

Cool Retrofit Solutions in Refrigerated Display Cases

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ABSTRACT

Supermarkets consume roughly 50 kWh per square foot in electricity—one of the highest energy use intensities of all building types. Refrigeration accounts for nearly 50% of electrical energy use and 30-40% of that is utilized by refrigerated display cases. Historically, display case manufacturers have not invested much in energy-efficiency improvements of their products. This has primarily been due to the lack of energy efficiency standards and the fact that electricity accounts for a small portion, only 2%, of total supermarket operating costs. (SCE RTTC 2007)

Retrofitting display cases can significantly improve the energy use of refrigeration equipment. This paper presents laboratory tests results of several energy-efficient retrofit technologies for refrigerated reach-in display cases. These measures are intended to impact energy use of display cases due to improved lighting, the use of anti-fog film, and reduced infiltration from improved door gaskets.

Fiber Optic, LED, and Cold Cathode Lighting

Standard T-8 fluorescent lighting was compared with LED, fiber optic and cold cathode lighting in a low temperature display case. Lighting quality, direct lighting power consumption, and secondary effects on refrigeration system (due to heat dissipation) were examined. Total estimated annual energy savings in California Climate Zone (CTZ) 9 were 314 kWh for LED, 556 kWh for fiber optic, and 444 kWh for cold cathode, each savings on a per door basis. CTZ 9 was selected to represent an “average” climate.

Anti-Fog Film for Glass Doors

This technology is applied to the inner surface of glass doors to prevent fog formation when the door opens. Manufacturers claim that the need for anti-sweat heaters can be greatly reduced or eliminated, saving over 900 kWh per door annually (RTTC 2007).

Door Gasket

Gaskets often wear out due to the harsh treatment they receive in the store environment. However, there is very little research quantifying the effects of the resulting air leakage on refrigeration energy consumption. This study quantified the cooling load impact of improperly maintained glass door gaskets, and the resulting compressor demand implications. Annual energy savings ranged from 4 to 22 kWh per foot of gasket replaced, depending on climate zone and application.

Lessons learned from these projects will enhance Southern California Edison (SCE) energy efficiency incentives and could provide meaningful data to reformulate both state and federal codes and standards.

Test Methodology

A series of laboratory experiments was conducted by SCE's Refrigeration and Thermal Test Center (RTTC) on a 3-door reach-in low temperature (LT), or "freezer", display case. Tests were conducted at the RTTC according to ASHRAE Test Method 72-2005 "Methods of Testing Commercial Refrigerators and Freezers" (ASHRAE 2005). This standard requires monitoring certain key variables within the display case, as well as ambient conditions inside the test chamber. A LabVIEW-based data acquisition system was used to record measurements every minute over the 24-hour test period. One deviation from the test method was made for the lighting and door gasket tests, in that, the glass doors were not opened according to the specified schedule. The intent was to remove inconsistencies in cooling load caused by infiltration and to focus solely on the effects of these technologies. For the anti-fog film test, doors were opened as required due to the interest in fog formation and clearing time.

In addition to testing the lighting systems under ASHRAE Test Method 72-2005, a series of light quality tests was performed. These tests were designed to assess the lighting technologies for luminance, uniformity, and glare. The analysis from these tests and a more thorough description of the test setup are included in the lighting technologies section.

Lighting Technologies

Background

Typical display cases use fluorescent lighting systems that introduce a significant amount of heat into the cold space. New lighting technologies, such as the Light Emitting Diode (LED), Fiber Optic (FO), and Cold Cathode (CCFL) systems, claim to consume less power and provide improved light quality for merchandising while reducing the amount of heat introduced to the cold space.

In 2006, the RTTC conducted a series of tests to compare the performance of T8, LED, and FO systems (SCE RTTC 2007). Due to rapid technological advances, some of the products tested in this project have been superseded with newer, better performing models, especially in the LED system. Though not included in the laboratory tests, supplemental information is also provided for CCFL systems based on a very limited investigation.

