Big Savings in Small Grocery Stores

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ABSTRACT

Grocery stores are highly competitive businesses and operate on a very thin profit margin. One of the biggest expenses is the electric bill, which in small grocery stores can frequently exceed profits. According to end-use data from the California Energy Commission (CEC 2000), indoor lighting accounts for 26% and refrigeration for 38% of total energy usage in a typical food store. Grocery store lighting and refrigeration systems represent a fertile ground for potential energy savings.

This paper presents the results of a utility sponsored lighting and refrigeration technology retrofit project in a small grocery store in Santa Monica, California. The demonstration project assessed the benefits of improved indoor lighting and a sophisticated energy-efficient refrigeration system in a small grocery store environment. The project ascertained the retrofit solution impacts on:

1. Electric demand and energy usage
2. Owner profitability (based on electric utility bills)
3. Sales environment
4. Merchandising capacity
5. Human comfort
6. Environmental friendliness of the refrigeration system

Implementation of energy-efficient lighting and refrigeration technologies reduced lighting power demand by 22% and cut refrigeration power demand by up to 22%. During the post-monitoring period, the new energy-efficient retrofit system also reduced energy use of both lighting and refrigeration by 23%, each. Other benefits of the lighting and refrigeration system were:

- Improved human comfort by maintaining relatively constant indoor dry-bulb temperature regardless of ambient temperature fluctuations
- Improved sales environment through a 43% increase in store luminosity
- Increased merchandising volume by 60 cubic-feet

Background

In general, small grocery store owners and operators do not take any energy efficiency actions due to lack of knowledge about viable technologies and perceived risks of technology adoption. Absent intellectual and financial resources for investigating the benefits of technologies, the role of utilities is to educate and train these customers. Additionally, due to tight profit margins the store owners and operators require utility incentives to offset the incremental cost of technologies.

The main objective of this project was to obtain key information for the local utility on the effectiveness and applicability of typical large grocery store energy efficiency measures (EEMs) in a small grocery store. If successful, this information could be used by the utility to aid in the development of an incentive program for an effective retrofit package based on these measures. The project involved retrofitting lighting and refrigeration systems in a small, 2,000 ft^2, grocery store located in the coastal region of Southern California Edison (SCE) service territory.

The utility's interest in this project and the information that would be gained was the catalyst for this retrofit. The importance of this project in determining feasibility and effectiveness, as well as the program implications, allowed for the retrofit project cost to be completely offset by the utility. Therefore, capital cost was not a criterion for technology selection. The total lighting and refrigeration retrofit cost was about $73,000. The lighting system retrofit accounted for roughly $2,000 and the refrigeration system retrofit a little over $71,000. The average small grocery store owner is not anticipated to implement all of these EEMs in one project due to the large capital cost involved.

Study results were used to train store operators about the true benefits and viability of the applicable technologies. The results also verified the performance and effectiveness of the measures offered in statewide energy efficiency programs. In addition, the results were used in educational and training outreach activities.

Approach

This project employed a multi-faceted approach to select viable EEMs and to determine their true impact when implemented. The steps taken were:

- Perform an on-site audit, review billing data, and interview the store owner and operator to identify potential energy efficiency opportunities.
- Select applicable and suitable solutions by focusing on energy efficiency, improved operational economics and not necessarily first cost.
- Design new energy-efficient refrigeration and lighting systems.
- Conduct short-term (24 days) monitoring of baseline systems.
- Install new energy-efficient refrigeration and lighting systems.
- Conduct short-term (24 days) monitoring of new energy efficient systems.

On-site data collection. On-site data was collected before and after implementing the EEMs. The data collection period for the baseline or pre-retrofit system was 24 days. Data collection began on February 14, 2004 and ended on March 8, 2004. The data collection period for the new or post-retrofit system was also 24 days. Data collection for the new system started on June 8, 2004 and ended on July 1, 2004.

