## 5.0 Electrical

Table C-2-6 summarizes key information found during the site walk that is pertinent to the electrical analysis.

**Table C-2-6: Electrical Summary**

| Item | Key Information |
|---|---|
| **Service** | |
| Distribution voltage | 480V - 3 phase 4 wire |
| Building capacity | 665kVA |
| Limit on capacity | 800A Main Breaker |
| **Installed Plant** | |
| Normal boards | [1] DP { [8] RL, RH, RF (or RF-1), PG, PF, P1, P2 (or PZ), PK }; [1] CP1 { [2] CP2, RC } |
| Lighting boards | [2] LP-1; RL |
| Emergency boards | N/A |
| Mechanical boards | [1] MP |
| Bus taps | N/A |
| Transformers | [1] 225kVA (efficiency @ 35% load: 98.5%)<br>[1] 30kVA (efficiency @ 35% load: 97.5%) |
| Metering | Mains, Rack A, Rack B, RTU-1, RTU-2, Panel LP-1 |
| Landlord power for mech? | No |
| **Closets** | |
| Number of closets | [7] 106, 107, 109, 114, 118, 162, 201 |
| Closets meet code? | Yes |
| Space for additional | No |
| **Emergency Power** | |
| Tie in available? | No |
| Required to use? | N/A |

Source: LBNL

## Electrical Capacity Analysis

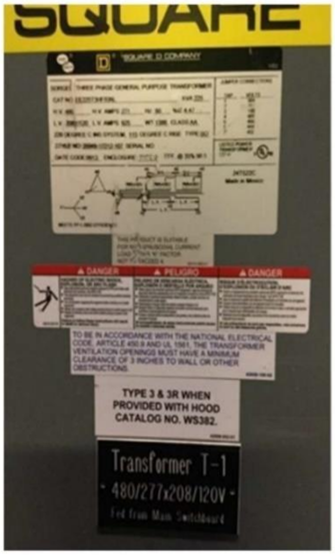
Electrical load is supplied through one metered service connection at 480V through an 800A main breaker (total capacity is 665kVA). The panels appear to be well kept with no obvious signs of damage. The panels have mixed loads, including lighting, receptacles and mechanical, across many of them.

The Main Distribution panel serves lighting (LP-1 @ 100A), mechanical (MP @ 225A, Rack A (90A), and Rack B (175A)), TVSS (80A), power monitoring (15A) and the two transformers (T1 @ 350 A and T3 @ 60A). There are 4 additional spares with ratings of 250A, 200A, 100A and 60A.

Transformer T1 - 225kVA (277/480V – 120/208V) serves panel DP (MCB @ 600A) {with MLO subpanels RL (100A), RH (60A), RF (225A), PG (225A), PF (225A), P1 (100A), P2 (100A), PK (225A), and 4 spares ([2] 225A [2] 100A)}.

Transformer T3 - 30kVA (277/480V – 120/208V) serves panels CP1 (MCB @ 100A) {with MLO subpanel RC (60A)} and CP2 (MLO @ A?).

**Figure C-2-8 Transformer nameplates for T-1 (left) and T-3 (right)**





Source: LBNL

A BMS monitors power consumption on Rack A, Rack B, RTU-1, RTU-2, and panel LP-1 in addition to the mains monitoring. RTU-1 and RTU-2 are on panel MP which also serves other loads.

Figure C-2-9 shows the panel schedule for the main distribution panel. Figure C-2-10 summarizes the panel schedule and breaker information found during the site walk.

**Figure C-2-9: Main distribution panel schedule**

| PANEL DP from TRANSFORMER T1 (120/208V) | | | |
|---|---|---|---|
| 1 | | | 2 |
| 3 | | | 4 |
| 5 | PANEL RL | PANEL RH | 6 |
| 7 | | | 8 |
| 9 | | | 10 |
| 11 | PANEL RF-1 | PANEL P-1 | 12 |
| 13 | | | 14 |
| 15 | | | 16 |
| 17 | PANEL PG | PANEL P-2 | 18 |
| 19 | | | 20 |
| 21 | | | 22 |
| 23 | PANEL PF | PANEL Pk1 | 24 |
| 25 | | | 26 |
| 27 | | | 28 |
| 29 | SPARE (?) [OPEN] | SPARE (?) [OPEN] | 30 |
| 31 | | | 32 |
| 33 | | | 34 |
| 35 | SPARE (?) [OPEN] | SPARE (?) [OPEN] | 36 |
| 37 | space | space | 38 |
| 39 | space | space | 40 |
| 41 | space | space | 42 |

Source: LBNL

## Figure C-2-10 Panel and Breaker Schedules

**PANEL CP-1 from T3 (120/208V)**

| | | | |
|---|---|---|---|
| 1 | IG CASH ROOM MEZZ. | IG OFFICE MEZZ | 2 |
| 3 | IG OFFICE MEZZ | IG MDF ROOM | 4 |
| 5 | IG EMS WORKSTATION MECH RM | IG MDF ROOM | 6 |
| 7 | IG OFFICE MEZZ | IG MDF ROOM | 8 |
| 9 | spare?(breakerclosed) | IG MDF ROOM | 10 |
| 11 | IG MEAT PREP MEZZ | IG MDF ROOM | 12 |
| 13 | IG MDF RM SEC. SYS | IG MDF ROOM | 14 |
| 15, 17 | R.O. Water stat. | IG BREAK RM MEZZ | 16 |
| | | IG BREAK RM MEZZ | 18 |
| 19 | R.O. Water stat. | SPARE (20A) [CLOSED] | 20 |
| 21 | R.O. Water stat. | SPARE (20A) [CLOSED] | 22 |
| 23 | SPARE (20A) [CLOSED] | SPARE (20A) [CLOSED] | 24 |
| 25 | space | space | 26 |
| 27 | space | space | 28 |

**PANEL PZ (PANEL P-2 from DP 120/208V)**

| | | | |
|---|---|---|---|
| 1, 3 | AIRDOOR2ndFLN.E. | space | 2 |
| | | space | 4 |
| 5, 7, 9 | ROLL UP DOOR | EF-3 | 6 |
| | | EF-4 | 8 |
| | | spare (20A) [CLOSED] | 10 |
| 11 | LIGHTING 2nd FLOOR | MECH RMNCONVRCPTHIGH | 12 |
| 13 | BAKERY JAM HEATER MEZZ | spare (20A) [CLOSED] | 14 |
| 15 | BAKERY JAM HEATER MEZZ | spare (20A) [CLOSED] | 16 |
| 17 | space | SPARE in Jbox NWCLG BY EX SIGN | 18 |
| 19 | space | 2ndFL HWH MECH RM | 20 |
| 21 | space | FURN. 2nd FL MECH RM | 22 |
| 23 | space | CIRCPUMP H2OHEATMECH RM | 24 |
| 25 | space | GFI RCPT BY EF-4 | 26 |
| 27 | space | | 28 |
| 29 | space | | 30 |

**PANEL RC from CP-1 (120/208V)**

| | | | |
|---|---|---|---|
| 1, 3 | RACK"B"CONTROLS | RACK"A"CONTROLS | 2, 4 |
| 5 | RACK"B" EMS(SPAREINCAB) | RACK"A" EMS(SPAREINCAB) | 6 |
| 7 | DOLPHIN SYS MECH RM | EMS BOARD @ GUTTER | 8 |
| 9 | SPARE (20A) [CLOSED] | EMSWKSTATIONMACHRM | 10 |
| 11 | DAMPER MOTOR MACH RM | SPARE (20A) [CLOSED] | 12 |
| 13 | DAMPER MOTOR RECEIVING | freezer lights | 14 |
| 15 | EMS BOARD CTRL PWR | fzr door heat tape | 16 |
| 17 | EMS BOARD @ GUTTER | freezer fan coils | 18 |
| 19 | EMS BOARD @ GUTTER | EMSBOARDLTG/LEAKD.PWR | 20 |
| 21 | CONV RCPT E 2nd FLOOR | EMS BOARD @ GUTTER | 22 |

**PANEL CP-2 from CP-1 (120/208V)**

| | | | |
|---|---|---|---|
| 1 | 10600A CHKOUT REGISTER | 10600B CHKOUT REGISTER | 2 |
| 3 | 10600C CHKOUT REGISTER | 10600D CHKOUT REGISTER | 4 |
| 5 | 10600J CHKOUT REGISTER | 10600F CHKOUT REGISTER | 6 |
| 7 | 10600G CHKOUT REGISTER | 10600H CHKOUT REGISTER | 8 |
| 9 | 10600K CHKOUT REGISTER | CHKOUT FLORAL/CUST SERV | 10 |
| 11 | RECEIVING OFFICE DESK | 1301 PRODUCE PREP | 12 |
| 13 | ??? (20A) [CLOSED] | GFI3300A, 3300B MEAT SERVICE | 14, 16 |
| 15 | 956 BAKERY REGISTER | | |
| 17 | 4300 SPECIALTY SERV | 5268 MEAT SERVICE | 18 |
| 19 | 9302 BAKERY SCALE | RECEIVING OFFICE FAX | 20 |
| 21 | 2300A, 2300B MEAT SERV | WHOLE BODY CPU | 22 |
| 23 | spare (20A) [OPEN] | spare (20A) [OPEN] | 24 |
| 25 | spare (20A) [OPEN] | spare (20A) [OPEN] | 26 |
| 27 | spare (20A) [OPEN] | spare (20A) [OPEN] | 28 |
| 29 | space | space | 30 |

**Panel MP (277/480V) from Main Switchboard**

| | | | |
|---|---|---|---|
| 1, 3, 5 | CONDENSER MECH ROOM | RTU-1 | 2, 4, 6 |
| 7, 9, 11 | AIR DOOR-5,6 WEST 2ND FLOOR | RTU-2 | 8, 10, 12 |
| 13, 15, 17 | CONVEYOR #1 | SPARE (20A) [OPEN] | 14, 16, 18 |
| 19, 21, 23 | CONVEYOR #2 | Parasense | 20, 22, 24 |
| 25 | | | 26 |
| 27 | | | 28 |
| 29 | | | 30 |

**PANEL RF-2 from DP (120/208V)**

| | | | |
|---|---|---|---|
| 43 | SPARE (15A) [OPEN] | MEATCOOLEREVAPA-24 | 44 |
| 45 | SPARE (15A) [OPEN] | MEATCOOLEREVAPA-24 | 46 |
| 47 | SPARE (15A) [OPEN] | MEAT PREP EVAP B-67 | 48 |
| 49 | SPARE (15A) [OPEN] | BAKERY FREEZER EVAP A-2 | 50 |
| 51 | SPARE (20A) [OPEN] | DELI COOLER B-65 | 52 |
| 53 | SPARE (20A) [OPEN] | SPARE (15A) [OPEN] | 54 |
| 55 | SPARE (20A) [OPEN] | SPARE (15A) [OPEN] | 56 |
| 57 | SPARE (20A) [OPEN] | SPARE (15A) [OPEN] | 58 |
| 59 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 60 |
| 61 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 62 |
| 63 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 64 |
| 65 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 66 |
| 67 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 68 |
| 69 | SPARE (20A) [OPEN] | SPARE (20A) [OPEN] | 70 |

**PANEL PG from DP (120/208V)**

| | | | |
|---|---|---|---|
| 1 | SWEEPER CONV RECEPT | HONEY HEAT RIGHT | 2 |
| 3 | RECEPT WHOLE BODY | HONEY HEAT LEFT | 4 |
| 5, 7 | NUT GRINDER | NUT GRINDER | 6, 8 |
| 9, 11 | NUT GRINDER | RECEPT AT NUT GRINDERS | 10, 12 |
| 13 | RECEPT ORDER DESK | DOOR HEATER | 14 |
| 15, 17 | ICE FLAKER 2114 (15A) | SOAP DISPENSER | 16 |
| | | ??? (20A) [CLOSED] | 18 |
| 19 | FLY TRAP | DAIRY COOLER ALARM | 20 |
| 21 | ??? (20A) [CLOSED] | SPARE (20A) [CLOSED] | 22 |
| 23 | FOOD PROCESSOR 1311 | SPARE (20A) [CLOSED] | 24 |
| 25 | SPARE AT COUNTER | WRAPPER 4301 | 26 |
| 27 | SPARE AT COUNTER | FOOD PROCESSOR 4505 | 28 |
| 29 | 1304 WRAPPER | MINI WRAPPER 4302 | 30 |

**PANEL PF from DP (120/208V)**

| | | | |
|---|---|---|---|
| 1 | CHECK STAND RECEPT | CHECK STAND RECEPT | 2 |
| 3 | CHECK STAND RECEPT | CHECK STAND RECEPT | 4 |
| 5 | CHECK STAND RECEPT | EXT WAREHOUSE LTS | 6 |
| 7 | DOOR OPENER SALES | RECEIVING OFFICE RCPT | 8 |
| 9 | ??? (20A) [CLOSED] | CHK STAND PENDANT LTS | 10 |
| 11 | WHOLE FOODS STORE SIGN | ??? (20A) [CLOSED] | 12 |
| 13 | WHOLE FOODS STORE SIGN | DESTRAT FANS 1 THRU 4 | 14 |
| 15 | REMOTE FIRE ALARM | CUST SERV CHKSTAND | 16 |
| 17 | ??? (20A) [CLOSED] | ??? (20A) [CLOSED] | 18 |
| 19, 21 | OUTSIDE POLE LIGHTS | EXHAUST FAN EF-2 | 20 |
| | | REMOTE ANN PANEL (EMS) | 22 |
| 23 | PARKINGLOTWHOLEFOODS | FLY TRAP | 24 |
| 25 | LT CONTACTOR CTRL VOLTAGE | RCPT RECEIVING DOOR | 26 |
| 27 | ??? (20A) [CLOSED] | AIR CURTAIN AD-1 FRONT EAST | 28, 30 |
| 29 | OUTSIDEGFI RCPTWEST | | |

Source: LBNL

## 6.0 Lighting

### Panels

Lighting is served by several panels. Panel LP-1 (277V) provides a majority of the interior lighting. Signage and parking lot lighting is served by panel PF (120V). Case lighting is provided by panel RL (120V). Second floor lighting is on panel P2 (120V).

### Fixtures

Ambient lighting on the Level 1 sales floor consists mainly of 3000K color temperature T8 fluorescent linear pendant fixtures. Task lighting in the sales area includes compact fluorescent downlights and metal halide pendants. Several metal halide luminaires are also installed for track lighting throughout the store, including in the beauty aisle, over the cheese case, and in the wine display area.

Refrigeration cases are fitted with a combination of T5 and T8 linear fluorescent fixtures.

Lighting in the back of house and walk-in coolers consists mainly of 3000K color temperature T8 and T5 fluorescent linear pendant fixtures.

Exterior lighting is a mixture of metal halide pendant downlights and compact fluorescent sconces. The exterior lighting is installed only on the south-facing front façade.

The parking lot is served by 3 high-pressure sodium lamps. Two lamps are mounted on the façade and one lamp is mounted on a pole in the parking lot.

After the interior renovation in 2009, additional lighting has been added in an ad-hoc fashion. This lighting is not illustrated in the 2009 As-Built drawings, and an updated lighting schedule has not been produced.

Lighting fixture types are illustrated in Figure C-2-11.

### Controls

Light fixtures are controlled through the building management system by time clock. During site walks it appeared that this time clock was overridden, as most lights were observed to remain on after scheduled hours.

The checkout area near the front curtain wall receives ample daylight for most of the day. Photocells in the checkout area automatically shut off half of the linear T8 fluorescent fixtures when sufficient daylight is available. Dynamic dimming is not currently used.

**Figure C-2-11 Lighting fixtures**

Compact fluorescent down-lights in the front of house sale area.

Linear fluorescent T8 fixtures in the front of house sales area.

High pressure sodium parking lot lighting

Metal halide accent track lights in front of house

Photocells in the checkout area automatically shut off half of the linear T8 fluorescent fixtures when sufficient daylight is available. Dynamic dimming is not currently used.

Linear fluorescent T5 fixtures in refrigerated display cases.


Linear fluorescent T8 pendant fixtures in back of house

Source: LBNL

# 7.0 Refrigeration

## Front of House Cases

The sales area contains both medium and low temperature refrigeration cases. Refrigeration cases are depicted in Figure C-2-12.

Dairy, meat, produce, eggs, beverages, and prepared foods are housed in vertical medium-temperature cases. These cases contain night curtains that must be manually drawn by staff after hours, though site observation indicated that this does not occur regularly. Two horizontal medium temperature cases contain cheese and meat. The medium temperature cases are open to the aisles, resulting in significant heat loss (Figure 13). Case temperatures are in the low 40s Fahrenheit. Anti-sweat heaters are not provided. Case lighting consists of T-5 and T-8 linear fluorescent fixtures embedded in the unit plus additional metal halide accent lighting above and directed at the cases.

**Figure C-2-12: Refrigeration case types**


Vertical low-temperature display case

Vertical medium-temperature display case

Walk-in low temperature cooler

Walk-in medium-temperature cooler

Source: LBNL

Frozen foods are kept in low-temperature cases. These cases are enclosed, though significant heat loss still occurs through the door frame (Figure C-2-13). Ant-sweat heaters are provided and do not appear to have controls (timer or humidity based). Case lighting consists of T-5 and T-8 linear fluorescent fixtures embedded in the unit plus additional metal halide accent lighting above and directed at the cases.

**Figure C-2-13: Heat loss through anti-sweat heaters on enclosed freezers (top left), open coolers (top right), walk-in freezers with leaky gaskets (bottom left), and walk-in coolers with strip curtains (bottom right)**


Source: LBNL

## Back of House Cases

The back of house also contains medium and low temperature walk-in coolers.

Medium temperature walk-in coolers contain produce. Cooler doors are enclosed by strip curtains, which allow significant heat loss (Figure C-2-13).

Low temperature walk-in coolers contain meat, frozen, foods, and non-perishable storage items like empty wine crates. While low-temperature coolers are enclosed with doors, thermal imagine indicates that some gaskets may require replacement (Figure C-2-13).

**Figure C-2-14: Compressor Racks**

Refrigeration rack A　　Refrigeration rack B

Source: LBNL

The refrigeration cases are served by two refrigeration compressor racks: Rack A and Rack B (Figure C-2-14). Each rack consists of a series of small compressors using 404A refrigerant. Condensing temperature is 90 °F. Heat is rejected by a 120 kBtu/hr Recold closed evaporative condenser located in the compressor room. The 15-horsepower condenser fan is modulated by a variable frequency drive (VFD). Cooler water is treated using an electronic chemical-free Dolphin Watercare system.

Rack A serves the low-temperature walk-in coolers in the back of house, low-temperature display cases in the front of house, and the ice maker. The total load on the rack is 13.5 tons. Rack B serves the medium- temperature walk-in coolers in the back of house and medium-temperature display cases in the front of house, total load 55.0 tons. Compressor suction temperature is 18 °F and condensing temperature is 90 °F.

Load is divided by compressor suction temperatures (Table 6).

**Table C-2-6: Compressors by Suction Temperature**

| Rack | Loop | Compressor Suction Temperature (˚F) | Capacity (kBtu/hr) | Subcooling (kBtu/hr) |
|---|---|---|---|---|
| A | None | -28 | 29.3 | 8.3 |
| A | A1 | -19 | 79.3 | 22.3 |
| A | A2 | 16 | 53.9 | N/A |
| B | B1 | 20 | 147 | N/A |

Source: LBNL

## 8.0 Kitchen

### Hot Water

The kitchen and prep rooms use relatively little domestic hot water since the Whole Foods store has low cooking loads. Domestic hot water for the kitchen, coffee service area, restrooms, and prep rooms is generated using a 250 kBtu/hr AO Smith gas-fired boiler (WH-1). This boiler is 96% efficient and set to 140 °F supply temperature. Boiler energy is partially offset by domestic water preheat using heat recovered off of the medium-temperature refrigeration rack with a Therm-Stor TS-II120-1 refrigerant heat recovery system.

### Equipment

Cooking, packaging, and food preparation equipment is summarized in Table C-2-7. This equipment is generally plug-in and is used as needed.

**Table C-2-7 Summary of Cooking Equipment**

| Equipment | Quantity | Rated Capacity |
|---|---|---|
| Ice machine | 2 | 624 W |
| Ice Flaker | 1 | 811 W |
| Rotisserie | 1 | 123 kBtu/hr |
| Wrapper | 3 | 750 W<br>900 W<br>780 W |
| Mini wrapper | 3 | 240 W |
| Microwave | 1 | 1600 W |
| Food processor | 2 | 1008 W<br>840 W |
| Scale | 8 | 120 W |
| Baler | 1 | 11592 W |
| Refrigerated table top | 6 | 660 W |
| Slicer | 1 | 300 W |
| Meat saw | 1 | 2200 W |
| Mixer | 1 | 9360 W |
| Sausage stuffer | 1 | 1296 W |

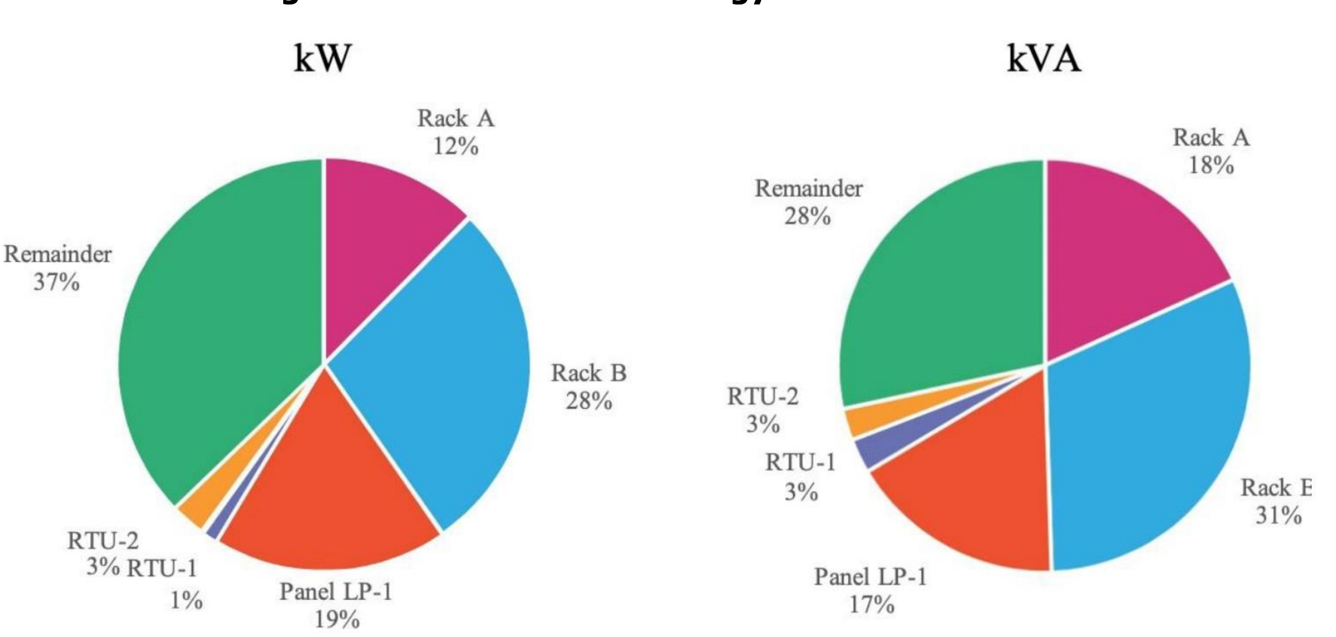
Source: LBNL

## 9.0 Energy

Energy is tracked by a Parasense on-site energy and performance monitoring system. While the Parasense system lends some insight into the division of energy by end use, a large portion of energy is not metered. Additionally, the panels that are sub-metered contain circuits with varying end uses.

In the absence of more robust sub-metered data, Figure C-2-15 illustrates the general energy end use breakdown of the Noe Valley Whole Foods Market.

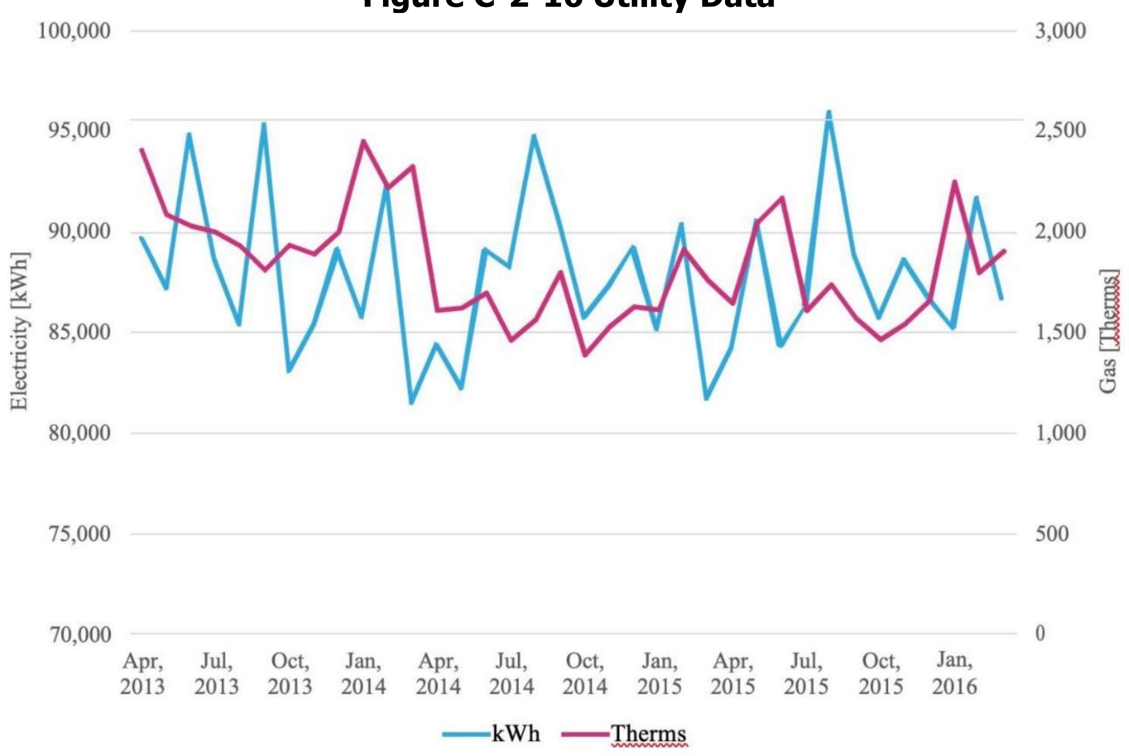
**Figure C-2-15 Parasense Energy End Use Breakdown**




Source: LBNL

Figure C-2-16 shows electric and gas data for a three year period. The electrical data shows a fairly large and constant base load as expected in a grocery store located in a mild climate, although there are peaks in the summer and valleys in the spring which may be due to HVAC use. Gas does not seem to have any major seasonal trends, indicating a large process base load. It also appears that gas use was higher on average in 2013 than 2014 or 2015, which could be the result of a retrofit or change in behavior to save energy.