T8 fluorescent. For many years, T12 lamps with magnetic ballasts were the standard lighting system in refrigerated display cases. T12s have essentially been phased out of new equipment. Today, the industry standard lighting system is T8 fluorescent with electronic ballast. The 3-door display case used for testing was equipped with four 5-foot T8 high-output (HO) lamps mounted vertically behind the door frame and two electronic ballasts, each serving two lamps. These lamps are special HO lamps designed for low temperature applications. Unfortunately, in stores they are often replaced with standard, low efficiency, 40W T8 lamps, which are less expensive.

The cold temperatures of refrigerated cabinets cause fluorescent lamps to flicker and have reduced life. To improve performance of fluorescent lamps, a rounded plastic lens houses the lamp. The dissipated lamp heat is then trapped within the lens assembly, resulting in higher operational temperature for the lamp. However, these lens assemblies can not trap all of the heat

generated by the lamps. The heat that can not be sequestered is dispersed into the refrigerated cabinet, creating more work for the compressor.

LED lighting. Today, the refrigeration industry is very interested in LED lighting systems. LED manufacturers have claimed many benefits for their products which have caught the attention of display case manufacturers and case operators. Some of their claims include:

- Lower power demand.
- Less heat into the case, resulting in compressor energy savings.
- Longer operating life.
- Even distribution of light across the shelves.
- Invisible light source so merchandise is highlighted.
- Dimmability and programmability to reduce demand and energy consumption during low-traffic periods.
- Impact resistant so the worry of potentially-hazardous lamp breakage is avoided.

LEDs are semiconductor devices that emit light when there is a proper amount of current in the semiconductor material. An LED driver is required to properly regulate the current to the LED, similar to a ballast for a fluorescent system. LED light can vary in color and, for white light, color quality as well. There are two ways to achieve white light with LEDs. One way is to use a mix of red, green, and blue LEDs. The other, more popular method, which is used in this project, uses blue LED with a phosphor to produce white light. Like all semiconductor materials, LEDs generate heat which causes their performance to degrade as the surrounding temperature increases. This heat is typically dissipated through a heat sink. Some products have integrated heat sinks that use the fixture itself as the heat sink material.

The LED lighting system used in this study was chosen because it was commercially available from the display case manufacturer. At the onset of this project, the LED system under study was believed to be the most advanced market-ready LED system for display case applications. However, since the inception of this project, rapid advances in LED technology have led to superior performing products. The tested technology is comprised of a linear strip of LEDs mounted on a reflective background separated by reflective diffraction housings. In order to create even light distribution throughout the display case, each center fixture has 32 individual LEDs and the two side fixtures have 16 LEDs. Two power supplies installed in the electrical raceway drove the four LED fixtures.

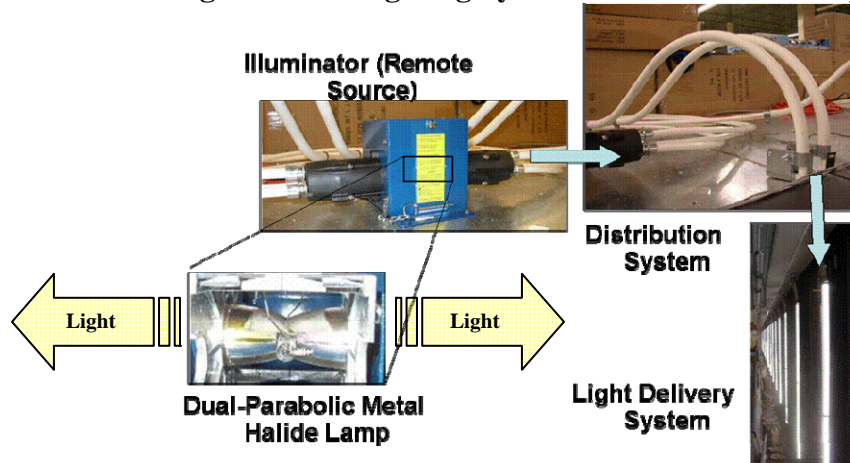
Fiber optic lighting. FO lighting is another innovative solution, but has not yet experienced the same degree of popularity as LED. Manufacturers of FO lighting systems have offered the following claims of supremacy over T8 fluorescent:

- Reduced power demand.
- Removed heat generating light source from cold space, resulting in compressor energy savings.
- Longer operating life.
- Even distribution of light across the shelves.
- Improved directional control, greatly reducing light spillage into the aisle.
- Easier lamp change-out.