The data acquisition system processed 25 data channels in 15-minute intervals. The collected raw data was then further processed and analyzed. The general monitoring points included:

- Building total power (kW)
- Refrigeration system power (kW):
  - Compressor power
  - Evaporator fan power

  - Condenser fan power
  - Anti-sweat heater (ASH) power
  - Electric defrost power
- Lighting system power (kW):
  - Indoor (or sales area) lighting power
  - Outdoor lighting power
- Dry-bulb temperature (DB) and relative humidity (RH):
  - Indoor (or sales area)
  - Outdoor (or ambient)

Lighting System

Baseline Indoor Lighting System

There were 24 fixtures in the sales area lighting system. Each fixture was equipped with four T12 fluorescent tube lamps and one magnetic ballast. Out of a total of 96 T12 lamps, 22 lamps were burnt out. The remaining 74 operable lamps provided relatively low illumination levels for customers.

New Indoor Lighting System

The lighting retrofit primarily focused on the sales area, however, additional changes were made in other areas. The lighting retrofit measures implemented were:

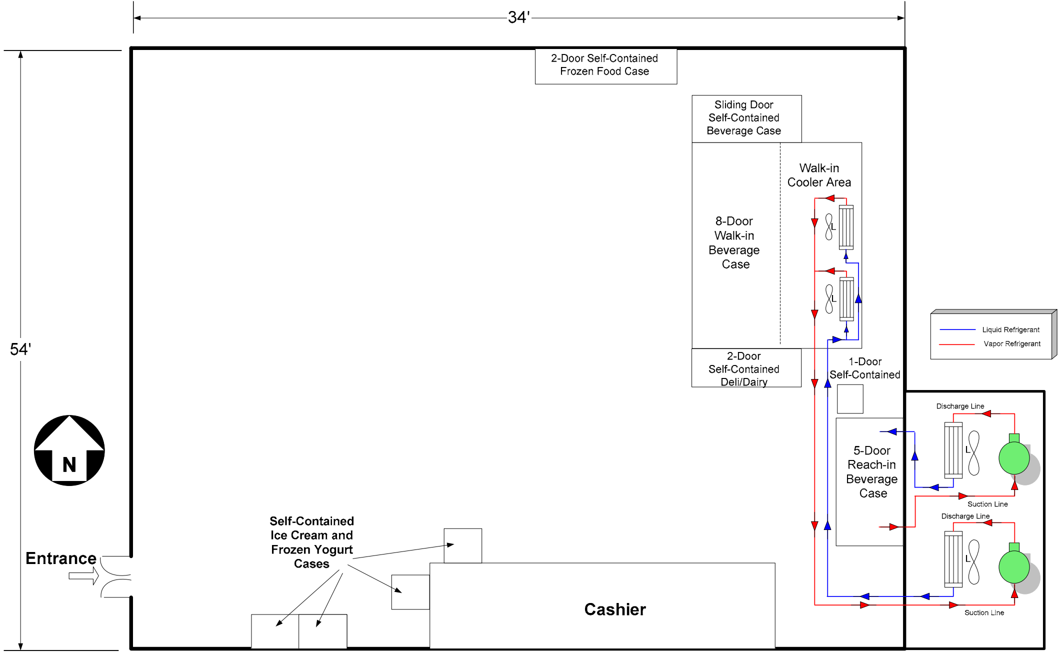
- Replacement of 96 T12 fluorescent lamps in the sales area with super T8 fluorescent lamps.
- Replacement of 24 magnetic ballasts in the sales area with low ballast factor electronic ballasts.
- Replacement of two 60-watt incandescent lamps in the restroom with two 15-watt compact fluorescent lamps.
- Replacement of six fixture lenses with identical new ones.
- Cleaning the inside of all 24 light fixtures.
- Installation of occupancy sensors in the storage area and restroom.
- Installation of a new 2 ft x 2 ft light fixture with two U-shaped T8 fluorescent lamps above the cash register area.

Refrigeration Systems

Baseline Refrigeration System

The store layout and baseline refrigeration system is shown in Figure 1. The baseline refrigeration system consisted of remote systems, as well as self-contained units.