**Figure C-2-16 Utility Data**



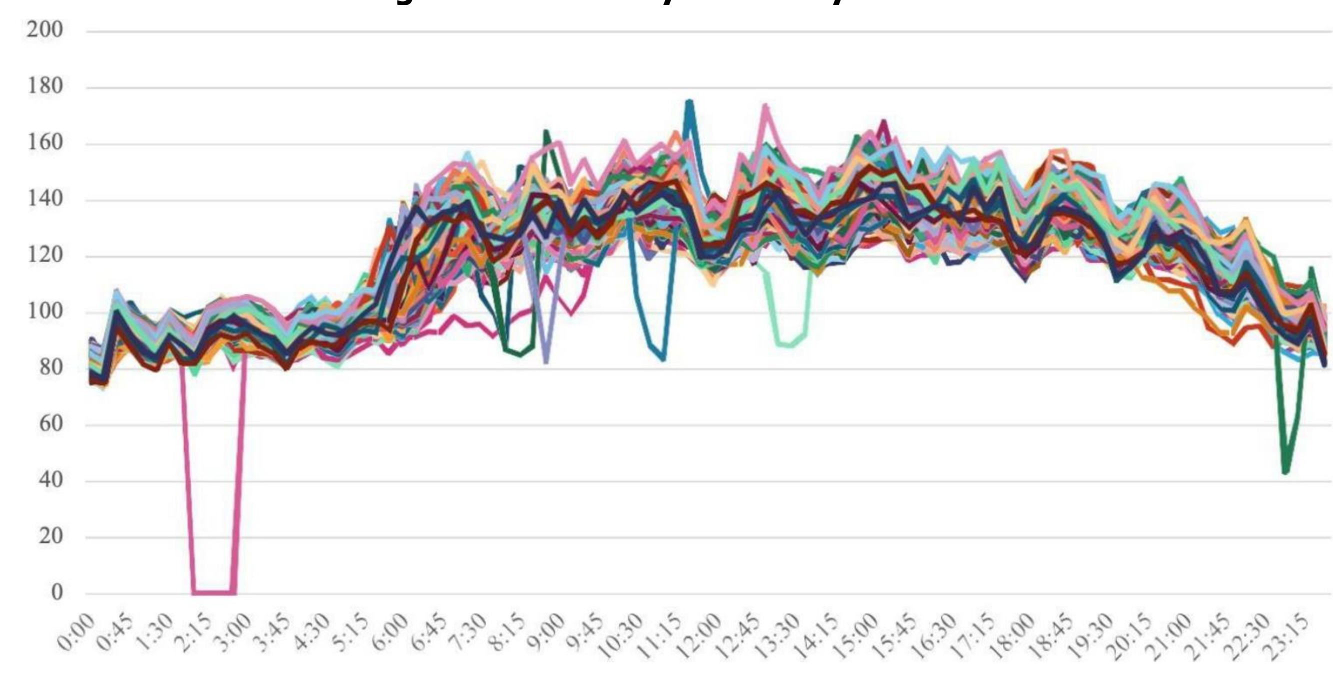

Source: LBNL

Overall, 37% of the real power (or 28% of the apparent power) is uncategorized (Remainder). The refrigeration system (Rack A and Rack B) uses nearly half of the building's power. Lighting (LP-1) is the next largest end user, accounting for nearly 20% of the power. In this data the RTU energy (RTU-1, RTU-2) seems to only be ~5% of the total. Although this is possible given the other major power draws, it is more likely that some of the RTU energy use is not captured by sub-meters and falls into the Remainder category.

Figure C-2-17 overlays multiple months of typical electrical data on top of each other to illustrate a typical daily profile. The typical daily profile provides the following insights:

- The daily profile varies little over the months, indicating minimal seasonal dependence. This trend was verified using three years of data, though only one year is shown here for clarity. This is also seen in the utility data in Figure 16.
- Major loads ramp up quickly around 6:00, remain constant from 9:00 until 18:45, and then slowly drop to reach the night time base load around midnight. This schedule should be explored further to identify base load shaving opportunities.
- Base load is massive, accounting for over 50% of the peak load. While this is expected because of high refrigeration loads, there is likely some energy waste occurring at night (e.g. lighting, equipment, loose seals). Control strategies identified during the design charrette could be used to help mitigate some of this base load.

**Figure C-2-17 Daily Electricity Profiles**




Source: LBNL

Unfortunately, gas data at this resolution is not currently available.

In summary, major energy reduction opportunities exist for the following systems:

- Refrigeration. Refrigeration uses by far the most energy and is a 24/7 load. Energy conservation opportunities include enclosing refrigeration cases and installing high-efficiency compressors.

- Lighting. Lighting is the second largest energy user according to submetered data. Fluorescent and metal halide fixtures can be upgraded to high-efficiency LEDs. Additional savings are available via daylight-integrated dimming and lighting controls.
- HVAC. Though current submetered energy indicates that HVAC uses little energy, it is likely that this energy is accounted for in the "Remainder" that is not submetered. Energy saving measures include replacing the RTUs with higher efficiency units, removing the wall units serving the back of house, and employing energy recovery.
- Electrical. Properly sized, premium efficiency transformers could reduce the entire store's energy usage by 5%. Additional savings could be realized using a DC microgrid that minimizes AC/DC conversion losses between solar PV, batteries, LED lighting, refrigeration compressors, and HVAC.
- Kitchen. Point of use water heating and reorganization of spaces into hot and cold areas could reduce hot water use. Plug-in kitchen equipment could be upgraded to premium efficiency units and better controlled.
- Façade. The façade is largely uninsulated, allowing significant thermal bridging through the roof and solar gains through the front façade. Energy improvements including adding roof insulation and reducing solar gains via window films or shading devices.

To determine further energy conservation opportunities, the base load needs to be explored further once more detailed sub meters are installed. This will allow the team to better understand which systems are contributing the most to the base load and help to calibrate the baseline energy model.

# APPENDIX D:
# Measurement and Verification Report Energy Upgrade Analysis - Model-based Performance Monitoring Performance Persistence Recommendations, Deliverables 3.3, 3.4 and 3.5

## 1.0 Summary

This report describes the results of an energy savings analysis for a grocery store retrofit. The San Francisco Noe Valley Whole Foods store was retrofitted with a range of technologies to reduce the refrigeration, lighting, and HVAC energy. The largest energy savings were obtained by the reduction in natural gas consumption. By replacing the gas space heating with an electric heat pump and swapping out the gas-fired rotisserie for an electric combi-oven, the gas usage in the store was reduced by 90 percent, which represents 68 percent of the overall total energy savings. The overall total energy savings from all the retrofits were 44 percent of the combined gas and electricity consumption thereby resulting in an energy use intensity (EUI) of 120 kBtu per square foot per year compared to an annual baseline EUI of 215 kBtu/sf.

A statistical model and a detailed building energy simulation model were developed to predict the store's energy consumption. Based on the difference between the actual store energy consumption and the predicted energy consumption, we were able to detect some potential problems with equipment or operation of the equipment that could reduce future energy savings.

## 2.0 Project Background

MarketZero is an initiative to help existing grocery stores achieve net-zero or near net- zero energy utilization, with a focus on energy efficiency. One objective of this project was to design and deploy a replicable, cost-effective, and high-impact MarketZero energy upgrade package that would yield a 40 to 60 percent reduction in energy use intensity (EUI) for a grocery store. This document provides a performance summary based on the evaluation of the measures and project from April 1, 2019, through February 15, 2020. This evaluation was based on an M&V plan that was created and submitted in November 2018, before construction began. The project team consisted of Arup, City of San Francisco Department of Environment, Prospect Silicon Valley, and Lawrence Berkeley National Laboratory (Berkeley Lab).

Berkeley Lab's involvement in the project was to analyze the store's energy performance. Arup led the selection of which measures were to be implemented. During construction and operation Berkeley Lab provided input related to energy efficiency measures beyond just measuring performance. The rooftop units (RTUs) that provided space conditioning for the sales floor required extensive input on the sequence of operation and verification of the implementation by the manufacturer.

### Site Description

The 25,187 square foot (sq. ft.) Whole Foods Market in San Francisco's Noe Valley area consists of a single story, double-height sales area with a mezzanine and second level in the back of house.

The densely populated store has limited staging area and a small 15,000 sq. ft. parking lot. The store is open to the public from 8 am to 10 pm (5,076 hours per year) but staffed by Whole Foods Team Members from 4 am to midnight, so the store is unoccupied only 1,476 hours each year.

### Report Organization

Section 3 contains the measurement and verification report, and Section 4 provides the energy upgrade analysis. Section 5 discusses the model-based performance monitoring, and Section 6 presents the performance persistence recommendations. Lessons Learned are presented in Section 7, and Section 8 offers the conclusions.

## 3.0 Measurement and Verification Report

### Background

The International Performance Measurement & Verification Protocol (IPMVP) is used to verify savings from energy projects and measures through a systematic process. The IPMVP has defined four M&V options (options A through D) that meet different needs based on the risk tolerance and M&V budget. The options are summarized in Table D-1.

**Table D-1: Overview of IPMVP options**

| IPMVP Option | How Savings Are Calculated | Typical Applications |
|---|---|---|
| A. Retrofit Isolation: Key Parameter Measurement<br><br>Savings are determined by field measurement of the key performance parameter(s) that define the energy use of the energy conservation measures (ECM's) affected system(s) and/or the project success.<br><br>Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period.<br><br>Parameters not selected for field measurement are estimated. Estimates can be based on historical data, manufacturer's specifications, or engineering judgement. Documentation of the source or justification of the estimated parameter is required. The plausible savings error arising from estimation rather than measurement is evaluated. | Engineering calculation of the baseline and reporting period energy from: Short-term or continuous measurements of key operating parameter(s); and Estimated values.<br><br>Routine and non- routine adjustments as required. | A lighting retrofit where power draw is the key performance parameter that is measured periodically. Estimated operating hours of the lights are based on facility schedules and occupant behavior. |
| B. Retrofit Isolation: All Parameter Measurement | Short-term or continuous measurements of baseline and reporting- | Application of a variable-speed drive and controls to a motor to adjust pump flow. Measure electric power with a kilowatt |
| Savings are determined by field measurement of the energy use of the ECM-affected system.<br><br>Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period. | period energy, and/or engineering computations using measurements of proxies of energy use.<br><br>Routine and non- routine adjustments as required. | (kW) meter installed on the electrical supply to the motor, which reads the power every minute. In the baseline period this meter is in place for a week to verify constant loading. The meter is in place throughout the reporting period to track variations in power use. |

| | | |
|---|---|---|
| C. Whole Facility<br><br>Savings are determined by measuring energy use at the whole facility or sub- facility level.<br><br>Continuous measurements of the entire facility's energy use are taken throughout the reporting period. | Analysis of whole facility baseline and reporting period (utility) meter data.<br><br>Routine adjustments as required, using techniques such as simple comparison or regression analysis.<br><br>Non-routine adjustments as required. | A multifaceted energy management program affecting many systems in a facility.<br><br>Measure energy use with the gas and electric utility meters for a 12-month baseline period and throughout the reporting period. |
| D. Calibrated Simulation Savings are determined through simulation of the energy use of the whole facility, or of a sub-facility.<br><br>Simulation routines are demonstrated to adequately model actual energy performance measured in the facility.<br><br>This option usually requires considerable skill in calibrated simulation. | Energy use simulation, calibrated with hourly or monthly utility billing data. (Energy end use metering may be used to help refine input data.) | A multifaceted energy management program affecting many systems in a facility but where no meter existed in the baseline period.<br><br>Energy use measurements, after installation of gas and electric meters, are used to calibrate a simulation.<br><br>Baseline energy use, determined using the calibrated simulation, is compared to a simulation of reporting period energy use. |

Source: Efficiency Valuation Organization (EVO), Core Concepts: International Performance Measurement and Verification Protocol, EVO 10000-1:2016, October 2016

## Proposed M&V Approach

The main goal of the M&V was to verify energy savings resulting from the aggregate of the ECMs that were proposed for the Whole Foods Market store. To better understand the impact of the project and underlying ECMs, a combination of M&V approaches was employed. The proposed M&V options and strategies are summarized in Table D-2.

**Table D-2: Summary of used M&V options**

| ECM | ECM Description | M&V Option | Summary of M&V Plan |
|---|---|---|---|
| Aggregate | The aggregate of all ECMs | Options C and D | Continuous baseline and post- installation kW metering; calibrated baseline model |
| Lighting | Lighting retrofit to light-emitting diodes (LEDs) (interior and exterior) | Option B | Short-term monitoring baseline; post-installation kW metering. Daylight responsive dimming of lighting requires Option B (using metered data over a longer period), instead of Option A (spot measurements). |
| Refrigeration | Refrigeration Scope of Work, Viking Cold Storage | Option B | Pre-retrofit monitoring baseline; post-installation kW metering; comparing energy consumption pre-retrofit and post-retrofit.<br>Evaluate correlation with weather or time-of-day to correct for routine events. |
| Refrigeration – Viking Cold Storage | Apply Viking Cold Storage thermal energy storage (TES) system to the walk-in freezer | Option B | Manufacturer (VKS) to measure baseline consumption and post-retrofit consumption and provide savings and raw data.<br>Corroborate these savings and approach with others. |

| ECM | ECM Description | M&V Option | Summary of M&V Plan |
|---|---|---|---|
| HVAC | RTU replacement | Option B | Pre-retrofit monitoring baseline; post-installation kW metering; comparing energy consumption pre-retrofit and post-retrofit. Evaluate correlation with weather or time-of-day to correct for routine events. Separate analysis for cooling and ventilation due to change of heating from gas to electric. |
| HVAC | SMC Motors | Option B | Pre-retrofit monitoring of fan speeds in the RTU. Short term monitoring of speed vs power characteristics for Trane and SMC motors. |

Source: LBNL

Some measures were evaluated using both the aggregate (Option C) and individual retrofit isolation-based approach (Option A or B). ECMs that were mostly equipment replacements or upgrades, where potential for energy savings is small, were not evaluated at the individual level but as a whole at the store level.

### M&V Approach

A total of 18 electricity meters were installed in the store (Table D-3). One meter, which records the total store electricity consumption, was installed in parallel with the Pacific Gas and Electric (PG&E) utility meter. Seventeen sub-meters were installed throughout the electrical system of the store, and those measure critical loads such as refrigeration components, rooftop units, and lighting. The electrical metering system was provided by Parasense. After installation of the Parasense meters a difference was detected between the PG&E whole facility electrical meter and the Parasense main meter. The PG&E readings were ~7 percent higher. Parasense was unable to perform verification measurements on the main load panel at the store and adjusted the meter calibration to match the PG&E readings. This correction was applied retroactively to the historic data. In February 2020 Berkeley Lab conducted another comparison between the PG&E data and the adjusted Parasense measurements and observed a 0.57 percent difference between the meters, with the Parasense meter reading higher. It is encouraging to see that the calibration did not change over time.

**Table D-3: List of energy meters installed in the store**

| Num. | Circuit Name | Load Description |
|---|---|---|
| 1 | Main feed | Main store power (existed pre-retrofit) |
| 2 | Rack A | Refrigeration rack A (existed pre-retrofit) |
| 3 | Rack B | Refrigeration rack B (existed pre-retrofit) |
| 4 | Panel LP-1 | Main sales floor lighting (existed pre-retrofit) |
| 5 | Panel RL | Refrigeration cases |
| 6 | Panel RH | Refrigeration cases |
| 7 | Panel RF-1&2 | Refrigeration cases |
| 8 | Panel RC | Refrigeration cases and controls |
| 9 | AHU-1 | Trane RTU 1 |
| 10 | AHU-2 | Trane RTU 2 |
| 11 | DXC-1 | Outdoor unit for variable refrigerant flow (VRF) system (offices and mezzanine) |
| 12 | Condenser | Refrigeration condenser |
| 13 | Panel DP | Various plug loads (upstream from transformer T1) |
| 14 | Panel CP-1&2, RC | Office and Register plug loads (upstream of transformer T3) |
| 15 | Panel MP | Used to sum-check the main switchboard |
| 16 | Panel PK-1 and PK-2 | Prepared foods area |
| 17 | Combi-ovens | In panel PK-1, combined load of two new 3-phase circuits (not implemented correctly) |
| 18 | Hot food and food bar | In panel Pk-2, circuits 18, 20, 22, 24, and 26 may be combined into one reading. |

Source: LBNL

## Whole Store

The whole store energy savings were calculated using Option C:

- Avoided energy use = Baseline energy ± routine adjustments to reporting period conditions ± non-routine adjustments to reporting period conditions - Reporting period energy

The process involved the following steps:

1. Collect 12 months of baseline hourly electricity data along with the corresponding weather data. This baseline period was set to be 2018, to characterize the pre- retrofit energy consumption.
2. Develop a model that correlates the electricity consumption with independent variables like outdoor air temperature, along with the time of week. Berkeley Lab's TOWT (Time of week and Temperature) was used to develop this model. Berkeley Lab's TOWT modeling algorithm accurately predicts building energy use for non-residential building

types and includes flexibility for improving model fit. Originally developed in 2011,[28] Berkeley Lab modified it in a recently released version.[29]

3. Assess goodness of fit for the model: After a linear regression model has been developed, the fitness of the model should be reviewed. This review needs to encompass a broader evaluation of statistical indicators than a mere criterion check of goodness-of-fit statistics. These following indicators could be used to assess the goodness of fit for the model:
   - Coefficient of Determination, $R_2$: This coefficient measures the extent to which variations in the dependent variable *y* can be explained by the regression model. The possible range for $R_2$ is between 0 and 1, with a value of 0 indicating that none of the variation can be explained by the model, therefore the model provides no guidance in understanding the variations in *y* using the selected independent variables. On the other hand, an $R_2$ of 1 means that the model explains 100 percent of the variations in y. Typically this value falls somewhere in between for most models, but generally the greater the coefficient of determination, the better the model describes the relationship of the independent variables and the dependent variable. Though there is no universal standard for a minimum acceptable $R_2$ value, as it is highly dependent on the context and use case and application, but the following documents offer some guidelines for this metric:
     - IPMVP: R2 > 75%
     - ASHRAE Guideline 14-2014:[30] R2 > 80%
     - Basic Statistics:[31] R2 > 70%
   - Coefficient of variation of the root mean square error ($CV_{RMSE}$): root mean squared error (RMSE) or standard error of the estimate (SE) is an indicator of the scatter, or random variability, in the data, and hence is an average of how much an actual *y*-value differs from the predicted *y*-value. It is the standard deviation of errors of prediction about the regression line. CV(RMSE) is the RMSE normalized by the average *y*-value. Normalizing the RMSE makes this a non-dimensional quantity that describes how well the model fits the data. It is not affected by the degree of dependence between the independent and dependent variables, making it more informative than $R_2$ for situations where the dependence is relatively low.
   - Net Determination Bias Error (NTBE): This is the percentage error in the energy use predicted by the model compared to the actual energy use. The sum of the

28 Mathieu, J. L., P. N. Price, S. Silicate, and M. A. Piette. 2011. "Quantifying changes in building electricity use, with application to demand response." *IEEE Transactions on Smart Grid* 2(3), pp. 507– 518.

29 28 LBNL GitHub RMV2.0, https://github.com/LBNL-ETA/RMV2.0

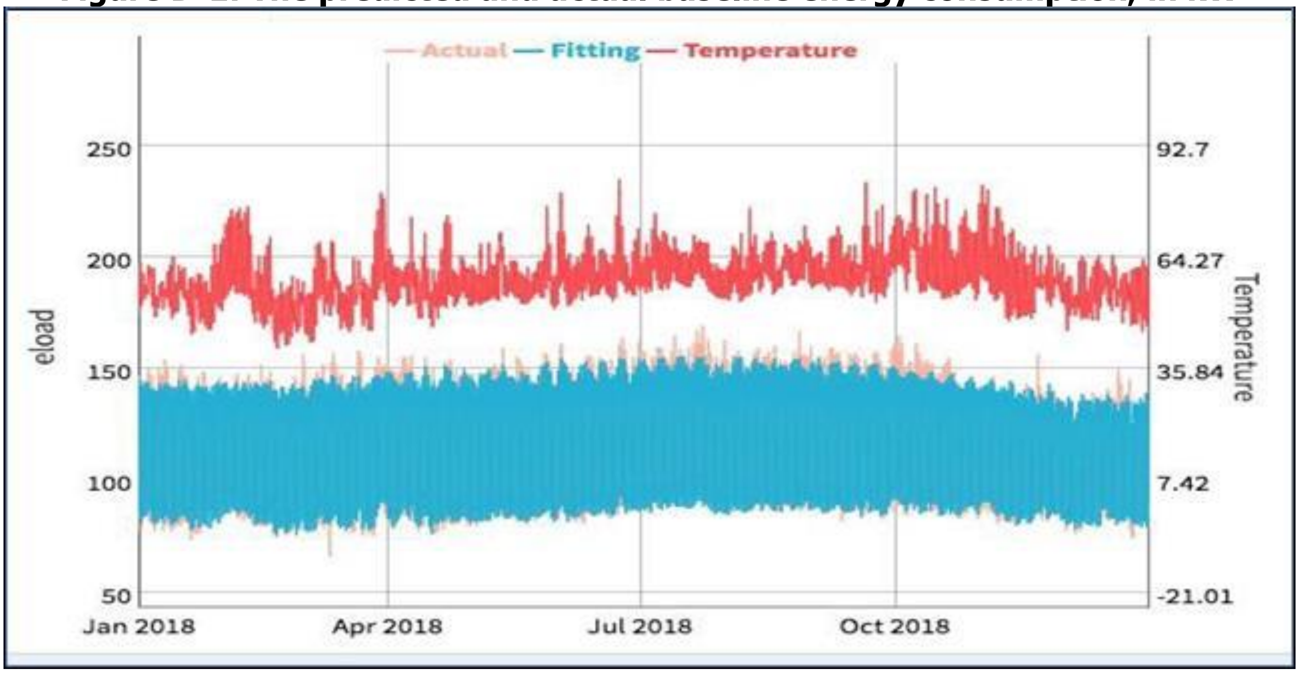
30 ASHRAE Guideline 14 (2014). ASHRAE Guideline 14-2014 for Measurement of Energy and Demand Savings, American Society of Heating, Refrigeration and Air Conditioning Engineers. Atlanta, Georgia.

31 J. Kiemele, S.R. Schmidt, and R.J. Berdine. (1997). "Basic statistics: Tools for continuous improvement." Fourth Edition, Air Academy Press.

differences between actual and predicted energy use should be zero. If NTBE is zero, that indicates there is no bias in the model. ASHRAE Guideline 14 accepts an energy model if the net determination bias error is less than 0.5 percent. Often, bias may be minor, but it still will affect savings estimates. If the savings are large relative to the bias, bias may not be important, but in many cases, bias could be influential

Figure D-1 shows the energy consumption predicted by the model (in blue, denoted as "Fitting"), along with actual consumption that was used to develop the model and the independent variable outside air temperature.

**Figure D-1: The predicted and actual baseline energy consumption, in kW**




Source: LBNL

Table D-4 summarizes the goodness of fit using different statistics that are recommended by IPMVP and other M&V guidelines.

**Table D-4: Summary of goodness of fit for the baseline model**

| Statistic | Criteria | Value |
|---|---|---|
| Coefficient of Determination ($R^2$) | IPMVP:[26] $R^2 > 75\%$ | 94.21% |
| Coefficient of variation of the root mean squared error CV(RMSE) | ASHRAE G14[29] < 25% | 4.21 % |
| Net determination bias (NTB) | < 0.5% | -0.04% |

Source: LBNL

1. Collect hourly electricity data along with the corresponding weather data for the post-retrofit period. The period from April 1, 2019 through March 31, 2020 was treated as the post-retrofit period.

2. Using the model developed from Step 2, estimate the post-retrofit energy consumption in the absence of the proposed retrofit, which is defined as adjusted baseline energy use. This energy consumption for this period was estimated using the corresponding outside air temperature and time of week.