- Less potential for hazardous lamp breakage because the light bulb is moved to an out-of-reach location.

The basic premise of FO lighting systems is that a remote light source feeds light into a fiber distribution system which is then dispersed by a light delivery fixture. This setup allows the light to reach the products, but moves the heat generating light source outside the refrigerated space; thus reducing work of the compressor. Figure 1 is a collection of photographs taken of the installed FO lighting system, showing the various components.

Figure 1. FO Lighting System Overview and Lamp Detail



Typically, heat generated from the FO light source is dissipated to the surrounding environment of the display case. This heat will slightly increase the thermal load imposed on the HVAC system that provides comfort cooling in supermarkets. From a previous study (RTTC 2006), the estimated added thermal load in the HVAC system from a FO light source is roughly 85 Btu/hr per door.

The system studied here is commercially available for display case retrofit applications and claims to provide better light quality than other FO products on the market. As with LEDs, there is rapid development in this technology (including using LED light sources) and several manufacturers with competing products. The performance of these systems should also be re-evaluated on a recurring basis.

In this particular system, the light source was a 68 W dual-parabolic cloverleaf metal halide lamp. The unique configuration of this lamp allows all light to be focused in two directions, as indicated in Figure 1. Light is then fed into three large diameter fibers butting up to each end of the lamp. The light travels through a flexible fiber into the refrigerated space, where it is connected to a luminaire mounted on the inside of the door frame. The rigid fiber luminaire has an array of reflective media on one side which controls how and where light is emitted from the rod. One benefit of the reflective media is it can be used to expel extra light at the top of the rod in order to properly illuminate the top shelf. Two luminaire rods are required for each door, for a total of six in this three-door cabinet. Each illuminator feeds light to six fibers, allowing it to provide light to three doors.

Cold cathode fluorescent lighting. Cold cathode fluorescent (CCFL) lighting systems are relatively new and were not included in the original scope of this project. However, they are

presented here to raise awareness of the technology and provide some comparison of expected performance. The basic premise of CCFL systems is similar to the baseline T8 systems, in that both apply a high voltage to ionize a gas, thereby producing light. Also, like the T8 system, CCFLs are installed vertically between the glass doors of a reach-in display case. However, in a typical 8 foot long 3 door case, four fixtures will be served by one ballast. Another difference between the two systems is that CCFL relies on cathode technology. Unlike T8 systems that rely on a heated filament to produce light, CCFLs do not require heat to generate light. This difference in principle of operation between the two technologies leads to three distinct advantages for CCFLs in display cases:

- Reduced power consumption. A study done by the California Lighting Technology Center (CLTC) on the 32W CCFL showed the power to be approximately 53% of the T8 system (Graeber 2008). However, test data from the RTTC shows 35% and 70% of the T8 system for the 16W and 32W CCFLs, respectively.
- Reduced heat dissipation into the refrigeration system.
- Extended life. The same CLTC study showed 80,000 hour lifetime for the CCFLs, or approximately eight times that of a T8 system. (Graeber 2008)

Analysis

Laboratory tests were conducted to capture the performance of these lighting systems. Tests were designed to address lighting quality in terms of luminance, uniformity, and glare. Additionally the tests were designed to address the demand and energy impacts attributed to both the lighting power and thermal effects on the refrigeration system. The CCFL system was only tested for electrical and power usage because it was not included in the original scope of the project and time constraints did not permit the full range of testing.