Figure 1. Schematic Drawing of the Store Layout and the Baseline Refrigeration System



Remote systems. There were two medium-temperature remote refrigeration systems serving a walk-in cooler and a five-door reach-in display case. Both condensing units were located in the parking lot behind the store. The clearance between the condenser coils and the adjacent wall was tight, restricting airflow across both condenser coils. The airflow restriction was furthered due to an excessive collection of dirt between fins. The combined effects of the airflow restriction and dirt accumulation on the coils hampered the ability of the condenser to reject heat.

The walk-in cooler, measuring 7ft W x 22ft L x 8ft H, was used to merchandize beverages such as milk, soft-drinks, fruit juices and beer. The walk-in had eight glass doors and a single, main, solid door. The evaporator coil of the walk-in cooler was equipped with five standard shaded pole fan motors. The condensing unit of the walk-in was comprised of a condenser equipped with two fans and a reciprocating compressor.

The five-door reach-in display case, measuring 2ft W x 10ft L x 5ft H, was used to merchandize soft-drinks and wine. The condensing unit serving this display case was comprised of a condenser with a single fan and a reciprocating compressor.

Self-contained units. The store had eight self-contained refrigeration units. Four were used to merchandize frozen food, soft-drinks, fruit juice, and dairy/deli products. The other four were used for point-of-sale products such as ice cream and frozen yogurt. The four point-of-sales units were located at the entrance of the store next to the cash register area. Shoppers tended not to completely close the sliding doors of these units, leading to severe frost or ice accumulation inside these units.

Overall, these self-contained units were found to be poorly maintained. Inspecting the refrigeration equipment revealed traces of neglected maintenance (Figure 2). For example, the condenser coils were dirty (Figure 2a), anti-sweat heaters (ASH) of walk-in and reach-in glass doors were not in operation (Figure 2b), walk-in glass door gaskets were worn, and the doors were not closing tightly due to misalignment (Figure 2c).

Figure 2. Samples of Neglected Maintenance

(a) Dirty Condenser (b) Disconnected ASH (c) Misaligned Doors

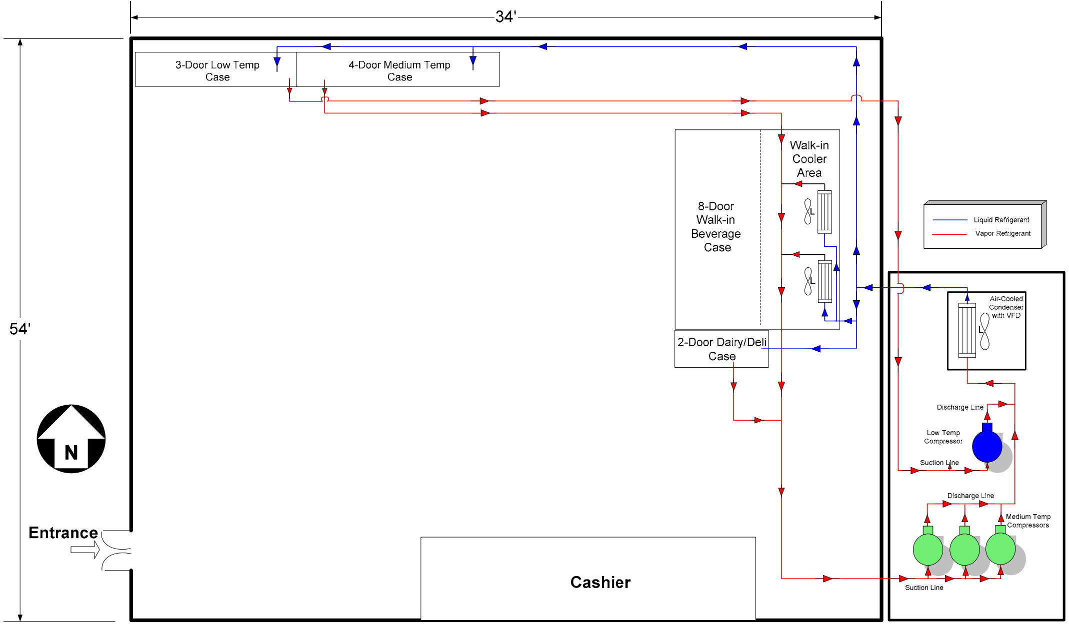
New Refrigeration System

A centralized multiplex system was selected for the new refrigeration system. The conversion to the new refrigeration system required removing all eight existing self-contained units and the five-door reach-in remote system. The baseline walk-in cooler was retained. The conversion also required furnishing a new three-door reach-in freezer case, a four-door reach-in beverage case, and a two-door reach-in dairy/deli case. The extent of the changes are shown in Figure 3.