Compare the estimated post-retrofit energy consumption from Step 4 above with the adjusted baseline energy use from Step 5 to arrive at the savings for the proposed set of retrofits that occurred in the store (Figure D-2).
Source: LBNL

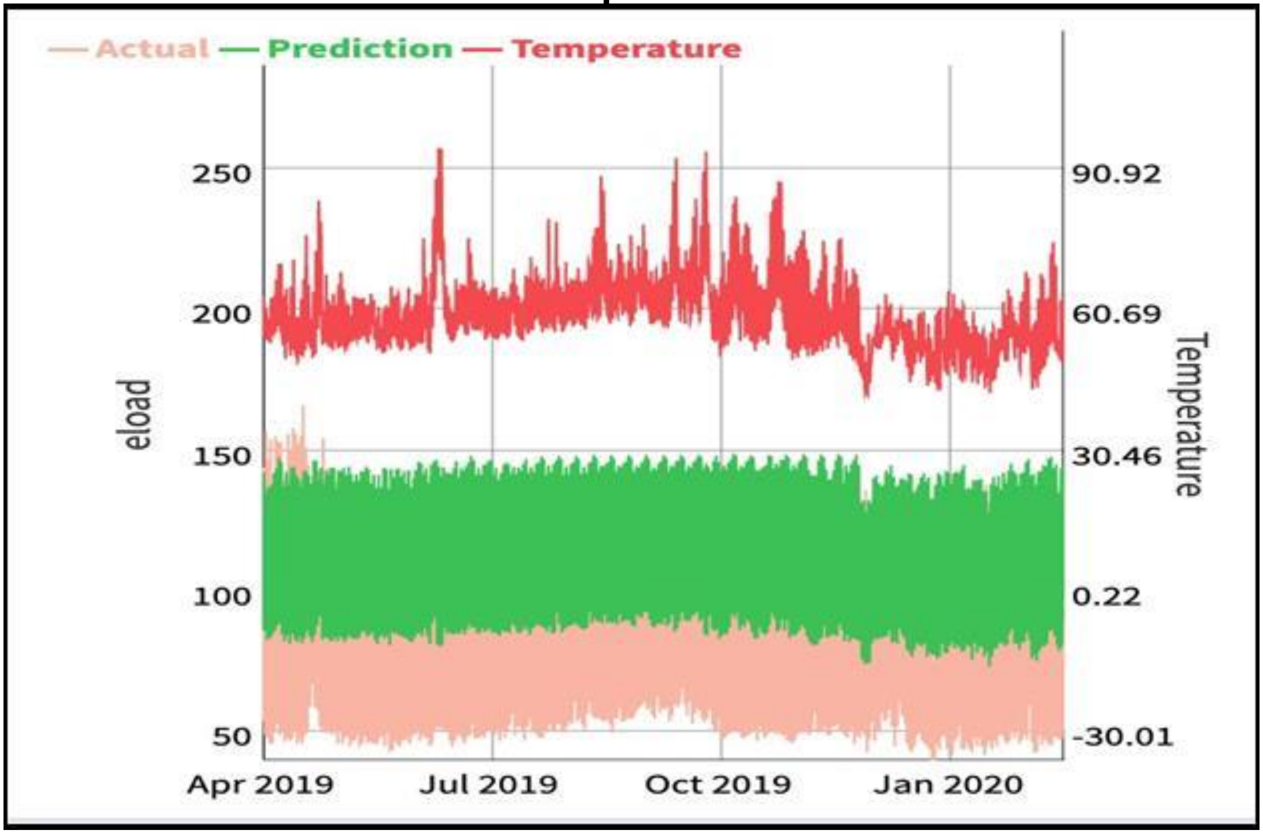
3. Figure D-3 shows the plot comparing the raw natural gas consumption between the baseline and post-retrofit phases of the project. Table D-5 summarizes the verified savings for the evaluation period, along with the proposed savings for the project. The proposed savings were based on simulation analysis performed by Arup during the selection of the ECM's.

**Table D-5: Verified savings for the performance year using the Option C whole facility level analysis**

| | Total Energy Use (Megajoules) | Total Energy Use (MMBtu) | Electric Energy Use (kWh) | Natural Gas (Therms)* |
|---|---|---|---|---|
| Baseline Use | 5,014,082 | 4,752 | 927,434 | 15,871 |
| Performance Year # Use (04/01/19-02/15/20) | 2,803,949 | 2,658 | 731,281 | 1,618 |
| Savings | 2,210,133 | 2,095 | 196,153 | 14,253 |
| % Savings/Baseline | 44.1% | 44.1% | 21% | 89.8% |
| Annualized Savings | 2,513,080 | 2,382 | 223,040 | 16,207 |
| Proposed Annual Savings | 2,438,013 | 2,311 | 351,374 | 11,119 |

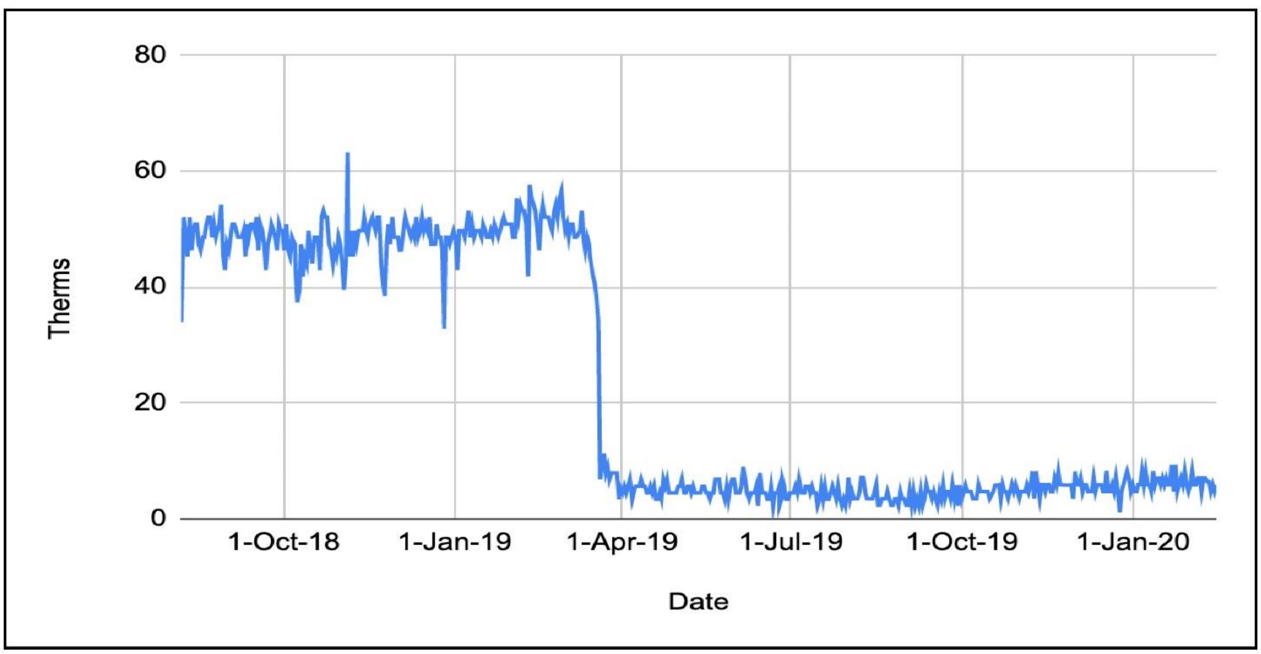
Source: LBNL

**Figure D-2: Plot comparing predicted baseline electricity with post-retrofit energy consumption in kW**




Source: LBNL

**Figure D-3: Plot showing pre and post-retrofit natural gas consumption (unadjusted) in Therms**




Source: LBNL

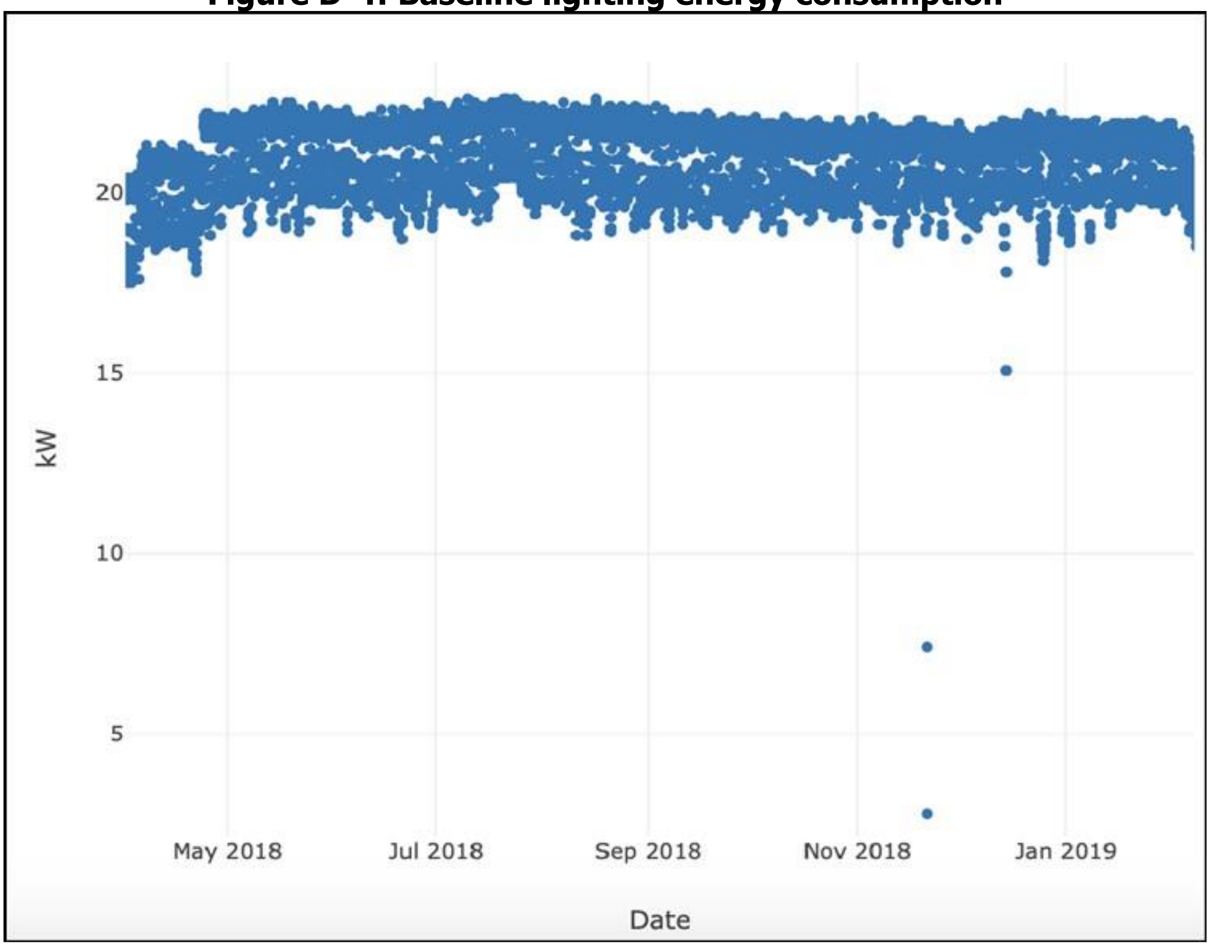
## Lighting

IPMVP option B methodology was used for the lighting analysis. Prior to the retrofit, the store was illuminated mostly by T8 fluorescent lights, with some metal halide lamps.

After the retrofit, all lighting was LED based, with occupancy sensors, and daylight dimming near the windows at the front of the store. The designed lighting load was 0.49 (W)/sq. ft. A few fixtures were added during construction, which increased the lighting load to slightly over 0.50 W/sq. ft.

1. The main lighting electrical panel (LP-1) is monitored by the data collection system (Parasense), and these data are assessed to compute the baseline energy consumption for lighting as a whole. A few lighting circuits (Second Floor Lighting, Mezzanine Lighting, and Parking Lot Lighting) were not powered by the main lighting panel before the retrofit and were not included in the baseline measurements. It is unclear how large these loads were, but it is safe to say that the actual lighting energy savings are somewhat larger because these loads were not connected to this panel during the baseline period. The plot (Figure D-4) shows the baseline energy consumption data for lighting for the period between April 1, 2018 through January 31, 2019.

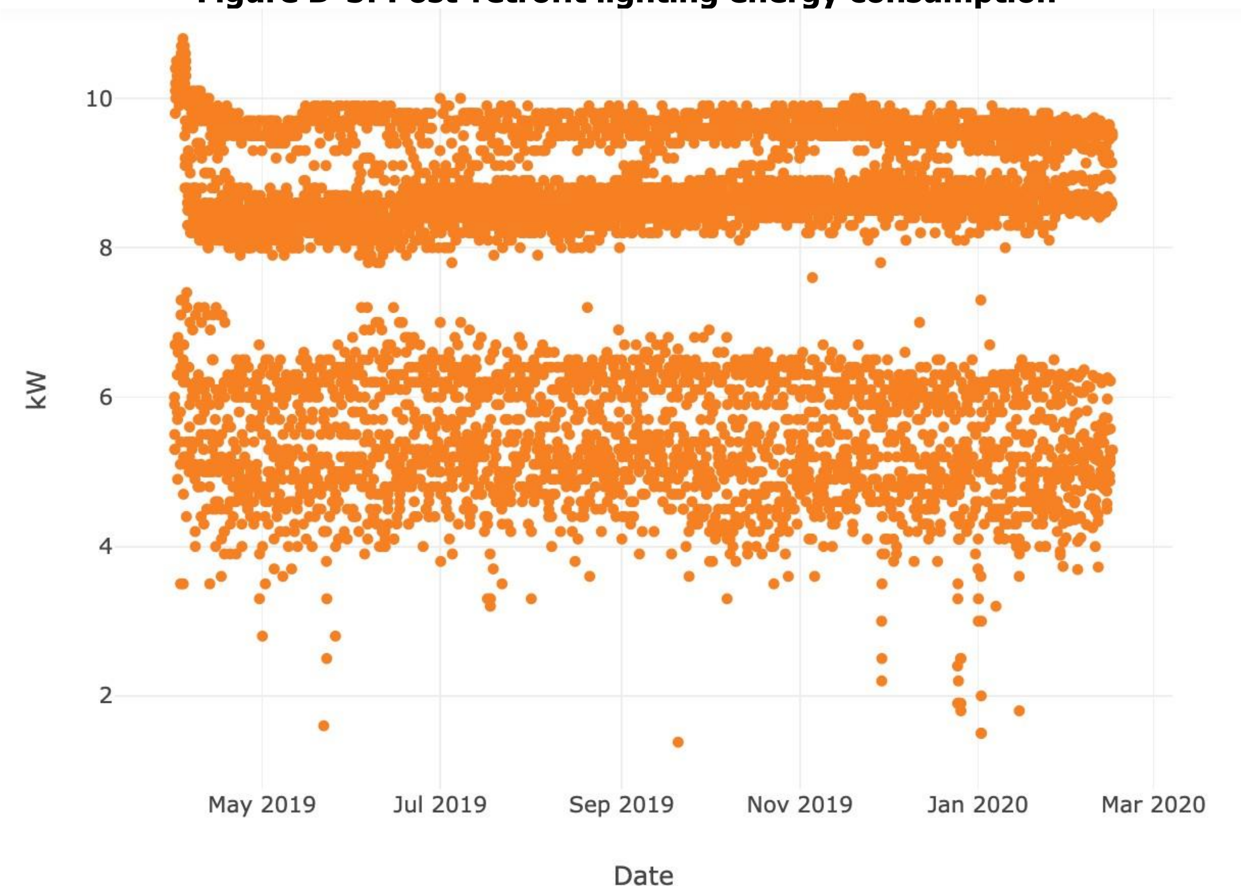
**Figure D-4: Baseline lighting energy consumption**




Source: LBNL

2. The period from April 1, 2019 through March 31, 2020 is considered to be post-retrofit phase, and the lighting energy consumption for this period was analyzed to assess the effectiveness of the retrofit, by comparing it with the baseline energy consumption. The plot (Figure D-5) shows the post-retrofit energy consumption data from April 1, 2019. There are a few bands of operation here, One band around 8 to 10 kW which occurs during the hours that the store is open, and another band between 4- and 6-kW during nighttime when the occupancy sensors turn on the lights as personnel is re-stocking the store. In the baseline case the lighting load was always around 20 kW, with very little reduction during the night.

**Figure D-5: Post-retrofit lighting energy consumption**




Source: LBNL

3. Table D-6 summarizes the annual energy savings based on a raw comparison of energy consumption from the baseline and post-retrofit phases, as shown in steps 1 and 2 above, without any adjustments.

**Table D-6: Verified Savings for Performance Year using Option B for lighting system**

| | Total Energy Use (Megajoules) | Total Energy Use (MMBtu) | Electric Energy Use (kWh) | Natural Gas (Therms)* |
|---|---|---|---|---|
| Baseline Use | 584,218 | 554 | 162,242 | |
| Performance Year # Use (04/01/19-02/15/20) | 212,633 | 202 | 59,050 | |
| Savings | 371,585 | 352 | 103,192 | |
| % Savings/Baseline | 64% | 64% | 64% | |
| Annualized Savings | 422,519 | 400 | 117,337 | |
| Proposed Annual Savings | 457,480 | 434 | 127,046 | (404) |

Source: LBNL

## Refrigeration

M&V option B was used to compare the energy consumption of the refrigeration system during the baseline pre-retrofit period with the post-retrofit period.

1. The refrigeration load includes the load from compressor racks A and B (meters 2 and 3), the condenser (meter 12), and various other panels that include case lighting, heaters, and controls (meters 5, 6, 7, and 8). Only data from meters 2 (Rack A), 3 (Rack B), and 12 (the condenser) were analyzed to verify the savings for this measure. This baseline phase is the period from January 1, 2018, through December 31, 2018, (shown in pink and denoted as "Actual" in Figure 6, Rack A, shown on the left). Due to limited data availability, the condenser baseline was evaluated from December 14, 2018, through December 31, 2018.
2. These data were used to develop a baseline model to predict the energy consumption of Rack A and Rack B as a function of outside air temperature and time of week in the absence of measures (shown in blue and denoted as "Fitting" in Figure D-6a and Figure D-6). Table D-7 provides the summary of the goodness of the fit for the baseline model for racks A and B.

**Table D-7: Summary of the goodness of the fit for the baseline model for Rack A and Rack B**

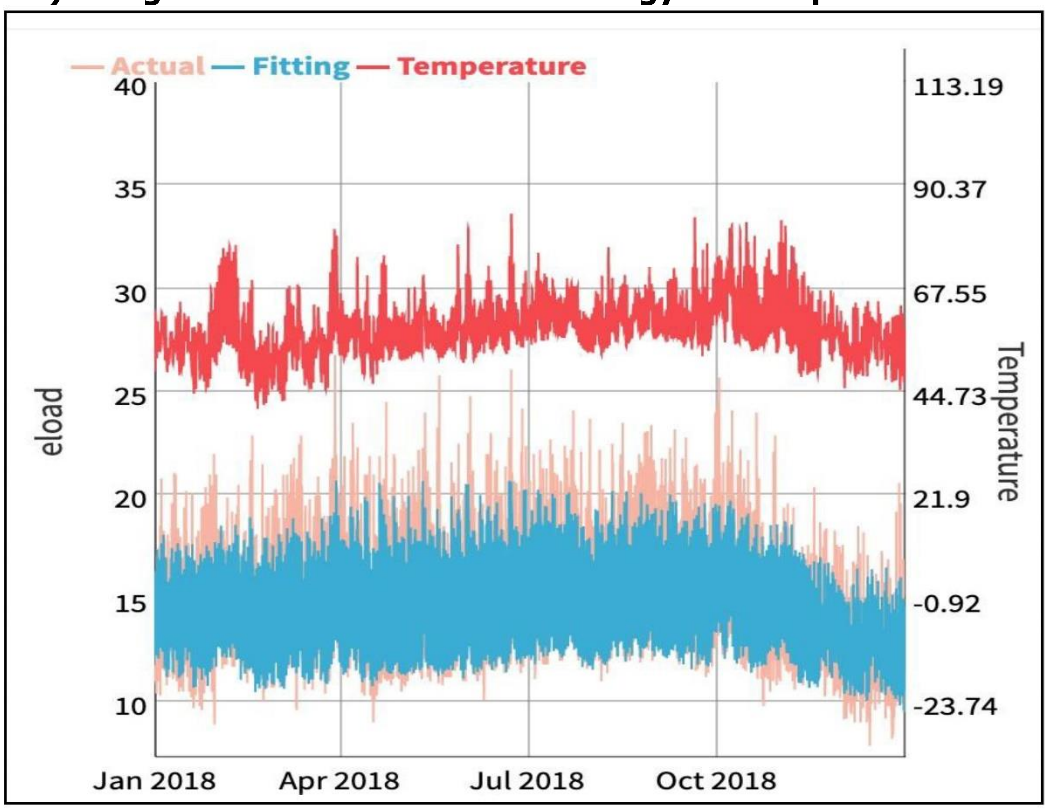
| Statistic | Criteria | Rack A (%) | Rack B (%) |
|---|---|---|---|
| Coefficient of Determination ($R^2$) | IPMVP:[26] $R^2 > 75\%$ | 66 % | 88 % |
| Coefficient of variation of the root mean squared error CV(RMSE) | ASHRAE G14[29]<br>< 25% | 10.03 % | 7.91 % |
| Net determination bias (NTB) | < 0.5% | -0.08 % | -0.06 % |

Source: LBNL

The actual post-retrofit performance was measured against the computed baseline energy from Step 2 to assess the performance of the measure. Source: LBNL

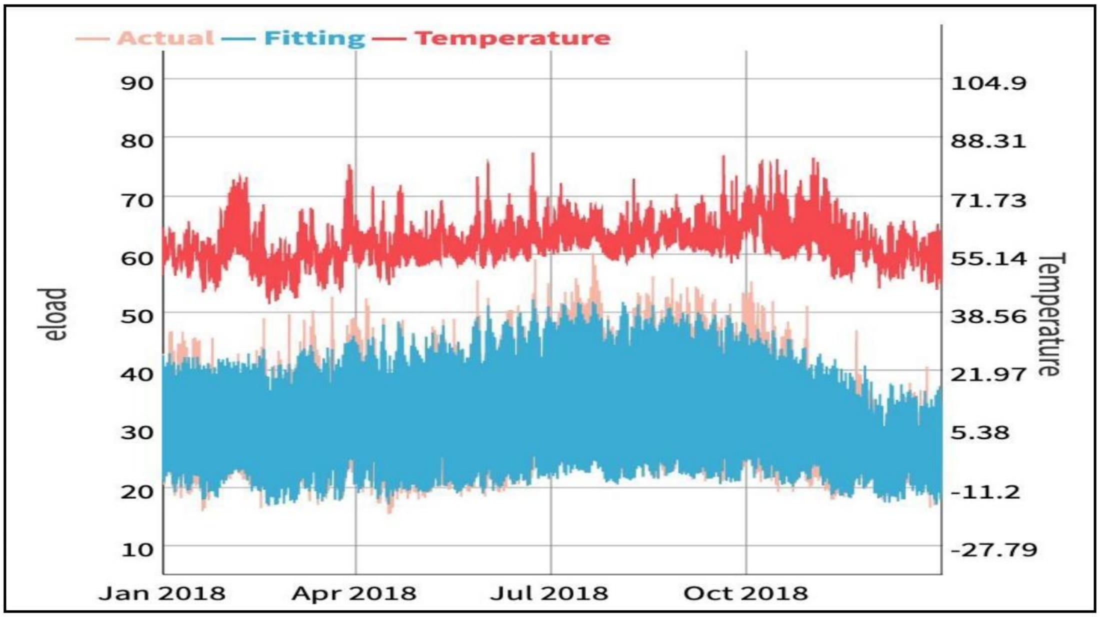
1. Figure D-7a and Figure D-7b show the predicted baseline energy computed from the model (shown in green and denoted as "Prediction") and the post-retrofit actual energy consumption (shown in pink and denoted as "Actual) for the period starting from April 1, 2019.