The changeover to the multiplex system required a major overhaul of the store's refrigeration system. The extensive changes allowed for additional EEMs to be considered and implemented. The new refrigeration system had these main components:

- A low-temperature (-25^{o}F suction) group served by a single 1-horsepower (hp), compressor.
- A medium-temperature (+25^{o}F suction) group served by three 1-hp compressors.
- A single air-cooled condenser serving both temperature groups.
- An energy management system (EMS) to control: compressor, condenser fans, temperature and pressures, and defrost initiation and termination.
- Environmentally friendly R-507 refrigerant.

Figure 3. Schematic Drawing of the Store Layout and the New Refrigeration System



New low-temperature group (-25°F Suction). The low-temperature group was served by a single 1-hp reciprocating compressor with a cooling capacity of 6,200 Btu/hr at a design saturated condensing temperature (SCT) of 100°F and suction temperature of -25°F. The low-temperature group was designed to provide a case temperature or discharge air temperature (DAT) of -15°F. The low-temperature group served a customized three-door reach-in freezer display case, measuring 3ft W x 9ft L x 8ft H, for storing frozen food and ice cream.

The energy efficiency features of the freezer box were three special glass doors that require low ASH connected load using electric heaters on the doorframe only, as well as three permanent split capacitor (PSC) type evaporator fan motors. Additionally, the time initiated and temperature terminated electric defrost system (8.1A, 230V, single phase) was set for two defrosts per day with a 35-minute fail safe period and termination temperature of 50°F.

New medium-temperature group (+25°F Suction). The medium-temperature group was served by three 1-hp reciprocating compressors. The EMS controller staged the compressors to match the load with capacity. The total cooling capacity of this temperature group was 27,900 Btu/hr (each capable of providing 9,300 Btu/hr of cooling) at a design SCT of 100°F and suction temperature of +25°F. The medium-temperature group was designed to provide a case temperature, or DAT, of +35°F for the walk-in cooler, the new four-door reach-in beverage display case, and the new two-door reach-in dairy/deli display case.

Walk-in Cooler Improvements. The envelope of the walk-in cooler remained unchanged, while the retrofit effort focused on the energy efficiency features. The improvements included replacing five shaded pole motors with electronically commutated motors (ECM), replacing eight standard and misaligned glass doors with special glass doors requiring low ASH connected load, and using a liquid-to-suction heat exchanger (LSHX). A temperature termination defrost system replaced the time termination defrost system. The new defrost system operated based on four defrosts per day with a 60-minute fail safe period and termination temperature of 50°F.

New Customized Four-Door Reach-In Beverage Case and Two-Door Reach-in Dairy/Deli Case. The new four-door reach-in, measuring 3ft W x 11ft L x 8ft H, was used to hold beverages including soft-drinks, beer, wine, and fruit juices. The new two-door reach-in, measuring 3ft W x 6ft L x 8ft H, was used to hold dairy/deli products. The energy efficiency features of these display cases included special glass doors requiring low ASH connected load and PSC type evaporator fan motors. In addition, the time initiated and temperature terminated defrost system was set for two defrosts per day with a 45-minute fail safe period and termination temperature of 50°F.