**Figure D-6a: Plot showing predicted baseline energy consumption (fitted shown in blue) along with the baseline actual energy consumption for Rack A**



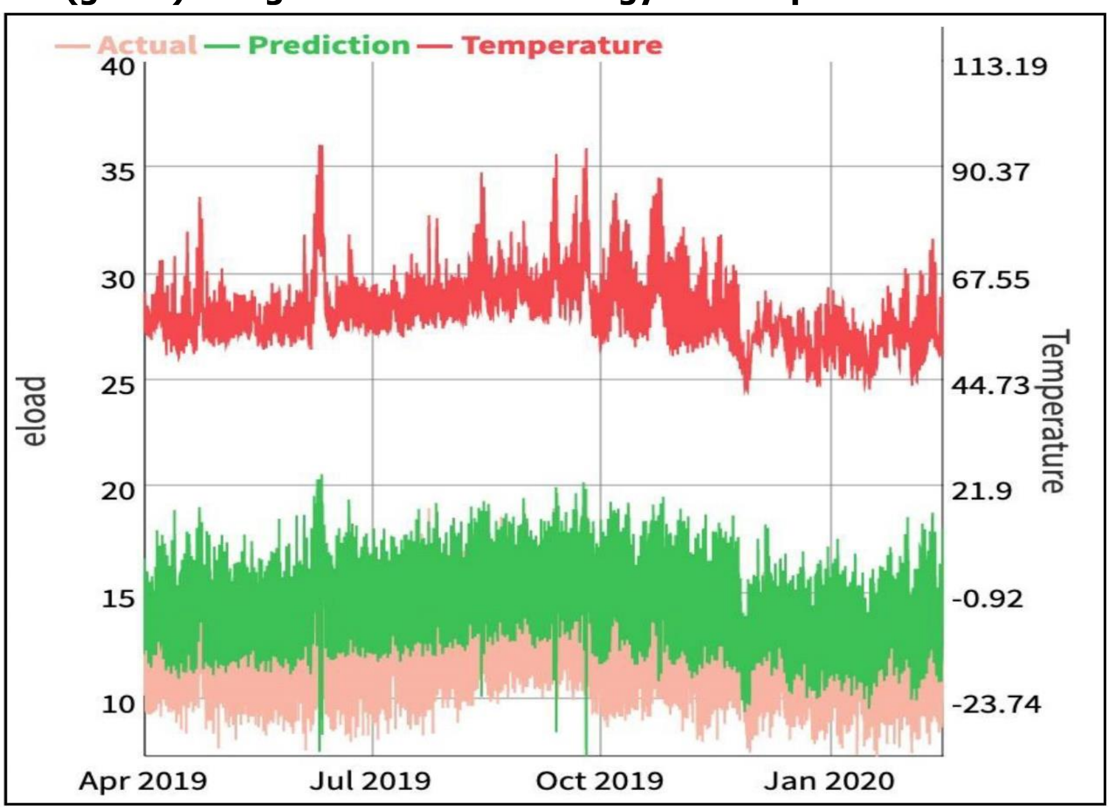

Source: LBNL

**Figure D-6b: Plot showing predicted baseline energy consumption (fitted shown in blue) along with the baseline actual energy consumption for Rack B**



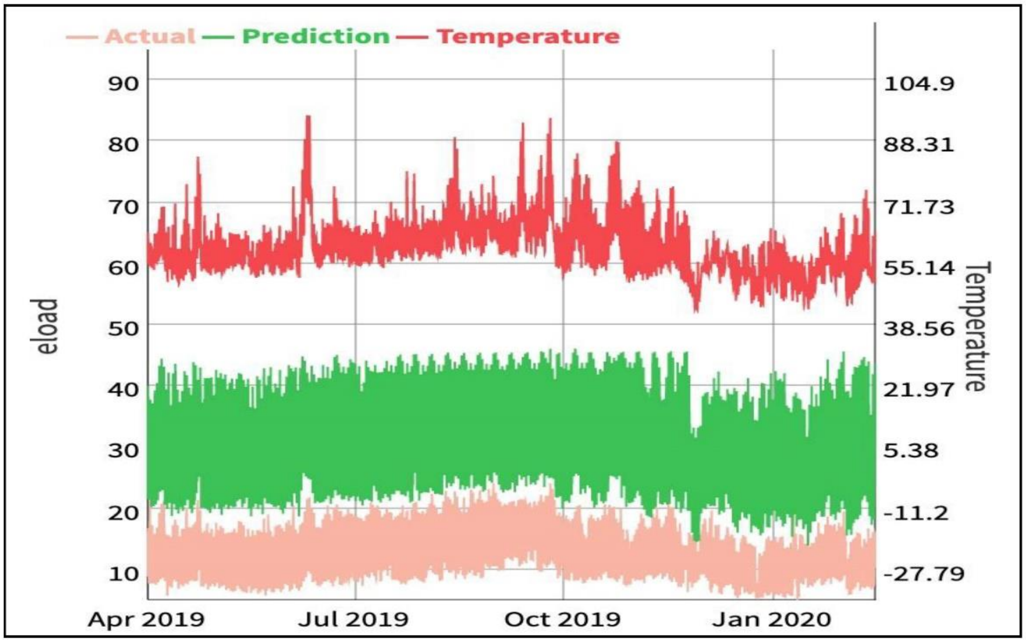

Source: LBNL

**Figure D-7a: Plot showing post-retrofit predicted baseline energy consumption (green) along with the actual energy consumption for Rack A**




Source: LBNL

**Figure D-7b: Plot showing post-retrofit predicted baseline energy consumption (green) along with the actual energy consumption for Rack B**




Source: LBNL

2. The difference in consumption is the "energy savings" from the refrigeration related ECMs for the post-retrofit period. This is calculated to be 174,175 kWh for Rack A, Rack B, and the condenser together (Table D-8). No model was developed for the condenser because of lack of measured energy consumption for the condenser during the baseline period, and therefore raw comparison of energy data for the same time period in December was used to evaluate the condenser performance.

**Table D-8: Verified Savings for the Performance Year Using Option B for the refrigeration system (Rack A, Rack B, and the Condenser)**

| | Total Energy Use (Megajoules) | Total Energy Use (MMBtu) | Electric Energy Use (kWh) |
|---|---|---|---|
| Baseline Use | 1,318,005 | 1,249 | 366,020 |
| Performance Year # Use (04/01/19-02/15/20) | 766,423 | 726 | 212,842 |
| Savings | 551,582 | 523 | 153,179 |
| % Savings/Baseline | 42% | 42% | 41.8% |
| Annualized Savings | | | 174,175 |
| Proposed Annual Savings | 857,927 | 813 | 238,253 |

Source: LBNL

## The Viking Cold Storage System

The Viking Cold Solutions thermal energy storage (TES) system is a dynamically controlled system designed to store cooling capacity for future use. The TES system is comprised of phase change material (PCM) encapsulated in polyethylene "cells" and temperature sensors installed in the freezer. The non-circulatory cells are fixed to the interior of the freezer ceiling, and the sensors are installed along the interior wall and near the evaporators inside the freezer. Externally from the freezer, control panels and power metering equipment were installed in the refrigeration equipment room and near relevant equipment.

The PCM absorb heat and maintain freezer temperatures during periods when it is advantageous to turn off or reduce refrigeration. Communicating through existing controls, the Viking Cold Solutions system will also determine the most opportune time to defrost and run evaporator fans independently of refrigeration, with the overriding energy reduction strategy in mind.

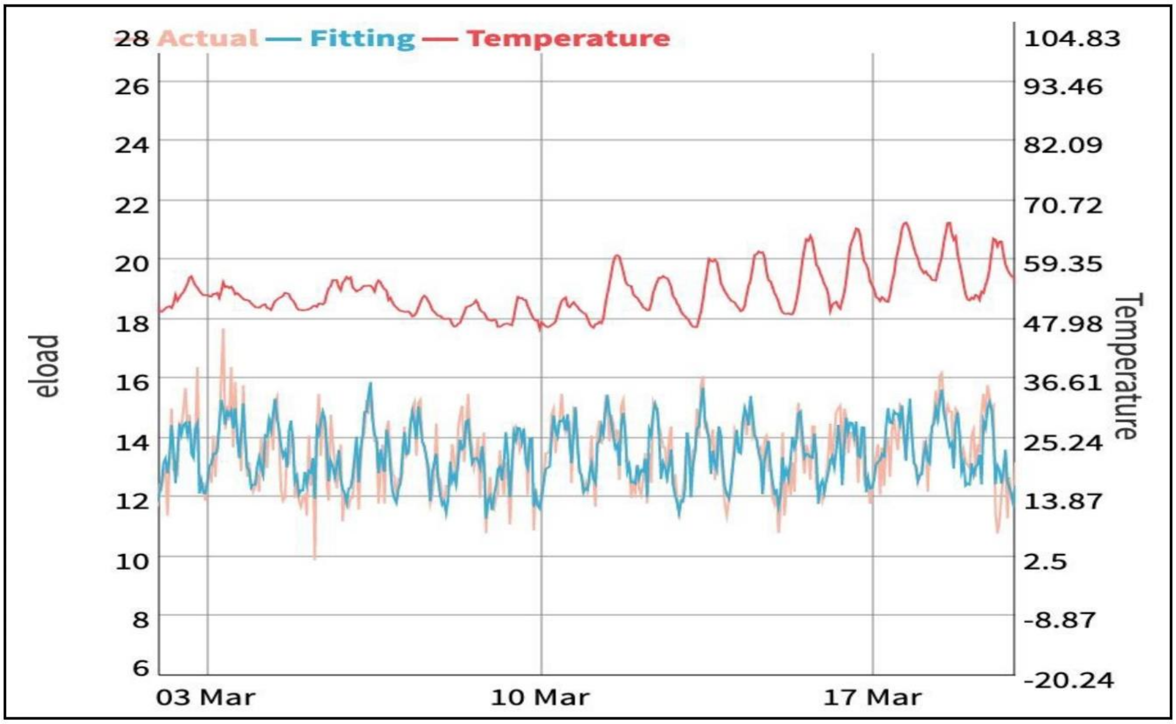
The Viking Cold TES system was installed on March 20, 2019, in the walk-in grocery freezer at the Whole Foods store. This installation included PCMs mounted on the ceiling of the walk-in freezer, as well as strip curtains behind the door, which help contain the cold air when the door is opened. Based on estimates from Viking Cold, these strip curtains save around 2.3 kilowatt-hours (kWh)/day for this store.

TES improves the efficiency of existing refrigeration systems by increasing the percentage of the total refrigeration run time that occurs during hours with lower ambient temperatures, thereby running the compressors at higher efficiency levels.

The VKS controller interfaces with the existing Micro Thermo control system that is used to control the existing refrigeration system. The M&V strategy for this measure, which employs IPMVP Option B, involves the following steps:

1. This walk-in freezer is being served by the low temperature refrigeration rack (rack A). This rack has six compressors that are providing refrigerant for the walk-in freezer, the bakery freezer, and all the low-temperature freezer cases in the store. One of the compressors is configured as a satellite compressor for the walk-in freezer but can also provide refrigerant to the other loads via a load transfer valve. Viking Cold installed a WattNode energy monitor on this compressor, which is the only way to approximate the energy consumption associated with the walk-in freezer. This WattNode energy monitor was installed on March 2, 2019, and provided baseline energy consumption (in pink, and denoted by "Actual" in Figure D-8) from March 2 to March 19, 2019. This period is assumed to be devoid of any mechanical or other problems outside of VKS control causing abnormal freezer operation.

**Figure D-8: Time series and scatter plots for refrigeration system that effected Viking cold**




Source: LBNL

1. These data were used to develop a baseline model that was used to predict the energy consumption of low-temperature (LT) compressors and its peripheral equipment as a function of outside air temperature and time of week in the absence of VKS (shown in blue and denoted as "Fitting" in Figure D-8). Table D-9 summarizes the goodness of the fit for the baseline model for this measure.

**Table D-9: Summary of the goodness of the fit for the baseline model for refrigeration system that effected Viking cold**

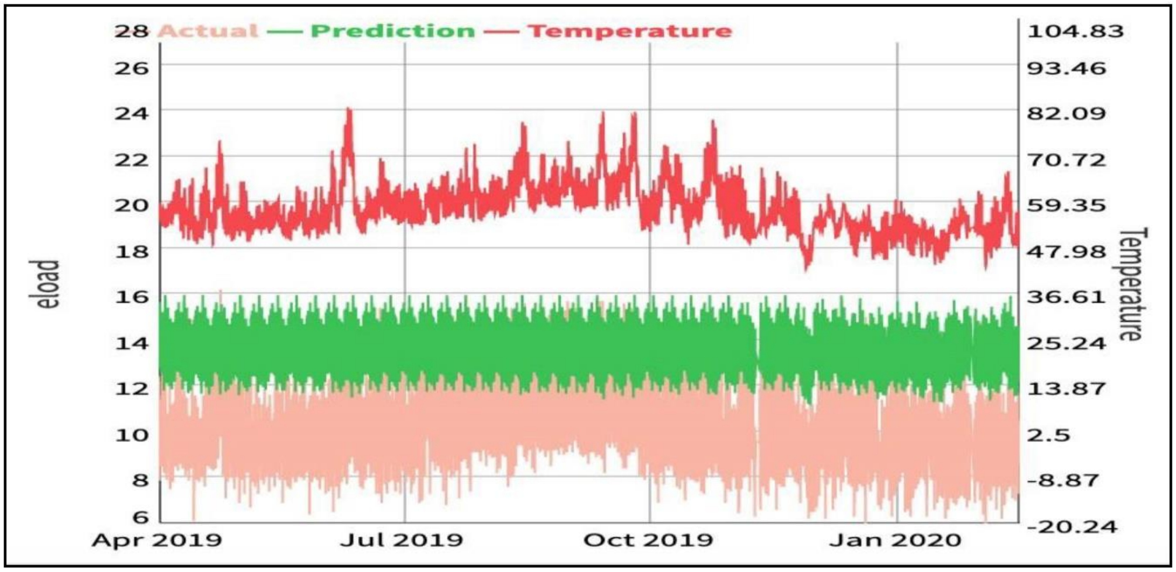
| Statistic | Criteria | Value |
|---|---|---|
| Coefficient of Determination (R2) | IPMVP: R2 > 75% | 68 % |
| Coefficient of variation of the root mean squared error CV(RMSE) | ASHRAE G1429<25% | 5.07 % |
| Net determination bias (NTB) | < 0.5% | 0 % |

Source: LBNL

2. After the Viking Cold TES system (VKS) was installed and controlling the equipment based on VKS logic, the post-retrofit energy performance was analyzed. This performance was measured against the computed baseline energy from Step 2, above, and compared with the reported post-retrofit energy consumption. Figure D-9 shows the computed predicted baseline energy from the model (shown in green

and denoted as "Prediction") and the post-retrofit actual energy consumption (shown in pink and denoted as "Actual) for the 12-month period starting from April 1, 2019.

**Figure D-9: Plot comparing the predicted baseline energy with post-retrofit energy consumption for Viking Cold System**




Source: LBNL

The difference in consumption is the "energy savings" from the VKS system for the 10.5-month period. This was calculated to be 25,888 kWh, a 25 percent savings compared to the baseline electricity.

3. The energy savings calculated by the Berkeley Lab model were extrapolated to a full year, showing 29,436 kWh of savings.

## Rotisserie and Combi-Oven

The store had a gas-fired rotisserie to prepare roasted chicken, and that rotisserie had a small electric motor with a rated nameplate capacity of 640 W. It is unknown exactly how many hours the rotisserie operated each day but based on store observations of the kitchen operations it was estimated that its daily energy consumption was 9.3 kWh/day.

On March 20, 2019, the gas-fired rotisserie was replaced by two electrical combi-ovens, with no gas connection. The plan was to have these combi-ovens monitored by a dedicated electrical sub-meter, but due to an installation error, the combi-ovens were not sub-metered directly. However, the electrical panel that the combi-ovens are connected to has a sub-meter. Based on the date of installation we were able to estimate the consumption of the combi-ovens at 39.6 kWh/day. Since the rotisserie was replaced, 9.3 kWh/day of energy consumption was eliminated, which resulted in a net load increase of 30.3 kWh/day. The annual impact of this is an increase in electrical consumption pf 11,051 kWh/year. It is unknown how large the gas savings were from this change of gas-fired to electric chicken roasting.

## Space Conditioning

Space conditioning, also known as heating, ventilation and air-conditioning (HVAC) for the sales floor is performed by two roof top units (RTUs). Before the retrofit the units provided heating using a gas-pack, which is a natural gas powered furnace. Cooling was performed by a compressor. The two RTU's were replaced with two new Trane Horizon Air Source Heat Pump units. These units use compressors for both heating and cooling, and do not use any gas. There are electric resistance heaters mounted in the units as a backup heating source in case the compressors fail, or the compressor capacity is insufficient. The electrical breakers in the unit are not sized to allow both the compressors and the electric resistance heat to run at the same time. The RTUs were installed on March 20, 2019. During commissioning it was observed that the compressors were not running while the unit was in heating mode. Further investigation revealed that the units were accidentally programmed to use electric resistance heating only to provide heating and bypassing the heat pump. This issue was identified on April 5, 2019 and fixed on May 1, 2019 Figure 3-10 below shows the electric power consumption of RTU-1. It shows peak power consumption around 30 kW in the period before May 2, and less than 10 kW after that. Similar trends were observed for RTU2.

The estimate is that this period of electric resistance heating decreased the overall energy savings for this project by about 1,734 kWh.

We used IPMVP option B and C options to evaluate the system's and project's performance through analyzing whole facility and refrigeration energy consumption data respectively. The baseline models for these options were developed based on the outdoor temperature and the time of week. When we developed this type of baseline model for the RTUs we could only use the sub-metered electricity data for the RTU, but no gas data. The amount of cooling in the store was very limited because of the open display cases and because the heating was done with gas during the baseline period. We were not able to get a statistically robust model for the baseline period. An additional problem was that that this model could not be used to analyze the post retrofit heating because of lack of electrical heating during the baseline. We therefore decided to create a model for the post retrofit situation using data from May 2, 2019 – December 31, 2019. May 2, 2019 was chosen to avoid the period with electric resistance heating problems in April 2019 described above as shown in Source: LBNL

Figure D-10.

To determine how sensitive this HVAC post retrofit model is to the difference in weather between 2018 and 2019 we used this model to predict the electricity consumption for February 15, 2018 through February 14, 2019 and February 15, 2019 through February 14, 2020. The difference in predicted energy consumption due to the weather for these two years was less than 2 percent. We therefore decided to use the directly measured HVAC electrical consumption from the Parasense system for the baseline and post retrofit period without any adjustments for weather using a statistical model.

Because the RTUs switched the heating fuel from gas to electricity, the annual electricity consumption for the two RTU's increased from a combined use of 11,756 kWh to 63,704 kWh as shown in Table D-10. There was an overall facility decrease in gas use of 90%, but because there was not sub-metering for natural gas, it is unclear how large the gas savings for the RTUs were. In order to look at the energy consumption for cooling and ventilation (but not heating) for the new RTUs, we estimated the energy consumption during heat pump operation and subtracted this from the overall consumption. This resulted in an annual cooling and ventilation consumption of 9,925 kWh annual for the post retrofit period, compared to 9,585 kWh annual in the baseline period. This 0.7 percent increase in cooling and ventilation energy use was due to an increased cooling load in the store in combination with a more efficient HVAC unit. We estimated the electricity consumption for heating during the baseline period at

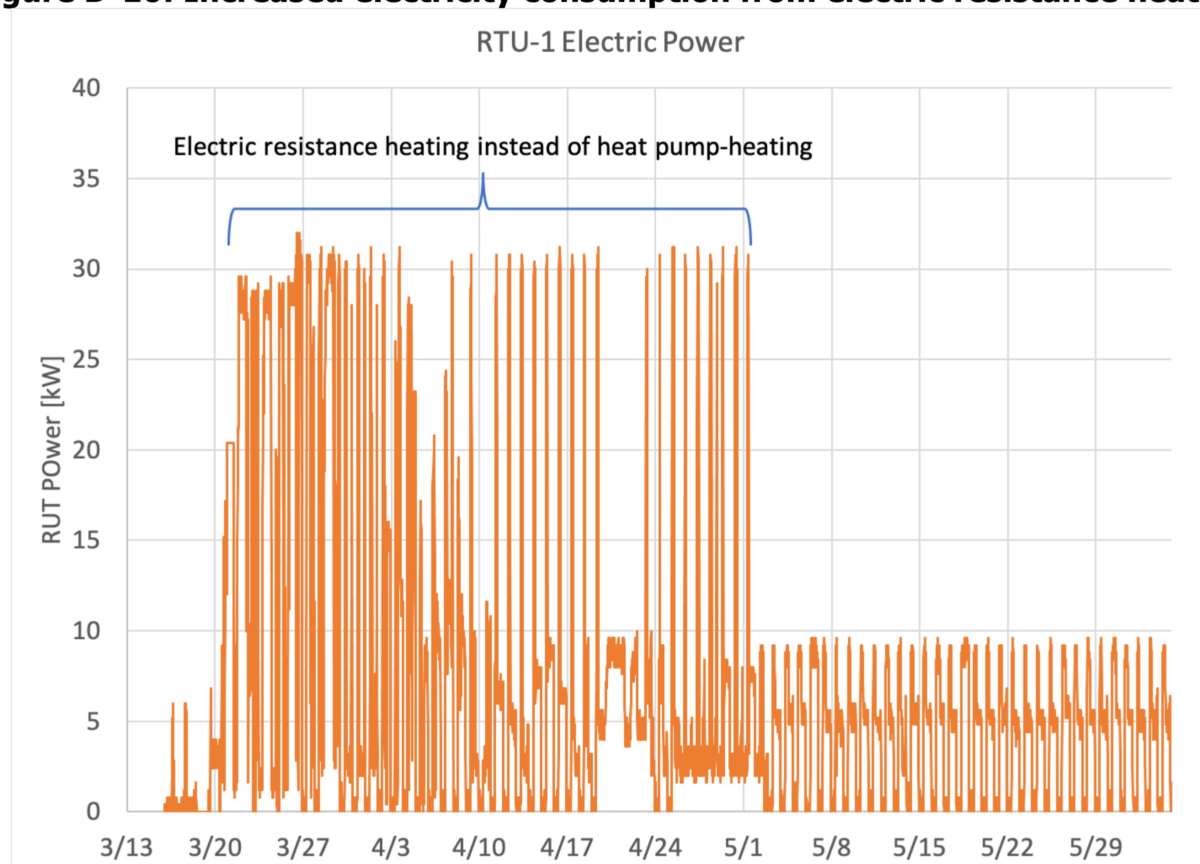
1,898 kWh. This is only the electricity for the fan, and excludes the gas used for heating. The electrical energy for the heat pump is 51,881 kWh.

**Table D-10: HVAC savings**

| | Baseline [kWh] | Post Retrofit [kWh] | Savings [kWh] | Savings Fraction |
|---|---|---|---|---|
| HVAC heating | 1,898 | 53,779 | -51,881 | N/A |
| HVAC Cooling + Ventilation | 9,858 | 9,925 | -67 | -0.7% |
| HVAC total | 11,756 | 63,704 | -51,948 | N/A |

Source: LBNL

**Figure D-10: Increased electricity consumption from electric resistance heating**



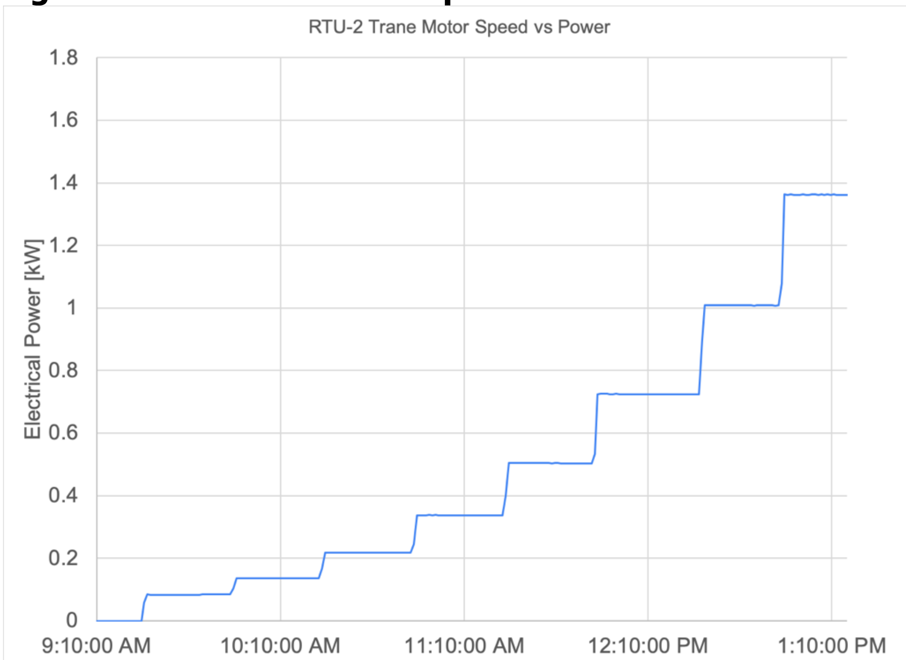

Source: LBNL

## RTU Motor Replacement

One of the emerging technologies that was evaluated for this project was the replacement of the roof top unit (RTU) indoor fan motor with a “high rotor pole switched reluctance” motor by SMC. In order to assess the savings of this motor over the factory standard Trane motor, we developed a measurement protocol. This protocol involved measuring the power consumption of the fan motor and the variable frequency drive (VFD) controllers. Two Dent ElitePro power meters were borrowed from the PG&E Tool Lending Library and one was installed in each RTU on the input power leads of the VFD. The power meters measured continuously and recorded one minute averaged values. The RTU’s were then programmed to change the fan speed from 30 percent to 100 percent in steps of 10 percent. Each speed was maintained for at least 10 minutes. Figure D-11 and Source: LBNL

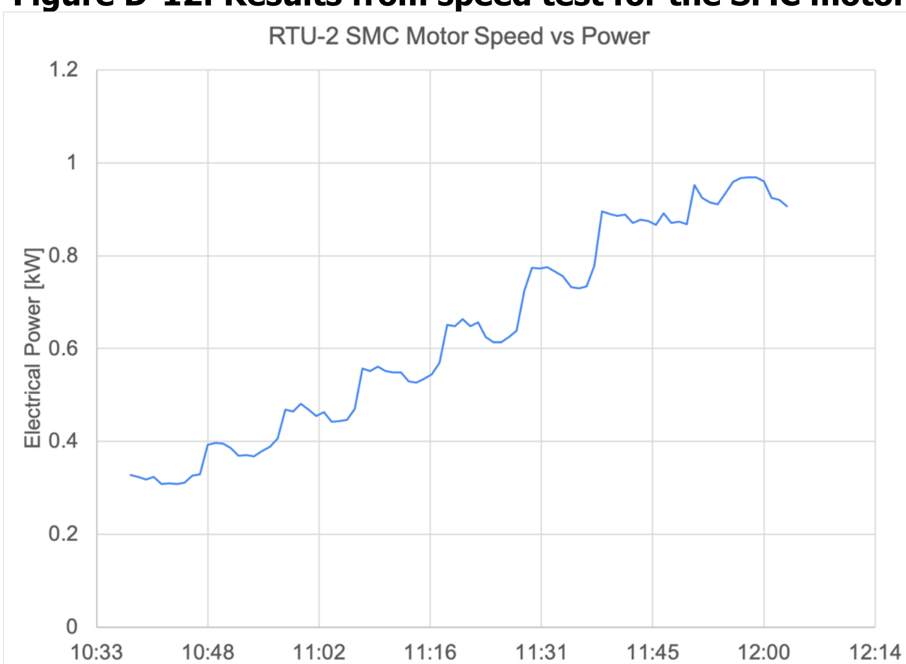
Figure D-12 show the raw results from the speed tests. The Trane motors were tested on February 18, 2020 and the SMC motors on February 27 and March 4, 2020.