Condenser. The new centralized multiplex system rejected its heat via a new, high efficiency air-cooled condenser with two PSC fan motors, and operated on a temperature difference of 10°F. Other energy efficiency features of the condenser included:

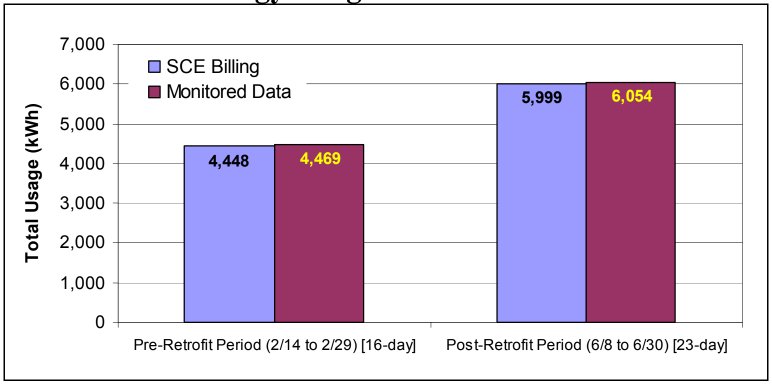
- Floating head pressures through fan cycling by an electronic controller and EMS system:
    - The lead fan was controlled by an electronic controller with a discharge pressure operating range of 175 psig to 250 psig.
    - The second fan was controlled by an EMS controller. It was designed to come on after discharge pressure exceeded 260 psig and the lead fan had reached its full speed.

Discussion of Results

Comparison of Monitored and Billing Data

To gain confidence in the on-site data collected, the monitored data was compared to the store's electric billing information. However, the billing data available was not for the same length of time as the on-site collection. This comparison only addresses days where both sets of data were available. As shown in Figure 4, during a 16-day pre-retrofit monitoring period, the store's electric billing data differed from the monitored data by only 21 kWh. In other words, there was only about 1 kWh difference in average daily energy usage between billing and monitored data during the pre-retrofit period. Similarly, during a 23-day monitoring period after the new equipment was installed, there was only a 55 kWh difference between the billing and monitored data. This translated to about a 2 kWh difference in average daily energy usage between billing and monitored data during the post-retrofit periods. As depicted, the on-site collected data were in excellent agreement with the store's electric billing data. It is important to note the months of the pre- and post-retrofit periods. The pre-retrofit store was monitored during February; where as the post-retrofit store was monitored during June. These two months have extremely different weather patterns, leading to the increased usage during the post-retrofit period seen in Figure 4.

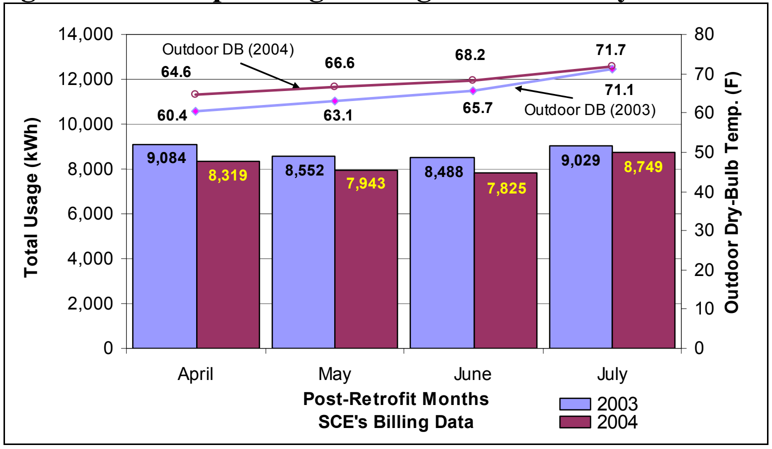
Figure 4. Comparison of Total Energy Usage Based on Monitored and Electric Billing Data



Seasonal Billing Comparison

The impact of refrigeration and lighting retrofits became evident by comparing post-retrofit billing data (2004) to the previous year's data (2003) over the same months, shown in Figure 5. The corresponding average outdoor DB temperatures, which were gathered from SCE's weather station, are also depicted in Figure 5. From this figure it can be concluded that the EEMs implemented did in fact reduce the energy usage, despite higher ambient conditions. The billing data comparison showed total electric usage reductions of 765, 610, 663, and 280 kWh for the months of April, May, June, and July, respectively.