**Figure D-11: Results from speed test for the Trane motor**




Source: LBNL

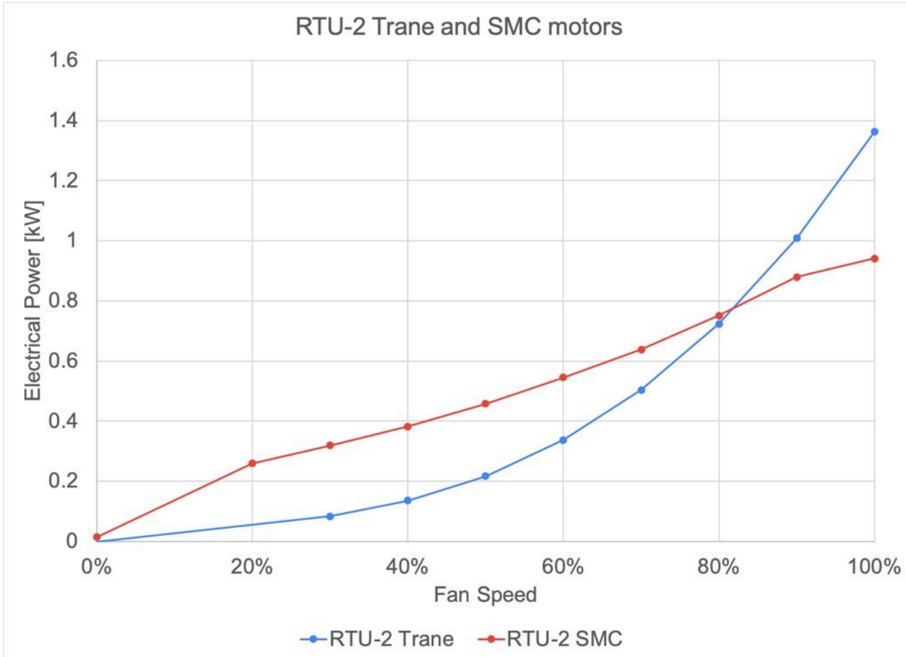
**Figure D-12: Results from speed test for the SMC motor**




Source: LBNL

Figure D-13 and Source: LBNL

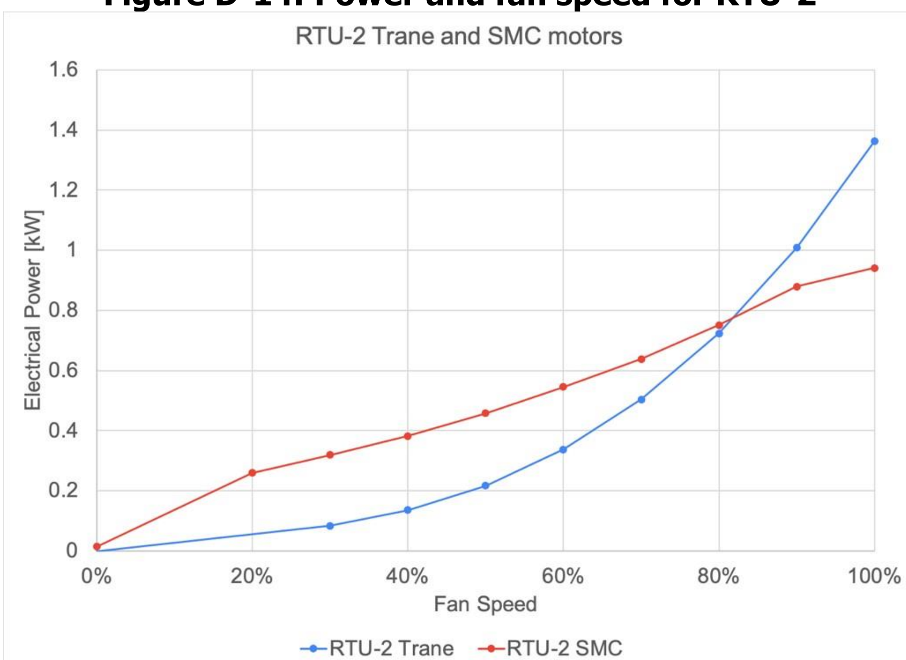
**Figure D-14: Power and fan speed for RTU-2**




are showing the relationship between speed and power for both motors for both RTUs. RTU-2 has a smaller motor, and lower power draws. The profile for the SMC motor in RTU-2 as shows in Source: LBNL

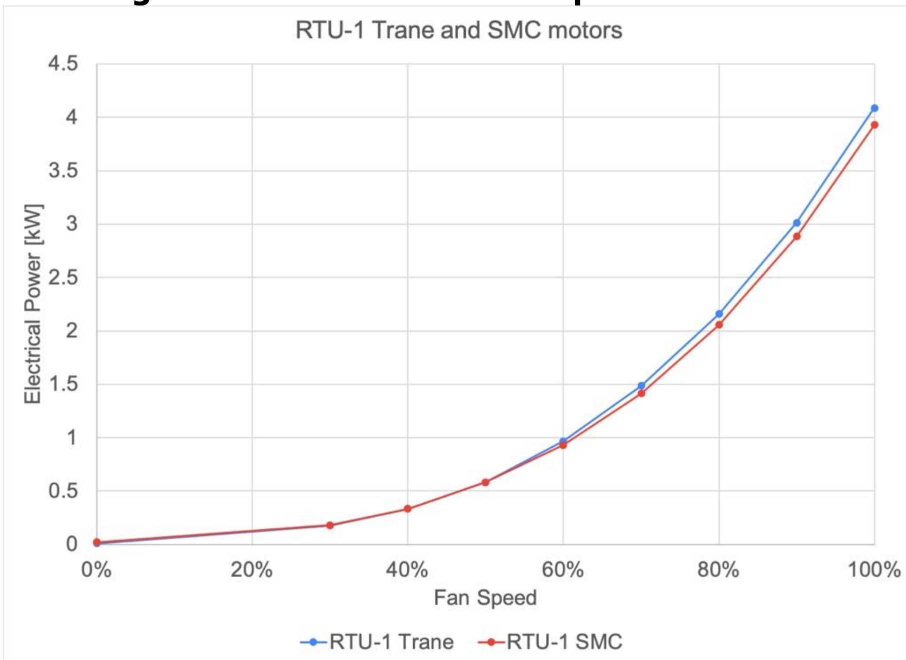
Figure D-12 and Source: LBNL

**Figure D-14: Power and fan speed for RTU-2**



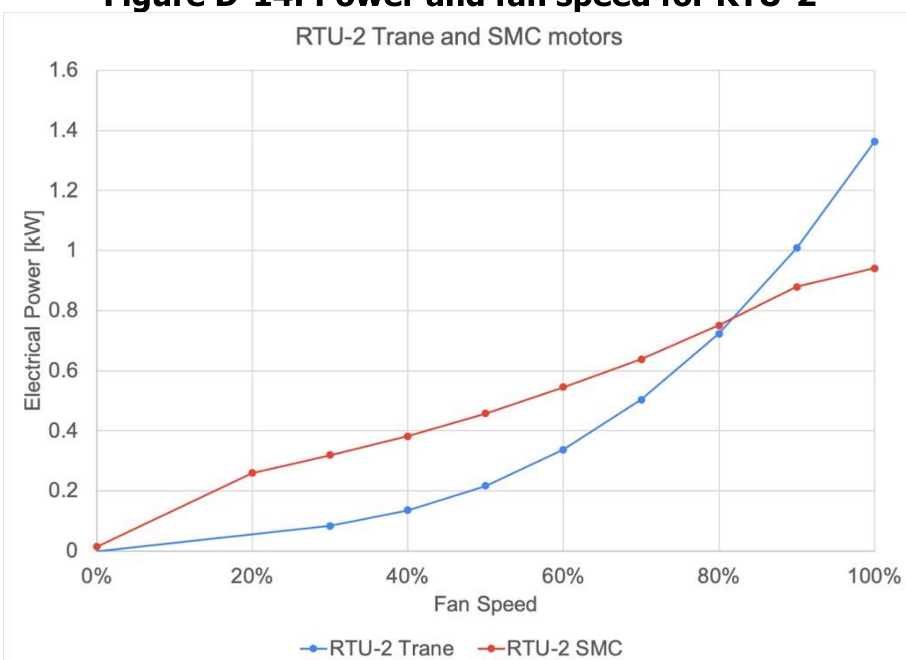

looks quite different from RTU-1 (Figure D-11 and Figure D-13). The test for the SMC motor in RTU-2 was conducted twice with identical results, it is unclear why the profile is different from RTU-1.

**Figure D-13: Power and fan speed for RTU-1**




Source: LBNL

**Figure D-14: Power and fan speed for RTU-2**




Source: LBNL

The SMC motors were installed in February 2020. In order to estimate the savings that these motors would have provided, had they been installed on April 1, 2019, we looked at the actual fan speeds for the two RTU's for each minute (395,722 values) between April 1, 2019 and December 31, 2019. By using the data from figures 3-13 and 3-14, we were able to predict the reduction in fan energy that would have occurred if the motors had been installed for the full period. The savings were calculated as 5% for RTU-1 and 14% for RTU-2. The energy savings during that period was 838 kWh for the two motors combined, which was extended to a full year estimate by extrapolating the 9 month period to a full year. The savings for a full year are 1,112 kWh, which represent 7.1 percent of the HVAC fan consumption. After installation of the SMC motors there was an observation from the store personnel that the new SMC motors were louder than the original Trane motors.

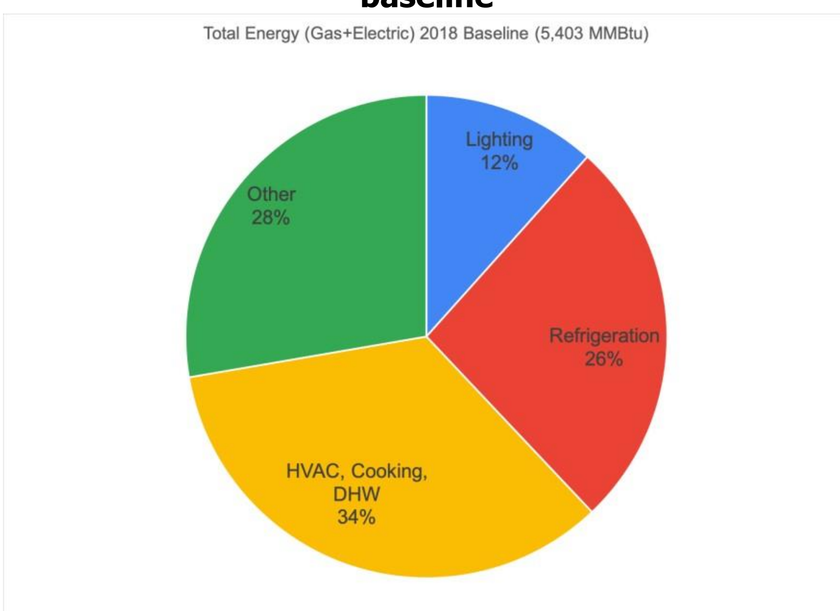
## 4.0 Energy Upgrade Analysis

Before looking at energy savings from the retrofit, it is useful to look at the baseline total energy consumption for various end loads in the store. The method to calculate this baseline was described in Section 3. Total energy consumption refers to a metric that converts the energy content of gas (measured in Therms) and electricity (measured in kWh) to a common metric: MMBtu (million British thermal units). This allows comparison of savings measures, some of which affect electricity only, and others that affect both gas and electricity consumption. Figure D-15 shows how the 5,403 MMBtu during the one-year baseline period is distributed across the various end- load categories for this store.

Since there was no sub-metering of the natural gas supply, we had to combine all the loads that use gas into one category. The loads are gas heating for the HVAC system, domestic hot water (DHW), and cooking by the gas rotisserie. The electrical loads associated with gas consumption (fans for HVAC and motors for the rotisserie) are also included in this category.

Figure D-15 shows that loads associated with gas consumption (HVAC, Cooking, DHW) make up 35 percent of the store's total energy consumption. The next largest category is "Other" which is also sometimes referred to as miscellaneous electrical loads (MELS), and includes plug loads like cash registers, the hot food bar, and back of the house loads like conveyor belts and roll-up doors. Refrigeration accounts for about one quarter (26 percent) of all the energy consumed, followed by lighting, at 12 percent.

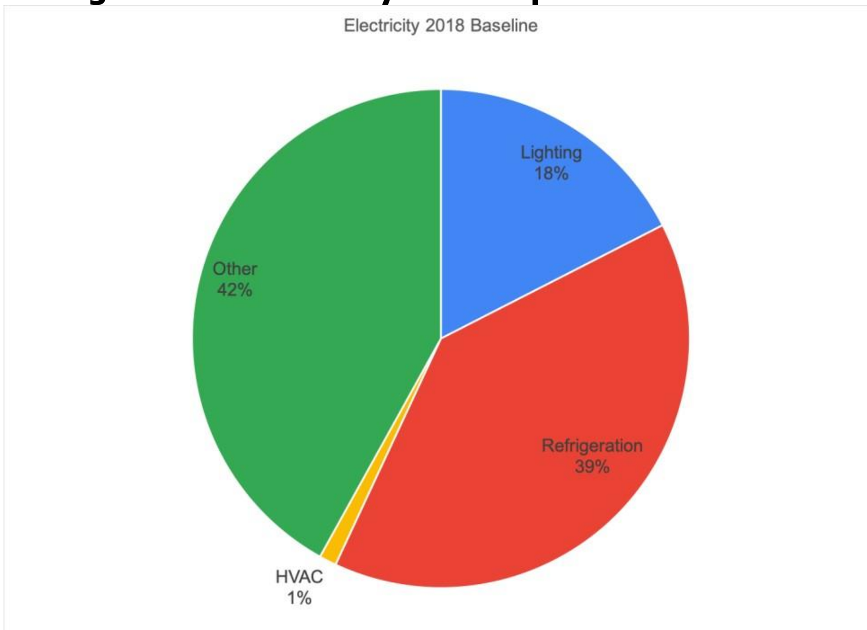
**Figure D-15: Total Energy (Gas+Electric) consumption by category for the 2018 baseline**




Source: LBNL

Figure D-16 shows the electricity-only portion of the 2018 baseline. Refrigeration and other loads are both responsible for about 40 percent of the load each (39 percent and 42 percent), lighting accounts for 18 percent, and HVAC energy constitutes only 1 percent of the baseline electrical consumption. The HVAC electricity consumption is low because the heating portion of the baseline HVAC system was achieved using gas. The cooling consumption was limited because the open refrigerated cases in the store provided a lot of cooling to the space. This cooling of the space by the refrigeration system is very inefficient because the cases have to be cooled to a much lower temperature, which takes more energy than cooling air to condition the space to 70°F to 72°F.

**Figure D-16: Categories of electricity consumption for the 2018 baseline period**



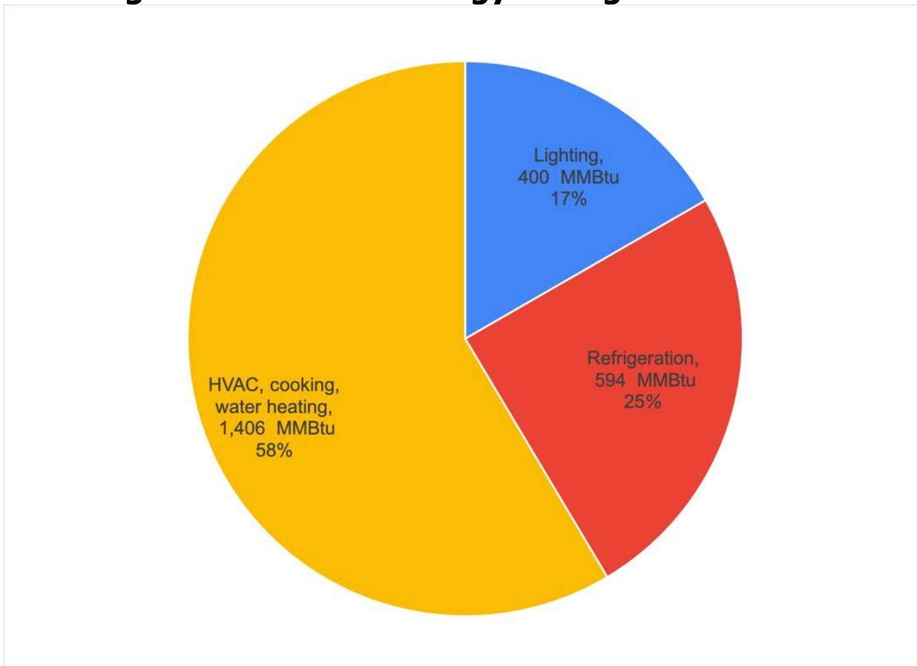

Source: LBNL

The ECMs were implemented between January 1, 2019 and April 1, 2019. The analysis of savings started on April 1, 2019 and continued through February 15, 2020. Due to the timing of the end of the project, it was not possible to gather data over the full 12- month period, but the period of April 1 through February 15 covers most climate conditions and store events such as Thanksgiving and Christmas. This 10.5-month period was then extended to a full year by linear extrapolation. Figure D-17 shows the distribution of the savings among the major categories. Not shown is a slight increase (19 MMBtu or 1.3 percent) in the "Other" category, which was due to normal fluctuations in store operation. The large reduction in the HVAC, Cooking and DHW category is due to the large reduction in gas usage at the store.

Figure D-18 shows that the gas consumption in the store was reduced by 90 percent. Some of this reduction in gas consumption resulted in increases in electricity consumption, such as the electric heat pump in the HVAC rooftop units, which offset gas space heating, and the increased electricity for the electric combi-oven that replaced the gas-fired rotisserie, as can be seen in Figure D-19. The 90 percent gas savings represented a 1,621 MMBtu reduction in total energy, which is 68 percent of the total store energy savings.

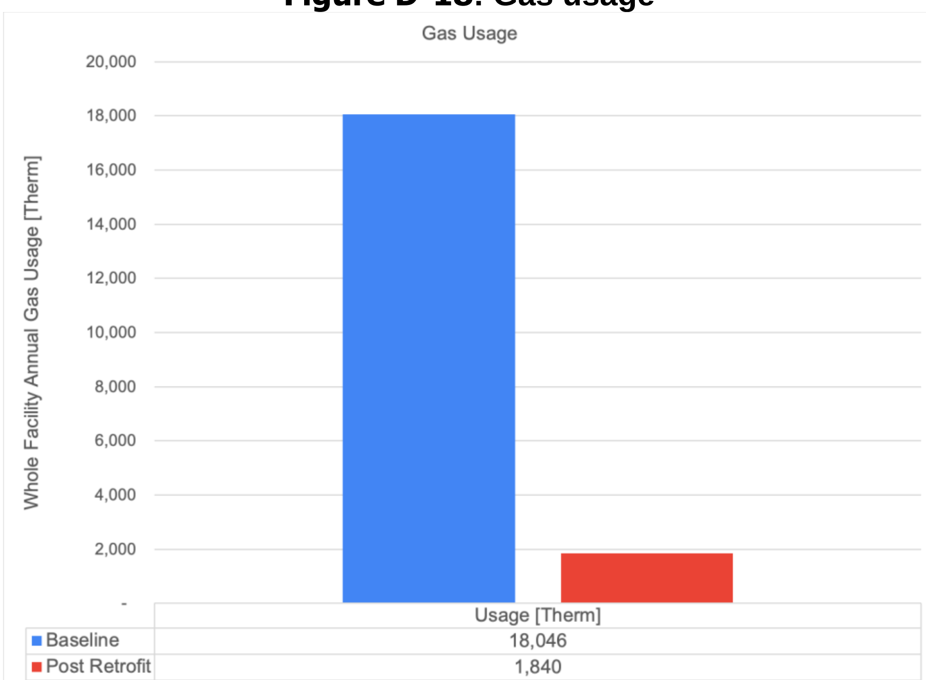
The SMC motor replacement resulted in a 7.1 percent reduction in HVAC fan energy and contributed to less than 0.5 percent of the overall savings.

**Figure D-17: Total energy savings distribution**



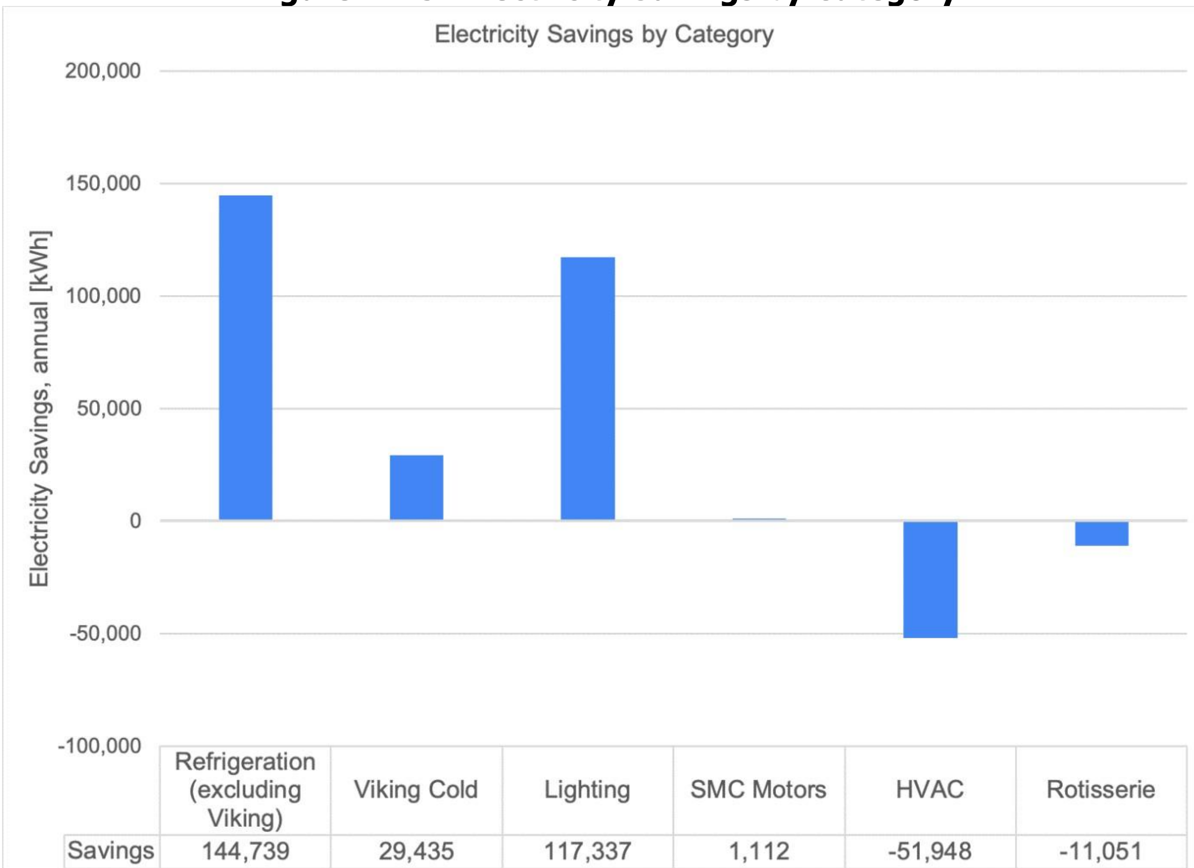

Source: LBNL

**Figure D-18**: Gas usage




Source: LBNL

**Figure D-19: Electricity Savings by Category**

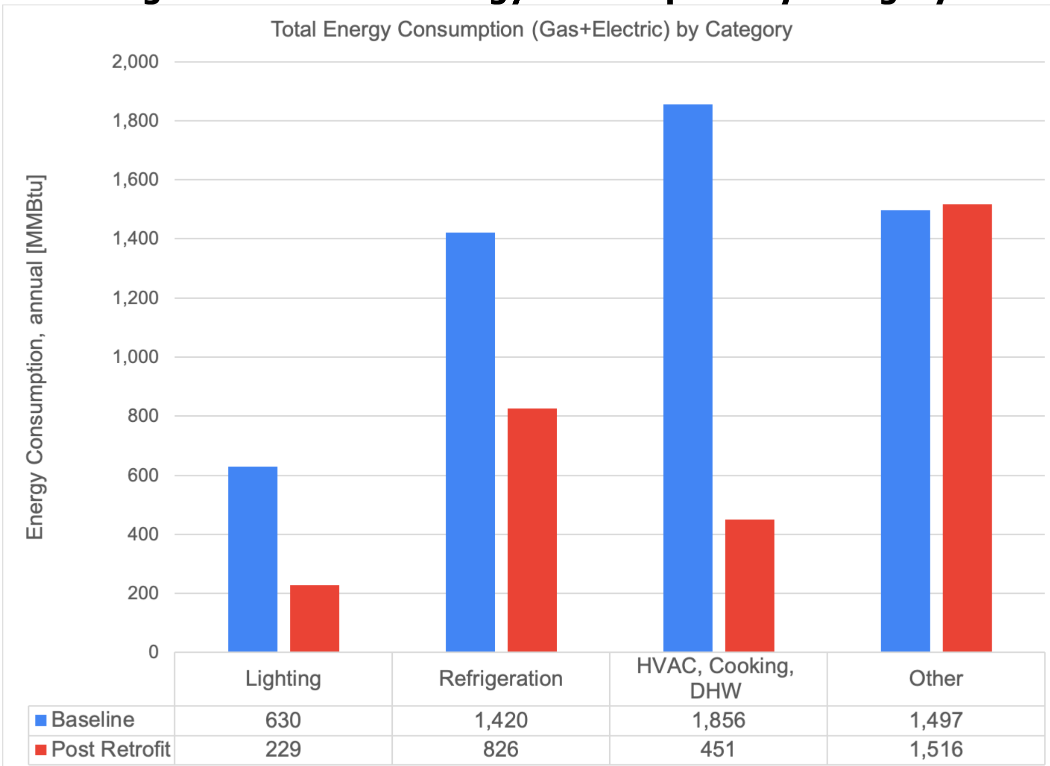



Source: LBNL

Figure D-20 shows for the various end loads how the usage changed due to the retrofits. The largest drop was for the "HVAC, Cooking and DHW" category, due to the significant reduction in gas consumption, as described previously.

Table D-11 provides the savings percentages for the various measures and table 4-10 shows the energy use intensity for the store. The HVAC energy for cooling and ventilation increased slightly from the baseline to the post retrofit period. This does not indicate that the new HVAC equipment is less efficient. The cooling load in the store has increased due to the addition of doors to the refrigerated cases. Because there were no airflow sensors in the RTU, it was impossible to calculate the cooling load, which would have allowed us to normalize the energy consumption to the actual cooling load and calculate the efficiency of the new and old RTU.

**Figure D-20: Total Energy Consumption by Category**




Source: LBNL

**Table D-11**: Energy savings overview

| | Baseline | Savings | Savings fraction |
|---|---|---|---|
| Electricity (kWh) | | | |
| Lighting | 184,481 | 117,337 | 63.6% |
| Refrigeration | 416,191 | 174,174 | 41.8% |
| HVAC heating | 1,898 | -51,881 | N/A |
| HVAC cooling + ventilation | 9,858 | -67 | -0.7% |
| Cooking | 3,413 | -11,051 | N/A |
| Other | 438,717 | -5,472 | -1.2% |
| Whole facility | 1,054,559 | 223,040 | 21.2% |
| Gas (MMBtu) | | | |
| HVAC heating, cooking, water heating | 1,805 | 1,621 | 89.8% |
| Total energy (MMBtu) | | | |
| Lighting | 629.6 | 400.5 | 63.6% |
| Refrigeration | 1,420.5 | 594.5 | 41.8% |
| HVAC heating, cooking, water heating | 1,822.8 | 1,405.9 | 77.1% |
| HVAC cooling + ventilation | 33.6 | -0.2 | -0.7% |
| Other | 1,497.3 | -18.7 | -1.2% |
| Whole Facility | 5,403.9 | 2,381.9 | 44.1% |
| Emerging Technologies (kWh) | | | |
| HVAC heating and cooling fans (SMC motor retrofit)* | N/A | ,112 | 7.1% |
| Walk-in freezer (Viking Cold retrofit)* | 117,831 | 29,435 | 25.0% |

***Baseline inferred from 2019 operations without emerging technologies in place.**

Source: LBNL

**Table D-12**: Energy use intensity

| | Pre retrofit [kBtu/sq/yr] | Post retrofit [kBtu/sq/yr] | Savings [%] |
|---|---|---|---|
| Energy Use Intensity (EUI) | 214.5 | 120 | 44.1 |

Source: LBNL

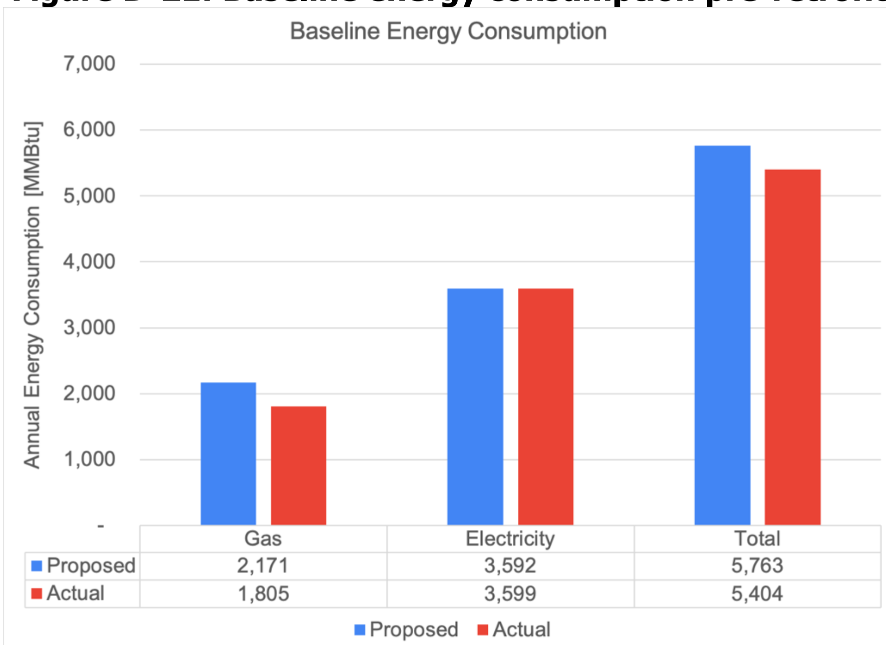
## 5.0 Model-based Performance Monitoring

Arup developed a detailed building energy simulation model in EnergyPlus for this project. This simulation model was calibrated by using the actual store utility bill data to create a pre-retrofit model. The simulation model was used in combination with a genetic algorithm to determine which combination of ECMs to apply based on the energy savings potential and payback period.

Once this set of ECMs was decided, the ECMs were implemented in the pre-retrofit (baseline) model to create a post-retrofit model. As part of the M&V process we compared the measured energy savings at the store with the results from the post- retrofit model. We used real (measured) weather data (including temperature, humidity, and solar radiation) as inputs for this post-retrofit simulation model.

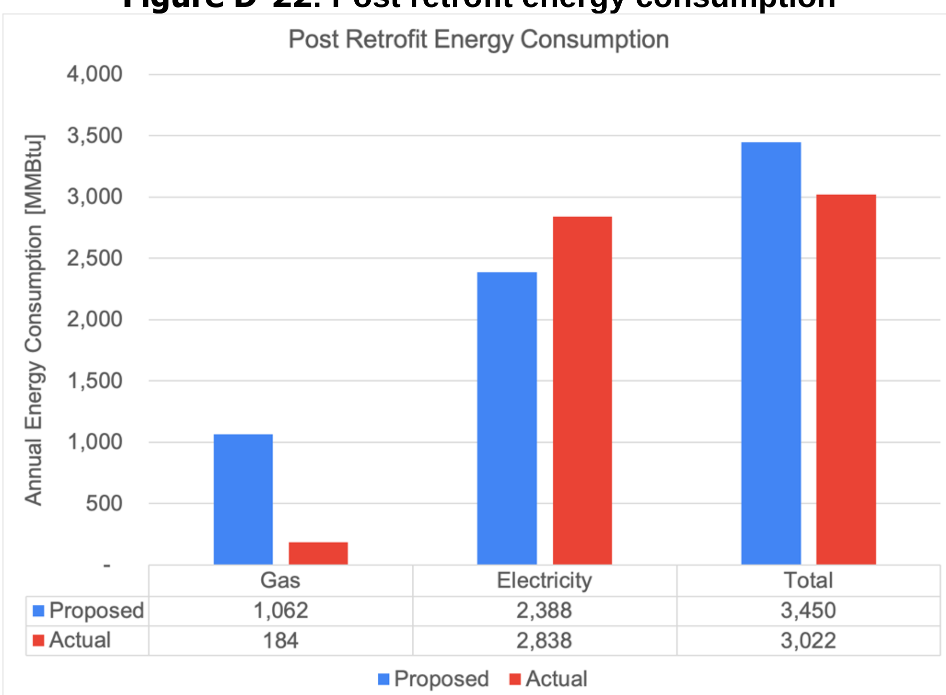
The pre-retrofit baseline model was developed and calibrated with 2016-2017 weather and store energy consumption data. Figure D-21 compares this "proposed" baseline energy consumption with the actual energy consumption in 2018, which was the baseline year just before the construction started in January 2019. Figure D-22 shows that the gas usage in 2018 was 17 percent lower than what was assumed in the proposed baseline model.

**Figure D-21: Baseline energy consumption pre-retrofit**




Source: LBNL

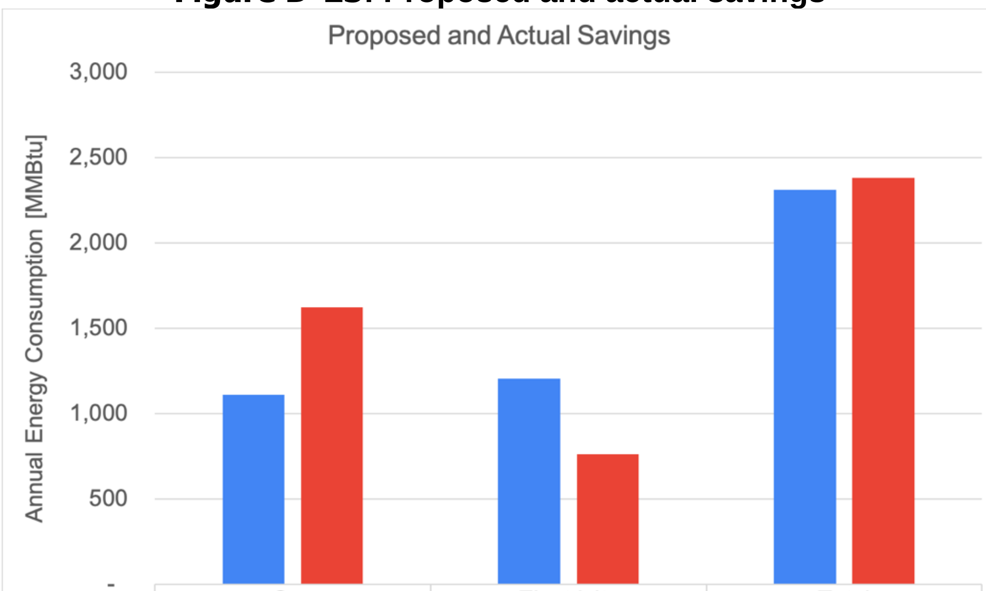
**Figure D-22: Post retrofit energy consumption**




Source: LBNL

The "proposed" energy consumption post-retrofit was a simulation by Arup predicting the energy consumption of the store after the implementation of a set of ECM's. Figure D-22 shows that the gas consumption was 83% lower than what was predicted, but the electricity consumption in the store was about 19 percent higher than what was predicted. The overall energy consumption of the store was about 12 percent lower than the predictions. The large difference between the proposed and actual gas consumption shows the challenge of creating calibrated simulation models when there is no sub metered data available. Even though the overall gas consumption was accurate in the calibrated baseline model, the assumed contribution of each of the end uses (cooking, water heating and space heating) turned out to be incorrect. This resulted in incorrect predictions of savings after the retrofit. Figure D-23 shows the savings figures and was derived from the data in Figure D-21 and Figure D-22.

**Figure D-23: Proposed and actual savings**




| | Gas | Electricity | Total |
|---|---|---|---|
| Proposed | 1,109 | 1,204 | 2,313 |
| Actual | 1,621 | 761 | 2,382 |

Source: LBNL

## Weather Data Generation

The post retrofit energy simulation uses the actual weather data for the period from April 1, 2019, to February 15, 2020. Typically, an entire year of weather data from past years are available from service providers for building energy simulation. However, the simulation task required the weather data daily basis for past days. We developed code to download the recent actual weather data and process them for building energy simulation using EnergyPlus.

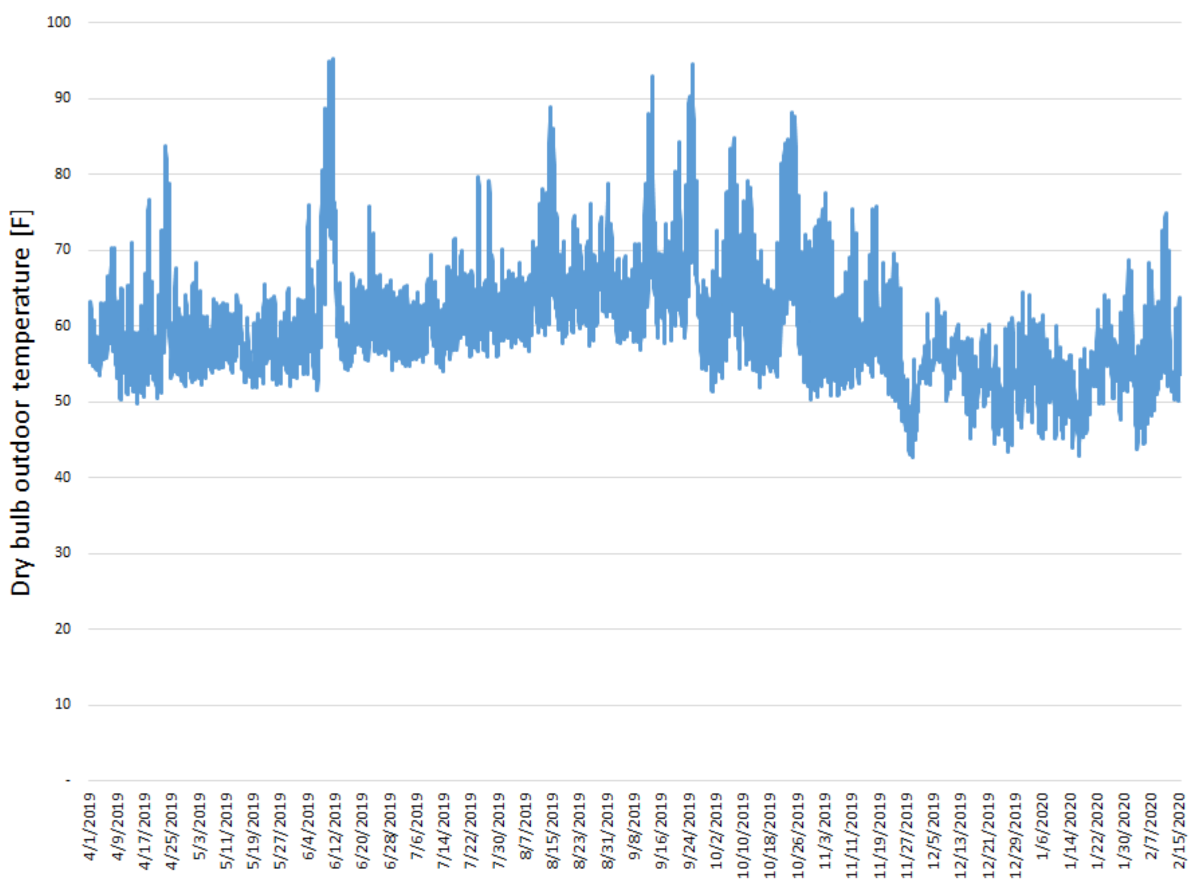
The weather data sources included the Whole Foods store sensors, Weather Underground,[32] and NOAA.[33] Outdoor air dry-bulb and dew point temperatures, as well as relative humidity

[32] Weather Underground (2020) Mission - Valencia 20th-21st - KCASANFR1141. Available at: https://www.wunderground.com/dashboard/pws/KCASANFR1141 (Accessed: 6 March 2020).

[33] NOAA (2020) *NOAA National Centers For Environmental Information Products*. Available at: https://www.ncdc.noaa.gov/isd/products (Accessed: 5 March 2020).

data, were obtained from the store sensors. Figure D-24 shows the hourly dry-bulb temperature data from the store temperature sensor. Hourly data for wind direction, wind speed, and pressure was downloaded from the closest weather station, KCASANFR1141 (Mission - Valencia 20th-21st), which reflects the local climate condition of the Noe Valley store Whole Foods Market (Weather Underground, 2020). Hourly sky cover data are available from the NOAA National Climatic Data Center (NCDC) (NOAA 2020), and we used San Francisco Airport weather station 724940- 23234 for the cloud cover data. The downloaded weather data were converted to an EPW (EnergyPlusWeather) file for EnergyPlus simulations.

**Figure D-24: Hourly Dry-Bulb Outdoor Temperature from the Whole Foods Store for the period from April 1, 2019 to February 15, 2020**



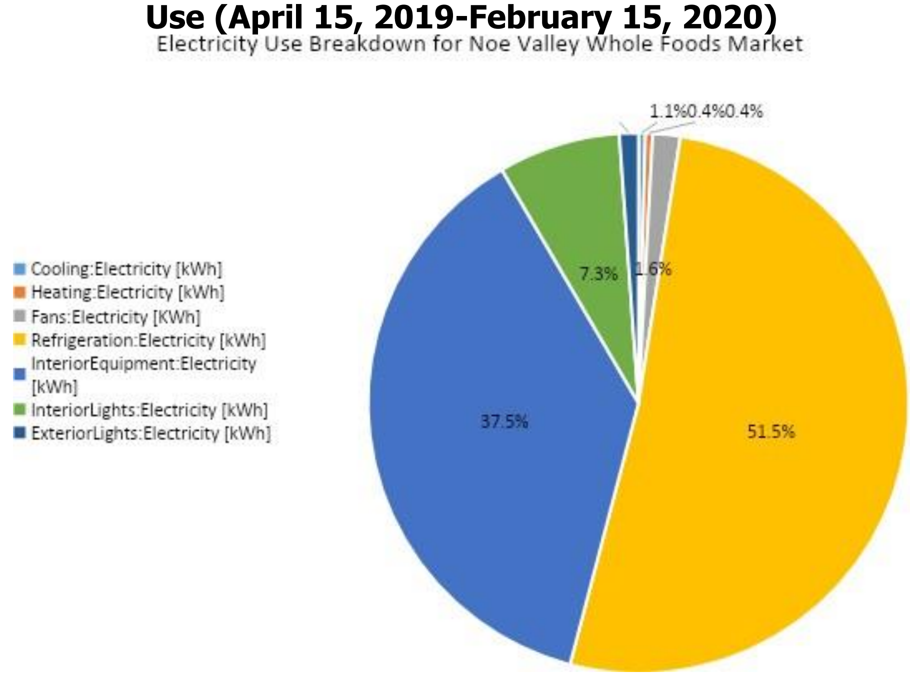

Source: LBNL

## Energy Model Calibration

We used the post-retrofit model and actual weather data for energy simulation and found that the simulated electricity consumption using the given EnergyPlus model was 10 percent less than the observed total electricity consumption for the period from April 1, 2019, to February 15, 2020. The sub-meters were available for HVAC, refrigeration, and lighting electricity. The energy end-use breakout analysis showed that the simulated HVAC electricity consumption was about 69 percent greater than measured HVAC electricity, the simulated refrigeration was 11 percent greater than the measured refrigeration electricity, and lighting electricity was 9 percent greater than the observed lighting electricity. The EnergyPlus model showed HVAC electricity consumption when the store was closed at night. The first calibration effort was to modify the heating and cooling system operation schedule, enabling the operation of the HVAC system during occupied hours only. Then the lighting energy calibration included the lighting schedule modification, to reflect the reduced lighting energy at night. The refrigeration case lights were on for 24 hours, and the calibration changed the lighting schedule off during the night. There was no calibration for the refrigeration system. Although the HVAC, lighting, and refrigeration electricity consumption was greater than the sub-metered electricity, the building's total electricity consumption was smaller than the observed electricity usage. Note that there is no sub-meter for the general plug load electricity consumption. Whole-building low electricity consumption is calibrated to the plug load electricity, where we modified the plug load schedule during the occupied hours, reflecting the profile of the building's total electricity consumption. Figure D-25 shows the breakdown of the modeled electricity use from the simulation using the calibrated model with the actual weather data for the period from April 1, 2019, to February 15, 2020.

The simulation results of the modeled store electricity were compared with the observed consumption using the normalized mean bias error (NMBE) and coefficient of variance of root mean square error (CVRMSE) to assess the goodness of fit. ASHRAE Guideline 14 specifies that NMBE be between ±5%, while CVRMSE be less than 15% for monthly data; ±10% for NMBE and 30% for CVRMSE for hourly data. It was found that NMBE and CVRMSE were found to be -2.8% and 4.2% respectively for monthly electricity consumption data (Table D-13), while the NMBE and CVRMSE were found to be - 2.7% and 11.5% respectively for hourly data (Table D-14). The monthly comparison was done for 10 months from April 2019 to January 2020, while the hourly comparison was done for the period between April 1, 2019, to February 15, 2020, for the report. The comparison statistics for the monthly and hourly data meets the goodness of fit criteria set forth in ASHRAE Guideline 14.

**Figure D-25: Modeled Electricity Consumption for the Whole Foods Store by End Use (April 15, 2019-February 15, 2020)**



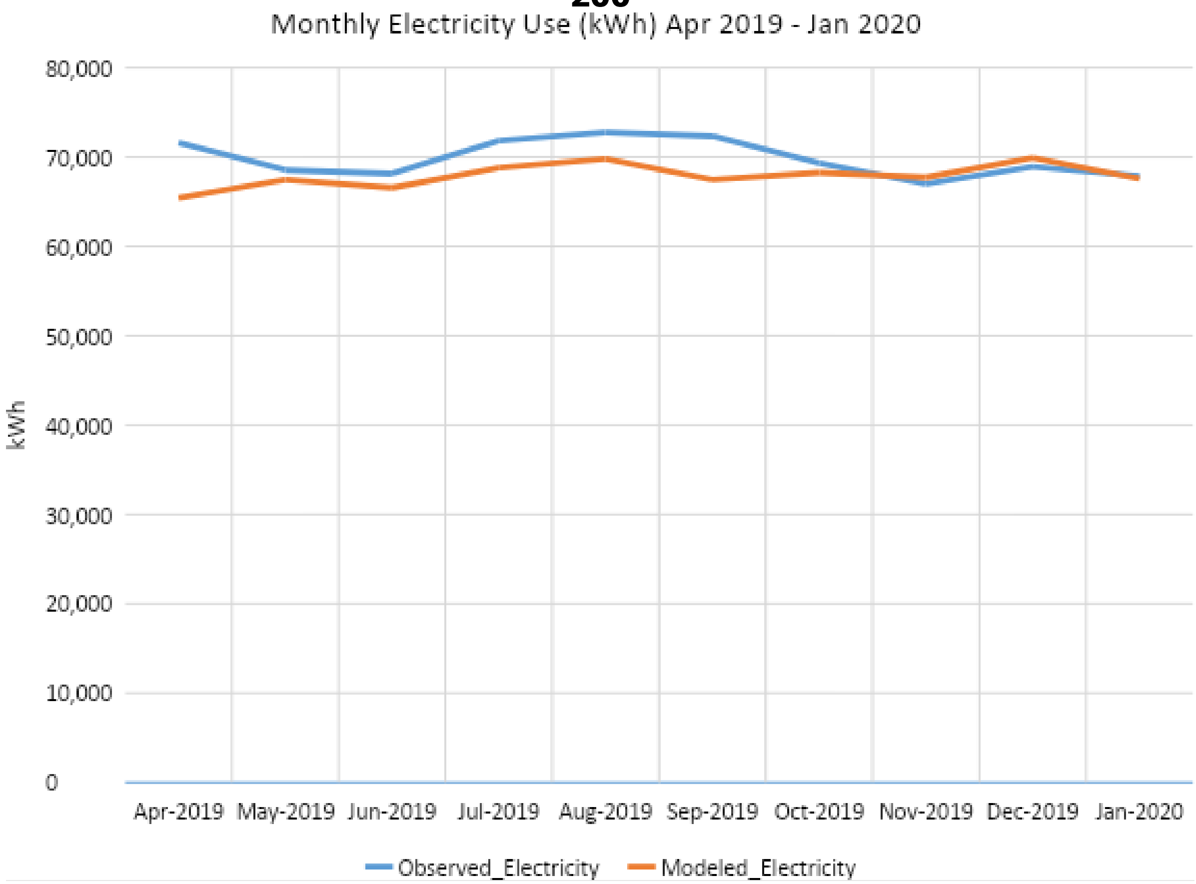

Source: LBNL

**Table D-13: Model Calibration Statistics with Monthly Electricity Consumption Data from April 2019 to January 2020**

| | |
|---|---|
| Monthly Electricity NMBE | -2.8% |
| Monthly Electricity CVRMSE | 4.2% |

Source: LBNL

**Figure D-26: Calibrated vs. Measured Electricity Consumption April 2019-January 200**




Source: LBNL

Figure D-26 illustrates the modeled end use and compares the modeled total electricity consumption to the observed total electricity consumption for one week in each season.