Figure 5. Four-Month Comparison of Pre-Retrofit (2003) and Post-Retrofit (2004) Total Energy Usage and Corresponding Average Outdoor Dry-Bulb Temperatures

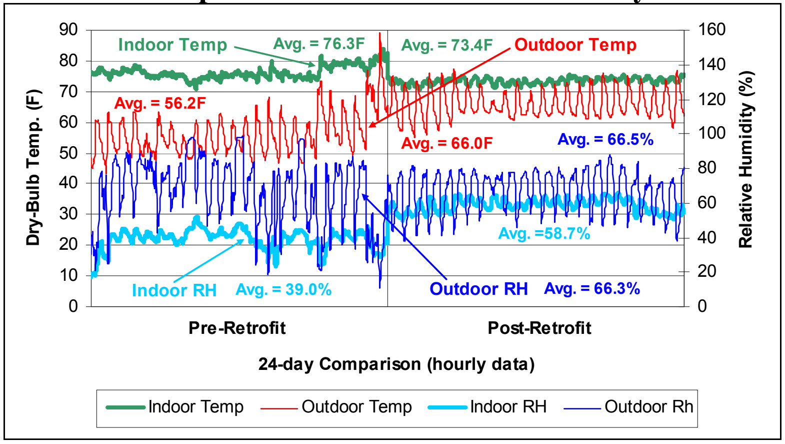


Indoor and Outdoor Dry-Bulb Temperature and Relative Humidity Comparisons

Figure 6 depicts the hourly profiles of indoor and outdoor DB temperatures and RH. The outdoor DB temperature was milder during pre-retrofit than post-retrofit periods. During pre-retrofit periods, the indoor DB temperature was significantly higher, whereas during post-retrofit periods the difference between indoor and outdoor DB temperatures was not as significant as the pre-retrofit periods. This observation is well explained by the fact that the pre-retrofit condensing unit for all eight self-contained refrigeration cabinets dissipated heat into the indoor environment, thereby increasing the DB temperature inside the store. Additionally, despite the larger variations in outdoor RH during pre-retrofit periods, the average outdoor RH was essentially the same during both periods. However, the indoor RH during pre-retrofit periods was lower than the post-retrofit periods. The increase in RH can be attributed to the decrease in indoor DB temperatures. In other words, provided that the absolute humidity ratio of outside and inside air does not change or the change is very minimal, any decrease in DB temperature will cause the RH to increase.

The indoor DB temperature and RH for both the pre- and post-retrofit situations were compared to ASHRAE requirements (ASHRAE 1993). The winter requirements, 68° F and 30% to 76° F and 23%, were used for the pre-retrofit comparison because pre-retrofit data was collected during winter months. The summer requirements, 72° F and 60% to 79° F and 60%, were used for the post-retrofit comparison because post-retrofit data was collected during summer months. Monitored indoor conditions were in closer agreement to the ASHRAE requirements during the post-retrofit period than the pre-retrofit period.

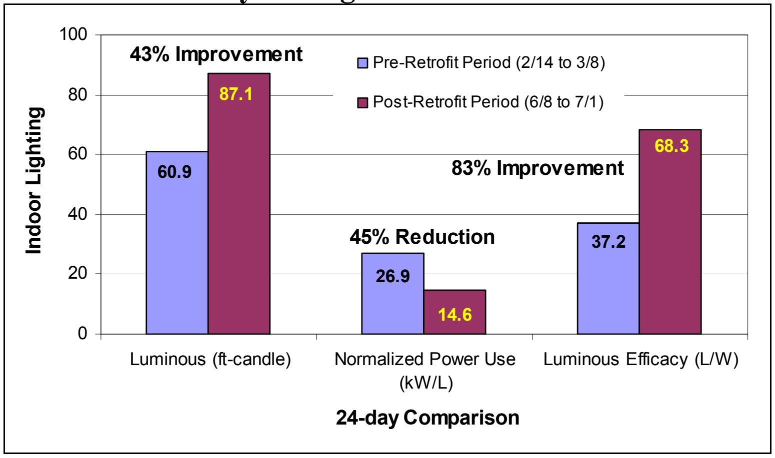
Figure 6. Pre- and Post-Retrofit Comparison of Hourly Indoor and Outdoor Dry-Bulb Temperatures and Relative Humidity



Indoor Lighting Luminosity, Efficacy and Power Comparisons

Figure 7 compares the indoor lighting system's luminosity, normalized power use, and luminous efficacy during pre- and post-retrofit periods. The weighted average sales area lighting intensity, or luminosity increased by 43% from 61 to 87 foot-candles during post-retrofit periods. The light intensity measurements for both pre- and post-retrofit systems were done at 1:00 PM and 3 ft above the floor level. For both pre- and post-retrofit systems, the measured light intensity levels, or horizontal illuminance, were above the recommended value of 50 foot-candles for supermarkets (IESNA 2000). Although the lighting intensity increased during post-retrofit periods, the power required per lumens decreased by 45%, from 27 to 15 kW/lumens. In other words, the luminous efficacy, which is lighting intensity per connected load of lighting, was improved by 83%.

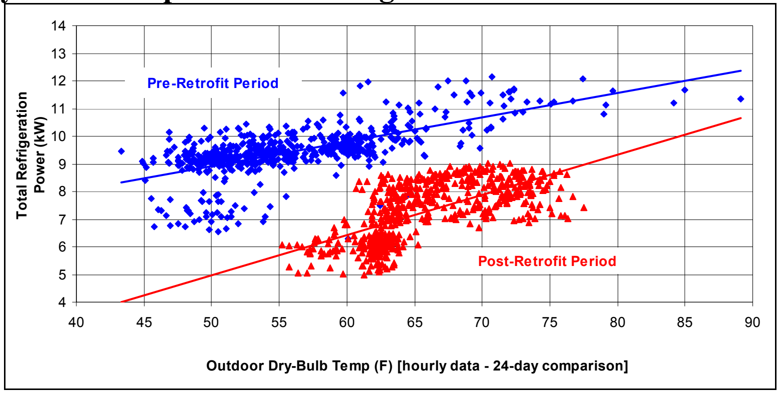
Figure 7. Comparison of Indoor Lighting Luminosity, Normalized Power Use, and Luminous Efficacy during Pre- and Post-Retrofit Periods



Comparison of Refrigeration Power Demand as a Function of Ambient Temperatures

Figure 8 shows the variations of refrigeration power demand with outdoor DB temperatures. As depicted, the refrigeration power demand during pre- and post-retrofit periods increased as a function of ambient temperatures. The post-retrofit results clearly indicated a noticeable reduction in refrigeration power. The reduction in power use provided by the new refrigeration system can be attributed to reduced heat gain of the display cases resulting from the improved indoor lighting and the removal of the self-contained refrigeration units.

Figure 8. Comparison of Total Refrigeration Power Demand as a Function of Ambient Dry-Bulb Temperatures during Pre- and Post-Retrofit Periods



End-Use Power Demand (kW) and Energy Usage (kWh) Comparisons

Figure 9 illustrates the power demand, based on 15-minute data collection intervals over the 24-day period, by end-use. The power requirement for indoor lighting was reduced by 22%, from 2.90 kW to 2.26 kW. This reduction was accomplished despite the fact that during the pre-retrofit period only 74 out of 96 fluorescent lamps were on, whereas during post-retrofit all 96 fluorescent lamps were on. Another significant observation in Figure 9 is the 22% reduction in the refrigeration power requirement. The increase in power demand for the exterior lighting system and the miscellaneous electric load were due to minor changes made in the store by the owner, not as part of this project. Despite increases in exterior lighting and miscellaneous electric load in the store, the lighting and refrigeration EEMs implemented reduced the total building power demand by 18%.