**Table D-14: Model Calibration Statistics with Hourly Electricity Consumption Data from April 1, 2019 to February 15, 2020**

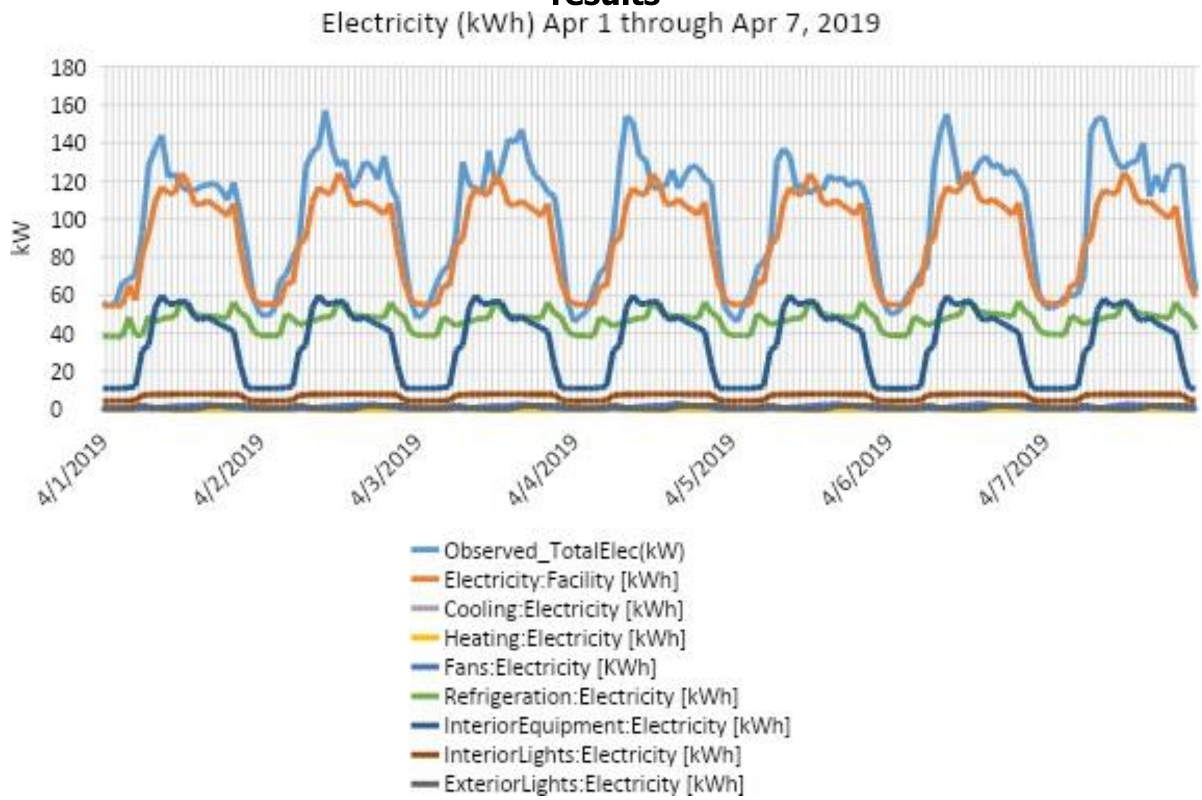
| | |
|---|---|
| Hourly Electricity NMBE | - 2.7% |
| Hourly Electricity CVRMSE | 11.5 % |

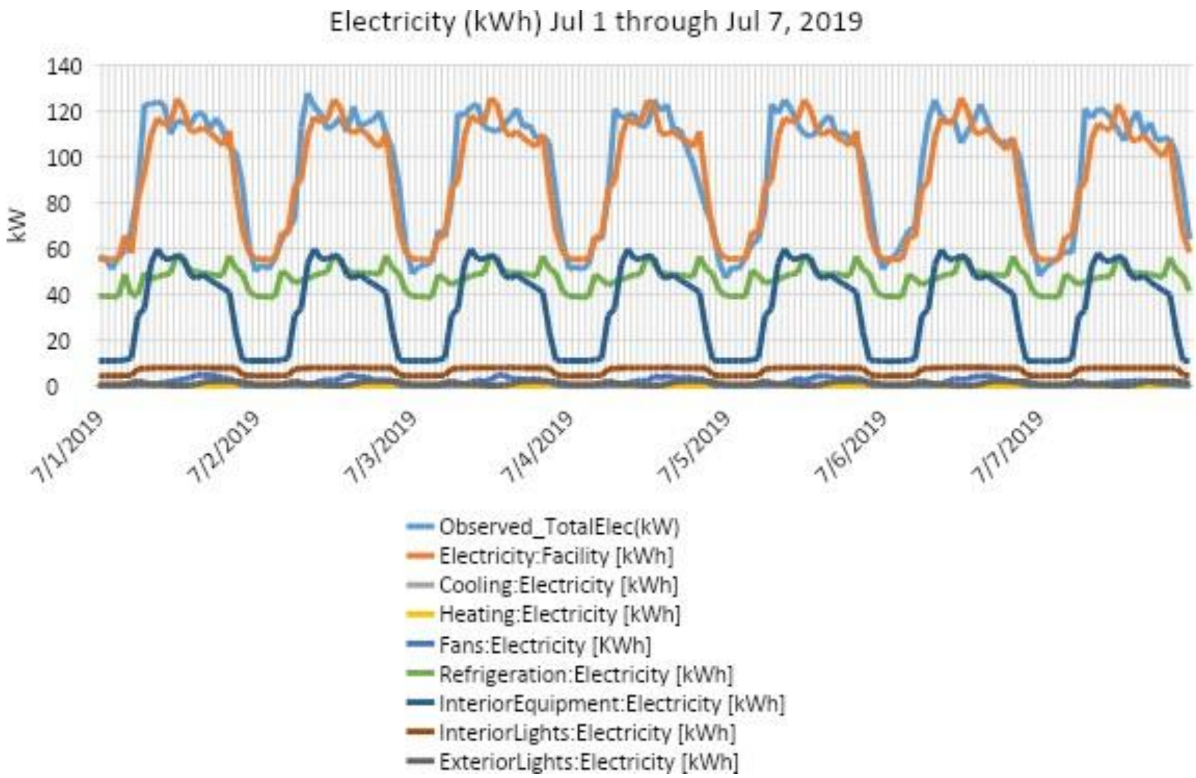
Source: LBNL

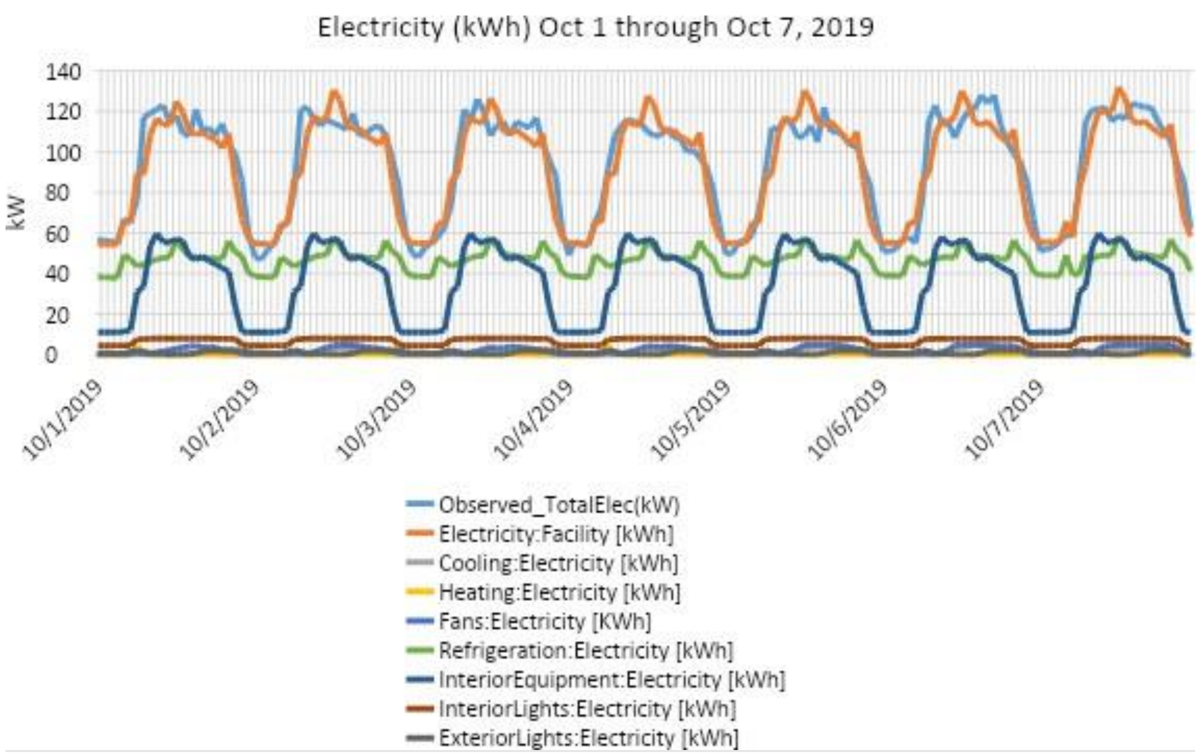
The April 2019 week chart in Figure D-27 shows the observed electricity is greater than the modeled electricity. For the early period after the HVAC system retrofit, the heating system was using electric resistance heating, which caused higher electricity consumption. This increased HVAC energy consumption due to electric resistance heating was resolved on May 1st, 2019. The January 2020 week chart shows that electricity consumption in the early morning hours is greater than the observed consumption. This is mainly caused by electricity consumption for heating. A bigger heat pump system capacity in the model can meet the heating need quickly. Thus, the modeled electricity consumption shows that heating electricity spikes in the early morning hours.

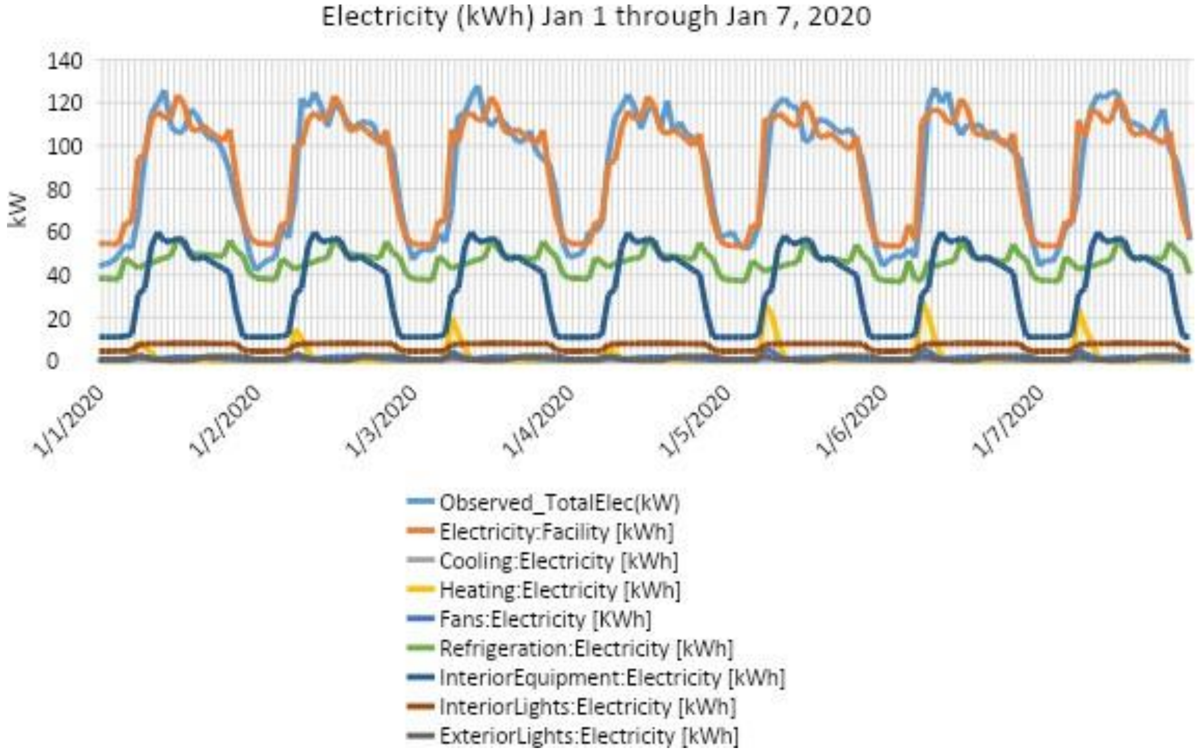
The calibrated post-retrofit simulation model was used for the performance persistence analysis described in Section 6. It was not used for the M&V process as described in Section 3.

**Figure D-27: Calibrated electricity use for four weeks from April 2019 to January 2020 with end-use and total modeled electricity and total observed electricity use results**




Electricity (kWh) Jul 1 through Jul 7, 2019
140
120
100
80
60
40
20
0
kW
7/1/2019
7/2/2019
7/3/2019
7/4/2019
7/5/2019
7/6/2019
7/7/2019
Observed_TotalElec(kW)
Electricity:Facility [kWh]
Cooling:Electricity [kWh]
Heating:Electricity [kWh]
Fans:Electricity [KWh]
Refrigeration:Electricity [kWh]
InteriorEquipment:Electricity [kWh]
InteriorLights:Electricity [kWh]
ExteriorLights:Electricity [kWh]


Electricity (kWh) Oct 1 through Oct 7, 2019
140
120
100
80
60
40
20
0
kW
10/1/2019
10/2/2019
10/3/2019
10/4/2019
10/5/2019
10/6/2019
10/7/2019
Observed_TotalElec(kW)
Electricity:Facility [kWh]
Cooling:Electricity [kWh]
Heating:Electricity [kWh]
Fans:Electricity [KWh]
Refrigeration:Electricity [kWh]
InteriorEquipment:Electricity [kWh]
InteriorLights:Electricity [kWh]
ExteriorLights:Electricity [kWh]




Source: LBNL

# 6.0 Performance Persistence Recommendations

## Background

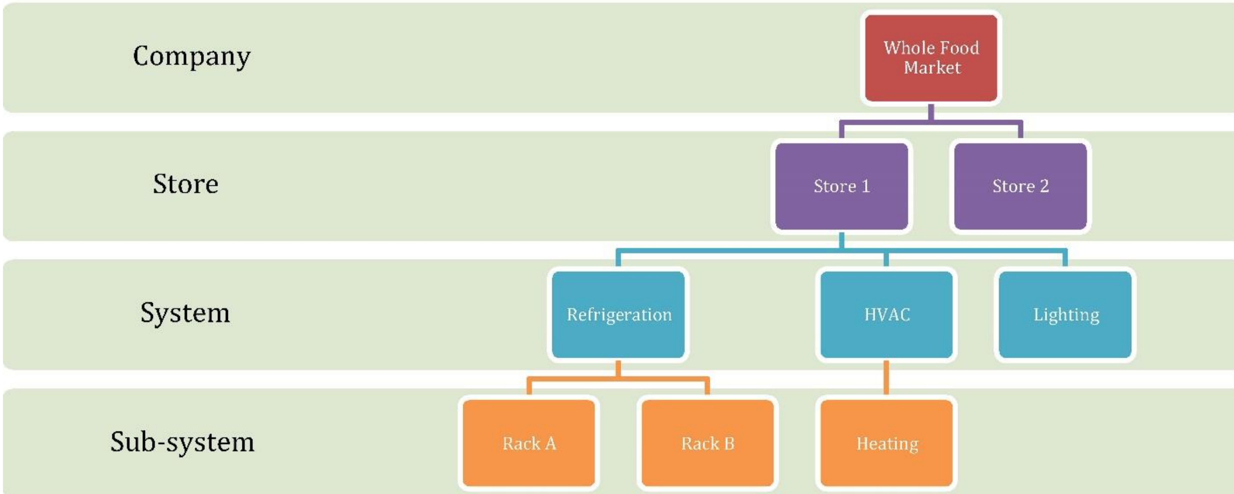
To evaluate if the energy conservation measures that were implemented can provide persistent savings and the overall facility performance is being maintained, anomalies have to be flagged. Anomaly detection and adjustments can get quite complicated and involves understanding as to what constitutes an anomaly, mechanism to monitor and look for that change, gathering sufficient information and data surrounding the change in factors, along with ways to account for this change to make the necessary changes. Some of the related issues to the anomaly detection and adjustments are:

- Defining what is a change in energy consumption that constitutes an anomaly
- Detecting that there is a change in energy consumption as a result of the anomaly
- Identifying what specific factors caused the change in energy consumption
- Gathering preliminary data needed to understand that change in energy consumption is worth quantifying given the project's scope
- Gathering detailed data related to the factors in question during both the pre and post retrofit conditions
- Evaluate options to address the anomaly that's causing the deterioration in performance.

In order to assess how well the facility and individual systems are performing, we compared the current performance of the store with established benchmarks. This benchmarking can be based on an aggregate number like EUI or can be at a higher granularity to assess the performance of the facility in a more real time manner. Figure D-28 provides a generic schematic that can be used for anomaly detection. These benchmarks were obtained from an

EnergyPlus simulation model and a statistical model, then compared with actual performance to identify any potential anomalies that might affect energy consumption and performance.

**Figure D-28: Schematics showing the benchmarking to identify anomalies**




Source: LBNL

A statistical model and a simulation model were used as benchmarks to establish what the whole facility level energy consumption will be given the time stamp and the outside air temperature, and this energy consumption is compared with the actual consumption to detect anomalies. The same approach can be used to assess performance related issues at the system or sub system level to identify any issues related to these systems or sub systems. To illustrate this, we adopted this approach on the refrigeration system by analyzing the energy consumption from the sub-meters.

## Approach

To detect these anomalies, we adopted a technique called "change point detection" to look for patterns in the store's energy consumption. The goal of this analysis was to identify the time stamps or the time periods where the facility's energy consumption pattern had changed or fluctuated in a significant way. These change point algorithms aim to detect single or multiple points at which the statistical properties of a series of observations, such as mean and variance, change. To tackle this challenge, over the years, many algorithms were proposed. Two of these mainstream approaches—Binary Segmentation and Pruned Exact Linear Time (PELT)—were evaluated.

### Binary Segmentation

The binary segmentation procedure proposed by Scott[34] was the first to detect multiple change points in a series. In each iteration of change point research, a single-change- point model is compared to a constant model (with no change points). Once a change point is identified, the data are split into two segments; hence the name "binary." Later, Vostrikova[35] showed the consistency of the algorithm in a stochastic setting. A potential problem with the binary

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[34] Scott, A. J. and Knott, M. (1974) A Cluster Analysis Method for Grouping Means in the Analysis of Variance, Biometrics 30(3), 507–512

[35] Vostrikova, L. (1981). Detecting 'disorder' in multidimensional random processes. Soviet Math. Dokl. 24 55–59.

segmentation algorithm is its inability to detect a small segment located in the middle of a long observation series.

### Pruned Exact Linear Time (PELT)

Similar to many optimization algorithms, the PELT algorithm identifies change points by minimizing a cost function across possible numbers and combinations of candidate points. The power of the method increases with the size of the change, which means the bigger the change is, the easier it can be identified. Studies have shown that the method is more highly sensitive than others to changes occur at different locations of the observation series.[36, 37, 38]

## Analysis

### Statistical Model as a benchmark for performance

*Facility Level*

The facility level residuals (the differences between the model predicted energy consumption and the actual energy consumption) were analyzed to detect potential anomalies in energy performance. Both variance and mean of these residuals were used to detect the changes in the energy consumption pattern. In this analysis, we investigated the changes related to the mean using a binary segmentation algorithm, assuming 5 and 10 change points (Figure D-29). Alternatively, the PELT algorithm was employed to detect the change points (Figure D-30) where a change in variance was observed, the Changepoints for a Range of Penalties (CROPS) method was used to evaluate the various time periods or segmentations to obtain an optimal choice for the constrained cost function of the PELT algorithm.[39] [40]

[36] Chen, J. and Gupta, A. K. (2000) Parametric statistical change point analysis, Birkhauser.

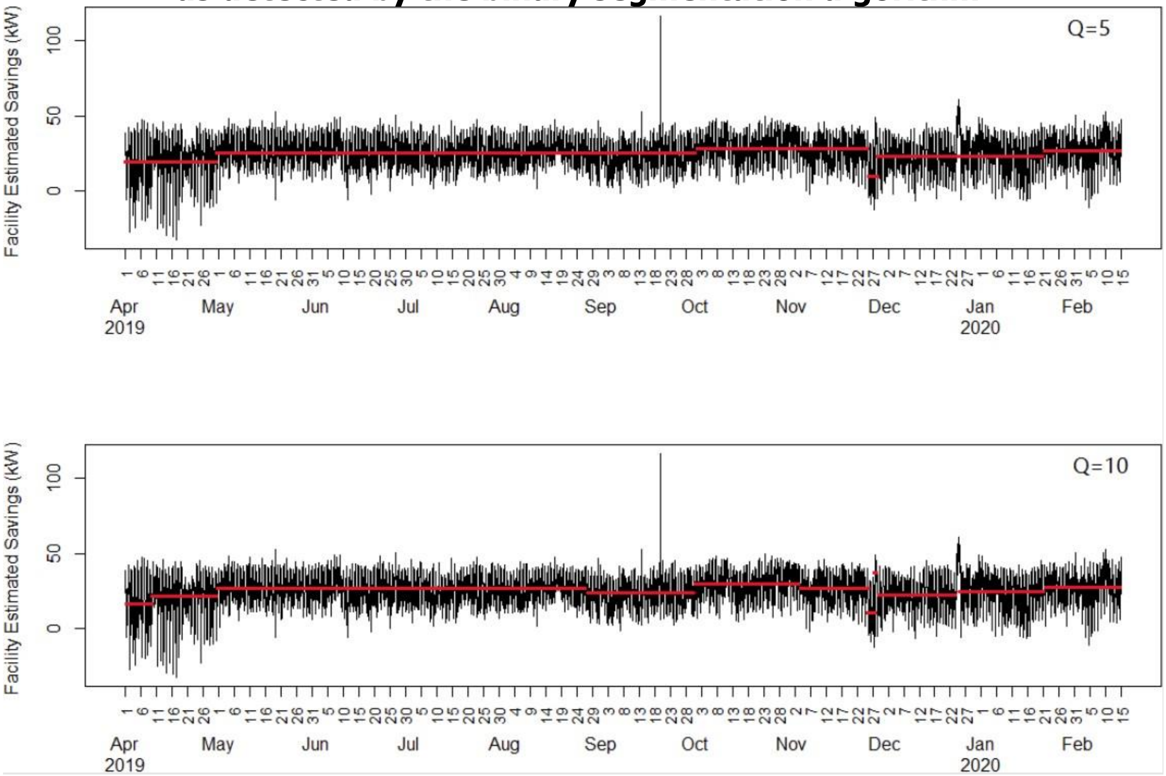
[37] Killick R, Fearnhead P, Eckley IA (2012) Optimal detection of changepoints with a linear computational cost, JASA 107(500), 1590–1598.

[38] Wambui G.D., Waititu G.A., Wanjoya A. The Power of the Pruned Exact Linear Time(PELT) Test in Multiple Changepoint Detection. American Journal of Theoretical and Applied Statistics.Vol.4, No. 6, 2015, pp. 581-586. doi: 10.11648/j.ajtas.20150406.30.

[39] Haynes K, Eckley IA, Fearnhead P (2014) Efficient penalty search for multiple changepoint problems, arXiv:1412.3617.

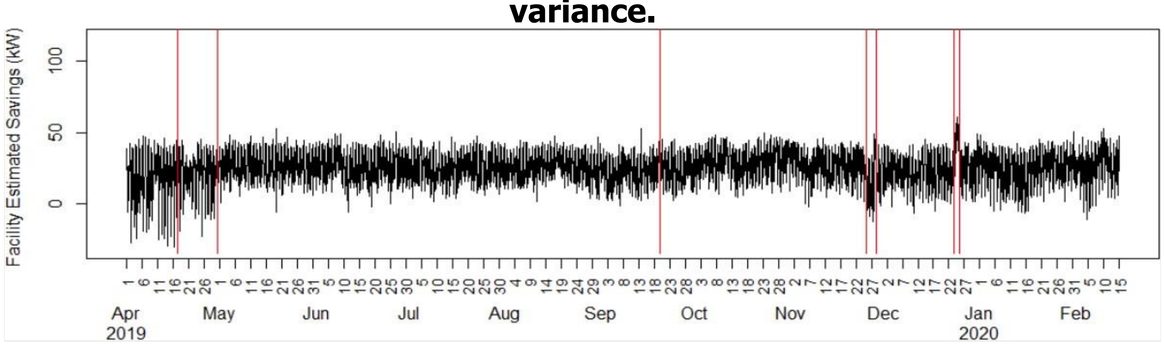
[40] Haynes K, Eckley I.A., and Fearnhead P (2017) Computationally Efficient Changepoint Detection for a Range of Penalties, Journal of Computational and Graphical Statistics, 26:1, 134-143, DOI: 10.1080/10618600.2015.1116445.