Figure 9. End-Use Maximum Power Demand during Pre- and Post-Retrofit Periods

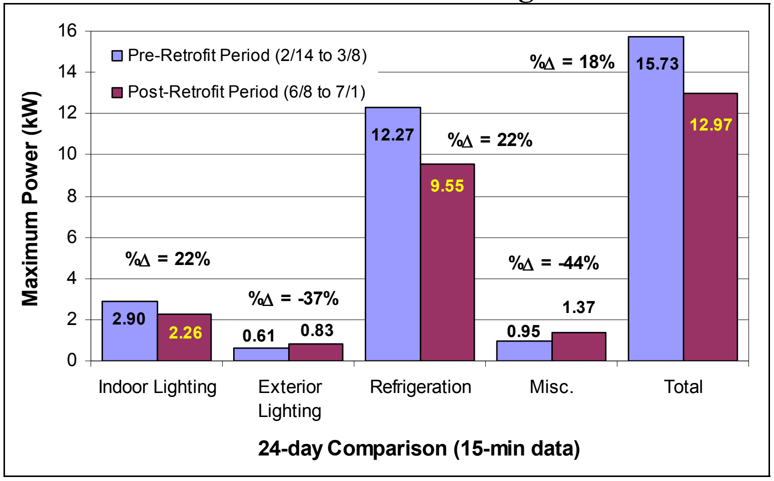
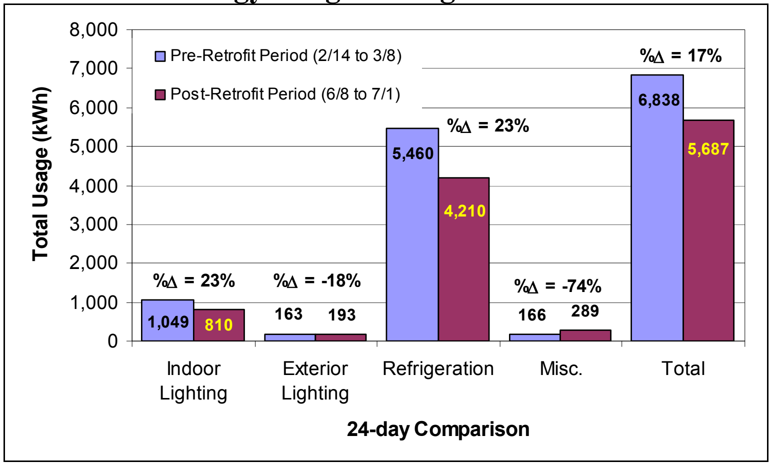


Figure 10 depicts the total energy usage by each end-use. Both the indoor lighting and refrigeration systems consumed about 23% less energy during the post-retrofit period when compared to the pre-retrofit period. These reductions were accomplished largely by reducing the end-use power requirements. In spite of the increase in power usage by exterior lighting and miscellaneous electric load in the store (see Figure 9), the total energy usage was reduced 17% by this retrofit project.

Figure 10. End-Use Energy Usage during Pre- and Post-Retrofit Periods



Conclusions

The EEMs implemented in the store significantly improved operations despite higher outdoor DB temperatures during the post-retrofit period. Specific improvements include:

- Reduced energy usage and maximum electric demand, quantified based on measured data for pre- and post-retrofit periods:
  - Storewide energy usage by 17% and electric demand by 18%.
  - Refrigeration system energy usage by 23% and electric demand by 22%.
  - Indoor lighting system energy usage by 23% and electric demand by 22%.
- Based on billing data, a comparison of the pre-retrofit to post-retrofit months showed total energy savings ranged from 280 to 765 kWh ($40-100) per month.
- Increased sales area brightness, measured in foot-candles, by more than 40%.
- Increased merchandising volume by about 60 cubic-feet.
- Reduced store indoor DB temperature by an average of 2.9°F resulting in improved human comfort.
- Increased sales potential as a result of added merchandising volume and improved human comfort levels.
- Improved environmental friendliness of refrigeration system by using alternative refrigerant R-507 with zero ozone depletion potential.

At the end of the project, the store owner was interviewed to ensure that the energy efficiency measures had truly improved his business economics. According to the store owner, this project resulted in increased revenue and reduced energy cost, ultimately improving his profit margin.

References

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