**Figure D-29: Plot showing five detected change points (top) and ten change points as detected by the binary segmentation algorithm.**




Source: LBNL

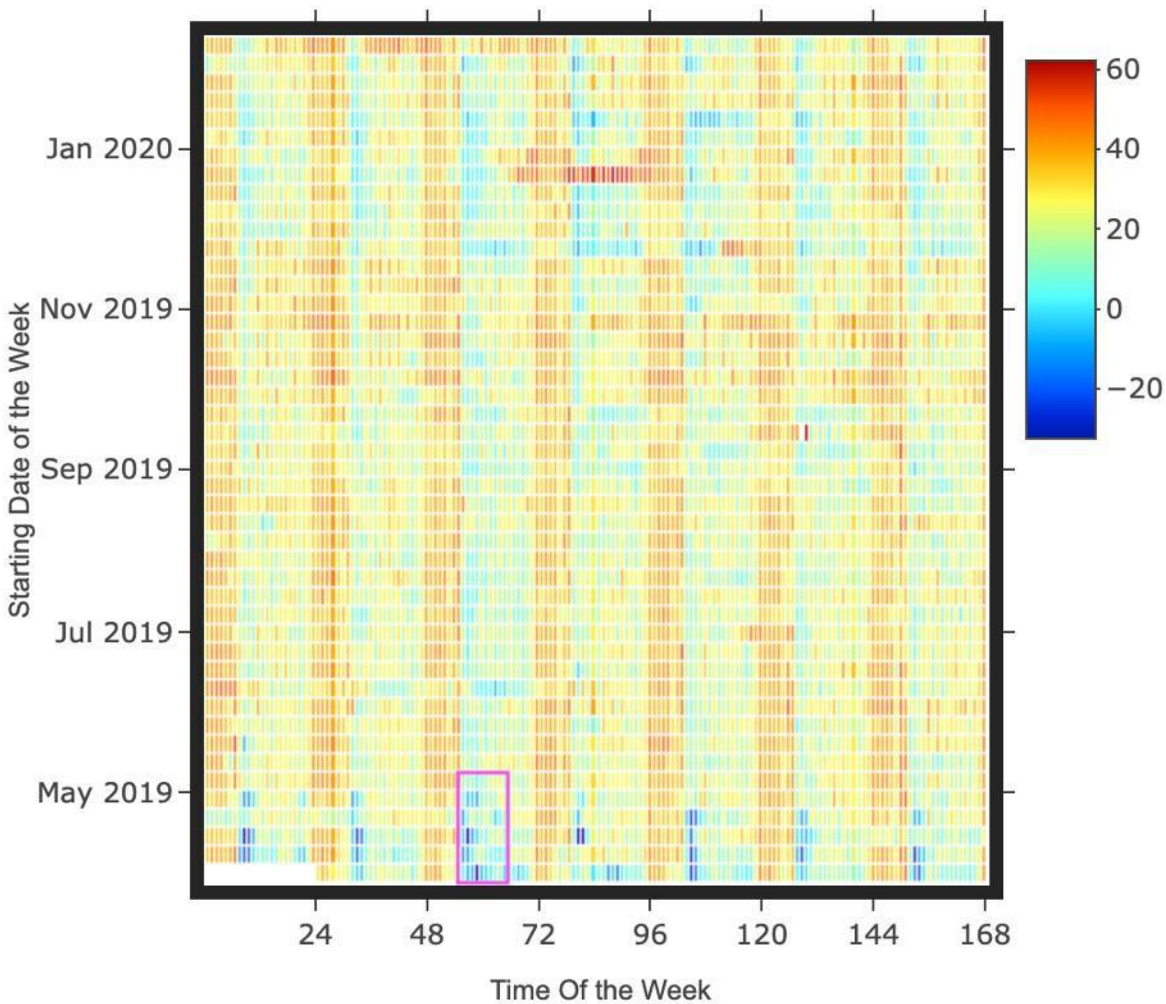
**Figure D-30: Change point detection using the PELT algorithm based on the variance.**




Source: LBNL

Figure D-31 shows the heat map with hourly savings distribution for the year. This figure indicates that the savings are negative during unoccupied hours during the month of April, and one of those events are identified with a pink box in Figure D-31.

**Figure D-31: Heat Map showing the electricity savings in kW**




Source: LBNL

The results are summarized in Table D-15. Change point detection as it applies to anomaly detection using energy consumption is an active area of research and understanding what algorithms works for what cases is still evolving. Based on this analysis, the we found several change points that are worth investigating and confirming with the field personnel. For example, all these algorithms, detected a change point on 11/26/2019 6 am, which might be related to the store adding refrigerated containers to handle the surge in customers during Thanksgiving season. These two containers were temporarily connected to the store power supply, and reduced the load on the refrigeration system, but increased the overall store load.

**Table D-15: Summary of the change point detection analysis of the whole facility data**

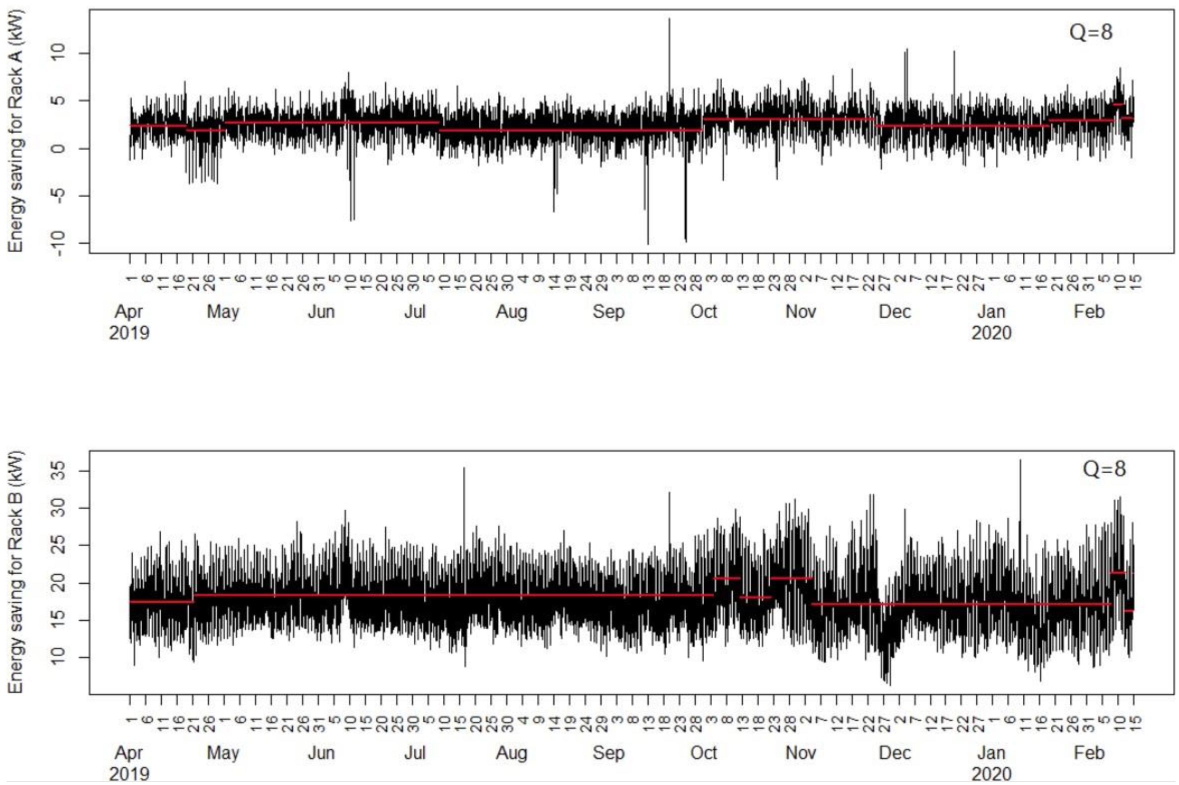
| BinSeg- 5 Change Points | BinSeg-10 Change Points | PELT | Description |
|---|---|---|---|
| | 4/9/2019 16:00 | | |
| | | 4/17/2019 10:00 | |
| 4/30/2019 21:00 | 4/30/2019 21:00 | | |
| | | 5/1/2019 13:00 | |
| | 8/27/2019 6:00 | | |
| | | 9/20/2019 7:00 | |
| | | 9/20/2019 9:00 | |
| 10/1/2019 22:00 | 10/1/2019 22:00 | | |
| | 11/4/2019 6:00 | | |
| 11/26/2019 6:00 | 11/26/2019 6:00 | 11/26/2019 6:00 | In 2019, the store used two refrigerated trucks:<br>~Two were in use 11/18- 12/3<br>~One remains in use 11/18 – 12/27 |
| 11/28/2019 13:00 | 11/28/2019 13:00 | | |
| | 11/29/2019 6:00 | | |
| | | 11/29/2019 10:00 | |
| | 12/24/2019 6:00 | 12/24/2019 6:00 | |
| | | 12/26/2019 9:00 | |
| 1/21/2020 21:00 | 1/21/2020 21:00 | | |

Source: LBNL

## System Level

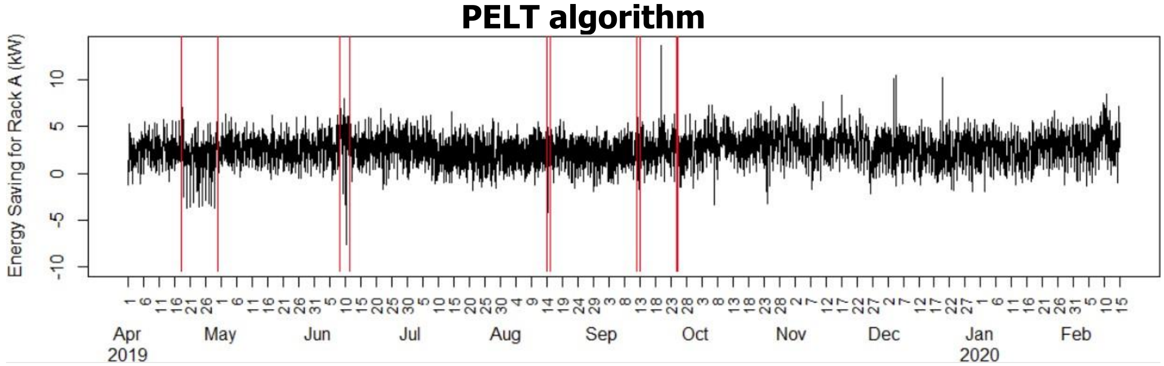
A major portion of the energy consumption at the store is attributed to the refrigeration system. To identify potential anomalies related to the refrigeration system, similar to what was done at the whole facility level, Rack A and B energy consumption was analyzed by looking at the residuals (the difference between model predicted energy consumption and the actual energy consumption) to detect potential anomalies in energy performance. Both the variance and mean of these residuals were used to detect the changes in the energy consumption pattern. In the following analysis, we investigated the changes related to the mean using a binary segmentation algorithm, assuming eight change points (Figure D-32). Alternatively, the PELT algorithm also was employed to detect the change points (Figure D-33 and Figure D-34) where a change in variance was observed. CROPS method was used to evaluate the various time periods or segmentations in order to obtain an optimal choice for the cost function using the PELT algorithm. Based on this analysis, we found several change points that are worth investigating and confirming with the field personnel. For example, one of the events was detected on 1/10/2020 9:00 for Rack B due the sub- cooler not working and as a result making the compressors working harder (see Figure D-34 and Figure D-35).

**Figure D-32: Plot showing eight detected change points for Rack A (top) and eight change points for Rach B as detected by the binary segmentation algorithm.**



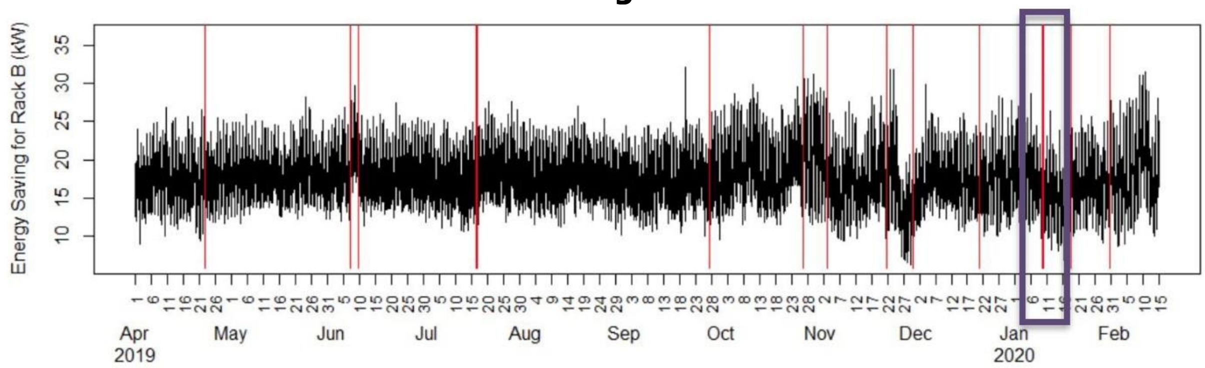

Source: LBNL

**Figure D-33: Plot showing ten detected change points for Rack A as detected by PELT algorithm**



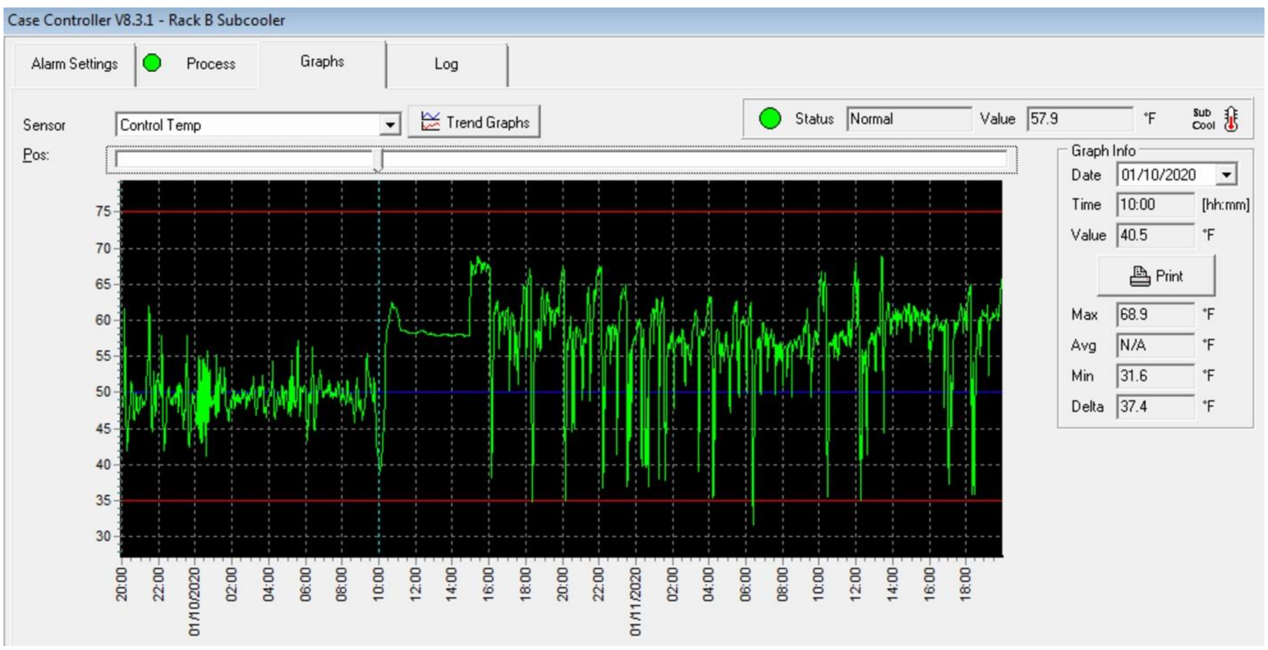

Source: LBNL

**Figure D-34: Plot showing ten detected change points for Rack B as detected by PELT algorithm**




Source: LBNL

**Figure D-35: Sub cooler failure on January 10, 2020 starting between 9am and 10am.**

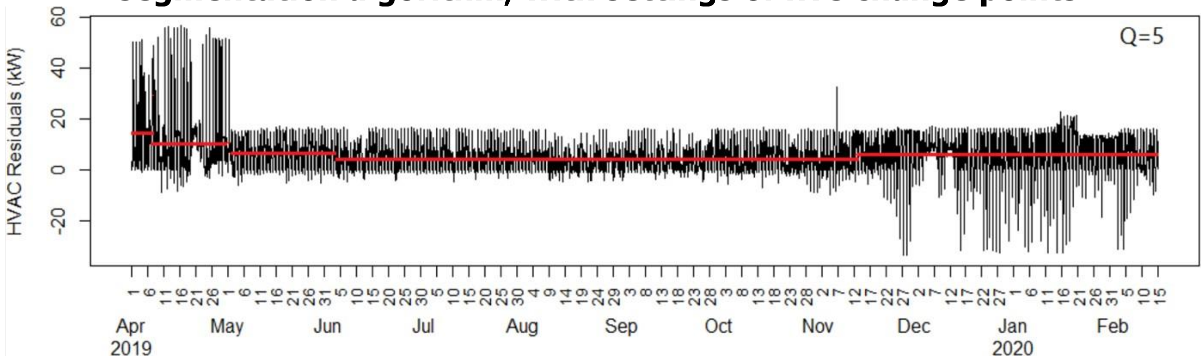



Source: LBNL

### EnergyPlus Model as a benchmark for performance

In addition to using the statistical model as benchmark for performance, we also analyzed the data with the EnergyPlus model as a reference point for analyzing the performance of the HVAC and refrigeration system. The analysis was conducted on the hourly residuals computed as the difference between the estimated energy consumption from the simulation model and the actual energy consumption for those systems. Based on mean values using the Binary Segmentation method, assuming 5 change points, the algorithm was able to identify several events that are worth investigating (Figure D-36). For instance, the algorithm detected an event 2019/05/01 22:00:00, which was corroborated from the field that the electrical resistance in the AHU was activate through May 1st.

**Figure D-36: HVAC system residuals change points detected by the binary segmentation algorithm, with settings of five change points.**




Source: LBNL

## Observations

Based on the change point analysis, some of the change points that were identified had anomalous energy consumption coincided with the Thanksgiving and Christmas holidays, when some operational changes were reported by the facility personnel. Some additional events around April and May 2019 were also picked up as the facility was going through installation of energy conservation measures during that time period.

The number of change points is a function of how sensitive the algorithm is to the change. If the number of change points is set to too low, the algorithm can detect small but permanent changes. The number of change points can be adjusted based on the sensitivity of detection desired, the data quality (the amplitude of noise), as well as the target indicated in the records. From a statistical significance point of view, the number of change points can be optimized by the CROPS algorithm when the detection method is PELT. It is very important to corroborate this with information from the field in order to identify the cause of the change points and quantify the effect of the change.

On the other hand, for those change points that were identified by the algorithm at the facility level but cannot be found in the records, it can be helpful to analyze the sub meter data if possible, to understand if any additional insights can be gained. It is also important to distinguish these events that are caused by the installed measures not working versus the events that are caused by exogenous factors like higher demand in stores or increased in operating hours.

# 7.0 Lessons Learned

Refrigeration systems are sometimes called the "heart" of grocery stores because they are essential to the store's operation and critically important for food safety. Stores usually have dedicated control systems to manage the refrigeration system. These control systems usually are connected to the Internet and have alarming functionality so that a technician can remotely diagnose the problem and dispatch a service technician before the ice cream melts. These are 24 hour a day services. This level of attention to a refrigeration system is in stark contrast to the operation of rooftop units (RTUs) that provide space conditioning—also known as heating, ventilation and air conditioning (HVAC) units. In contrast to the complexity of refrigeration systems, RTUs are often sold as a packaged system that has fairly basic controls embedded in the device that are programmed at the factory. A thermostat is often the only external communication element for an RTU. The building operator sets the temperature and schedule, and the RTU provides the service.

For this project, the team developed a custom sequence of operation (SoO) in order to pursue the most energy efficient operation of the unit. This custom SoO was more complex than the usual factory standard operation, and it resulted in a lot of troubleshooting and reprogramming of the units. One issue that was discovered during the M&V process was a programming error that resulted in electric resistance heating being utilized for space heating instead of the heat pumps, which are roughly three times more efficient. The electric space heating option was only intended as a backup heat source in case the heat pumps failed. Another discovery was that, at some point, the fan on the RTU was overridden to run at maximum speed (100 percent) all the time, which prevented energy efficient operation of the units.

It is our recommendation that a custom SoO should only be implemented if there are enough resources in a project to carefully observe the operation of the RTU over a period of at least six months. Research underway at Berkeley Lab and other partners is addressing the issue with proper implementation of specified control sequences.

The Open Building Control[41] project has defined a Control Description Language that can be used during design, simulation, implementation and commissioning of building systems such as RTUs. This common language can help reduce mistakes and misunderstandings during the design and construction process.

This project used detailed computer simulation models to predict savings from various measures. The overall savings predictions from the models (40 percent) was close to the actual savings (44 percent), but there were large errors in savings predictions for some ECMs. It is difficult to build calibrated simulation models when there is limited sub metered data available. As described in chapter 5, the gas usage prediction was 83% different between the savings prediction from the simulation model and the actual savings in the store.

# 8.0 Conclusion

This project analyzed the energy savings from a retrofit of the San Francisco Noe Valley Whole Foods grocery to reduce the store's refrigeration, lighting, and HVAC energy. It showed that it was possible to achieve a 44 percent energy savings by conducting a retrofit in a store even when it remains in operation during the entire construction period.

The largest energy savings were achieved by reducing the natural gas consumption. Measures that reduce a store's natural gas consumption can result in a large impact on overall energy savings because of the large embodied energy of natural gas and the low efficiency of many gas appliances. For example, the gas-fired rotisserie for roasting chicken was an open appliance, with flames exposed to the surroundings. These exposed flames heated the environment as well as the chicken, which resulted in additional cooling load and wasted natural gas.

Adding doors to refrigerated cases in supermarkets has a large effect on the refrigeration energy, but it also can make the store more comfortable and reduce the need for space

[41] Wetter, Michael, Jianjun Hu, Milica Grahovac, Brent Eubanks, and Philip Haves. "OpenBuildingControl: Modeling feedback control as a step towards formal design, specification, deployment and verification of building control sequences." In Proc. of Building Performance Modeling Conference and SimBuild, vol.775782. 2018.

heating to compensate for heat escaping into the refrigerated cases and reducing the store temperature.

It is important to pay close attention to the performance of “emerging technologies”' or novel control sequences because these might not always perform as expected without sustained observation and feedback to the manufacturer.

Natural gas savings of 90 percent were realized in this project, as well as 21 percent electricity savings, resulting in a combined savings of 44 percent. The energy use intensity for this store was reduced from 215 to 120 kBtu/sf/yr.

As part of this work, to ensure persistence of energy savings, we employed change point detection to detect anomalies in energy. Based on this analysis, we flagged several events that are worth investigating and some of which were confirmed by store personnel. Some of these events were during the Thanksgiving and Christmas holidays, when some operational changes were reported by the facility personnel. Some additional events were also detected by the algorithm as the facility was going through installation of energy conservation measures during that time period and issues related to malfunction of some systems.

# GLOSSARY/ACRONYMS

| Term | Definition |
| --- | --- |
| CROPS | Changepoints for a Range of Penalties |
| CVRMSE | Coefficient of Variation of the Root Mean Squared Error |
| DHW | Domestic Hot Water |
| ECM | Energy Conservation Measure |
| EPW | EnergyPlus Weather file |
| EUI | Energy Use Intensity |
| HVAC | Heating Ventilation and Air Conditioning |
| IPMVP | International Performance Measurement & Verification Protocol |
| kWh | Kilo Watt Hour |
| LED | Light Emitting Diode |
| M&V | Measurement and Verification |
| MMBtu | Million British Thermal Units |
| NMBE | Normalized Mean Bias Error |
| NTB | Net Determination Bias |
| PCM | Phase Change Material |
| PELT | Pruned Exact Linear Time |
| RTU | Roof Top Unit |
| TES | Thermal Energy Storage |
| TOWT | Time of Week and Temperature |
| VFD | Variable Frequency Drive |
| VKS | Viking Cold Thermal Energy Storage System |

# ATTACHMENT D-1

**Table D-16: Summary of the change point detection analysis of the whole facility data**

| Rack A BinSeg-8 Change Points | Rack B BinSeg-8 Change Points | PELT-Rack A | PELT-Rack B | Description |
|---|---|---|---|---|
| | | 4/18/2019 7:00:00 | | |
| 4/19/2019 00:00:00 | | | | |
| | 4/21/2019 8:00:00 | | | |
| | | | 4/22/2019 21:00 | |
| | | 4/30/2019 4:00:00 | | |
| 5/1/2019 6:00:00 | | | | |
| | | | 6/7/2019 12:00 | |
| | | 6/8/2019 9:00:00 | | |
| | | | 6/9/2019 21:00 | |
| | | 6/11/2019 18:00:00 | | |
| 7/8/2019 23:00:00 | | | | |
| | | | 7/16/2019 19:00 | |
| | | | 7/17/2019 0:00 | |
| | | 8/14/2019 12:00:00 | | |
| | | 8/15/2019 17:00:00 | | |
| | | 9/12/2019 11:00:00 | | |
| | | 9/13/2019 17:00:00 | | |
| | | 9/25/2019 12:00:00 | | |
| | | 9/25/2019 18:00:00 | | |
| | | | 9/27/2019 23:00 | |
| 10/1/2019 4:00:00 | | | | |
| | 10/4/2019 8:00:00 | | | |
| | 10/12/2019 23:00:00 | | | |

| Rack A BinSeg-8 Change Points | Rack B BinSeg-8 Change Points | PELT-Rack A | PELT-Rack B | Description |
|---|---|---|---|---|
| | 10/22/2019 14:00:00 | | | |
| | | | 10/27/2019 10:00 | |
| | | | 11/3/2019 19:00 | |
| | 11/4/2019 19:00:00 | | | |
| | | | 11/22/2019 12:00 | |
| 11/24/2019 3:00:00 | | | | |
| | | | 11/30/2019 14:00 | |
| | | | 12/21/2019 12:00 | |
| | | | 1/10/2020 9:00 | Sub-cooler stopped working |
| | | | 1/10/2020 14:00 | |
| | | | 1/19/2020 8:00 | |
| 1/19/2020 11:00:00 | | | | |
| | | | 1/31/2020 14:00 | |
| | 2/8/2020 10:00:00 | | | |
| 2/9/2020 4:00:00 | | | | |
| 2/11/2020 21:00:00 | | | | |
| | 2/12/2020 19:00:00 | | | |
| | 2/15/2020 8:00:00 | | | |

Source: LBNL