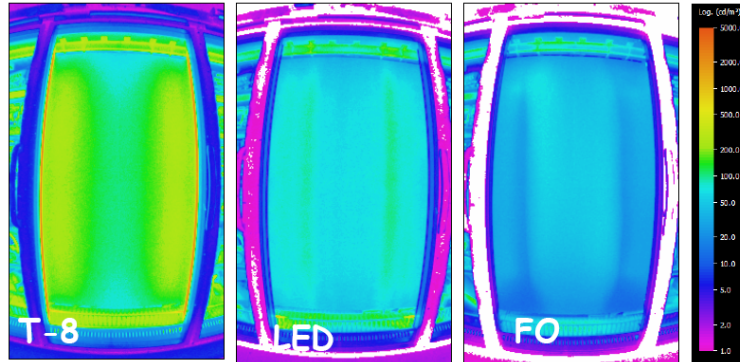
Lighting quality. Judging lighting quality for this type of application is inherently difficult due to the subjectivity in the perception of a viewer. Digital cameras also hinder the ability to compare images because many include algorithms which auto-correct for light and color balance.

The two metrics used in this project included the overall brightness and distribution pattern of light on the product face. To quantify these values, a digital camera that has been specially calibrated to capture luminance data was used. This process required taking a series of fourteen images using a standard set of aperture sizes and shutter speeds. These images were then fed into analysis software which determines the luminance of each pixel and produces a false-color luminance plot based on the measured values. This process was repeated for each different viewpoint or camera position. The case remained at its normal operating conditions for taking pictures. However, room humidity was reduced to 40% in order to inhibit fog formation on the outer surface of the glass doors.

For this project, the main focus was on the product face as it would be viewed by a shopper standing directly in front of the doors. The light distribution pattern was difficult to capture without a uniform background to project the light on to. To address this, uniform gray poster board was hung inside the case at the front edge of the shelving. Additionally, since the LED and FO manufacturers claim that less stray light is emitted into the aisle, this was an area of interest. In all, a set of images was captured from three viewpoints for each lighting technology; each repeated with and without ambient lighting.

Luminance plots were created for each lighting system for all six different images, however, the main focus was on the analysis of the front view using the uniform gray card background without ambient lighting. Figure 2 shows the luminance plot for each lighting system with the uniform background.

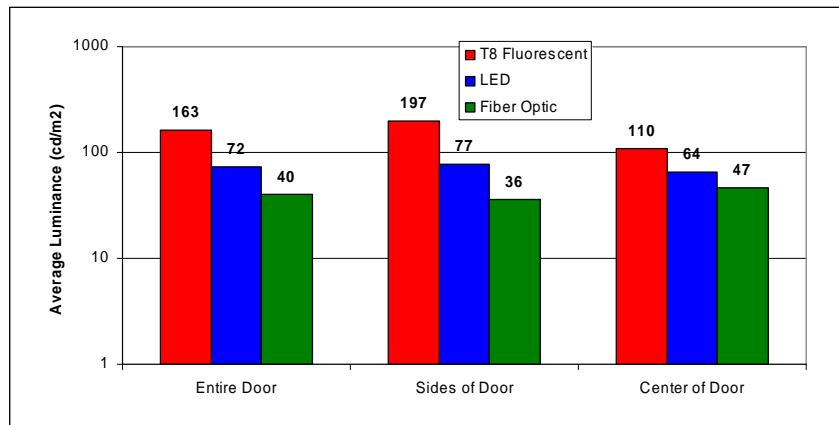
Figure 2. Luminance Plots of T8 (Left), LED (Center), and FO Lighting Systems



Uniformity of lighting systems can be characterized by plotting the luminance values across the product face. To compare the luminance values of each lighting system, the luminance plots were divided into three analysis areas; entire door, center of door, and sides of door.

Luminance software was used to calculate average luminance for each of the selected areas (note luminance is a logarithmic value). Figure 3 shows the results of this luminance analysis for the three areas of interest. The T8 system was brighter than the other technologies across the board, but had much higher light output towards the sides in comparison to the center of the door. The LED system maintained lower overall light levels with more even distribution, still slightly skewed toward the sides of the door. The fiber optic system provided slightly lower light levels than LED with similar even distribution, but focused more towards the center of the door rather than the sides. Unfortunately, since there are no industry standards dictating appropriate light levels or requirements for even distribution, interpretation of this data is purely subjective.

Figure 3. Luminance Analysis Areas (Left – Entire Door, Center – Sides of Door, Right – Center of Door) and Average Luminance of the Three Lighting Technologies

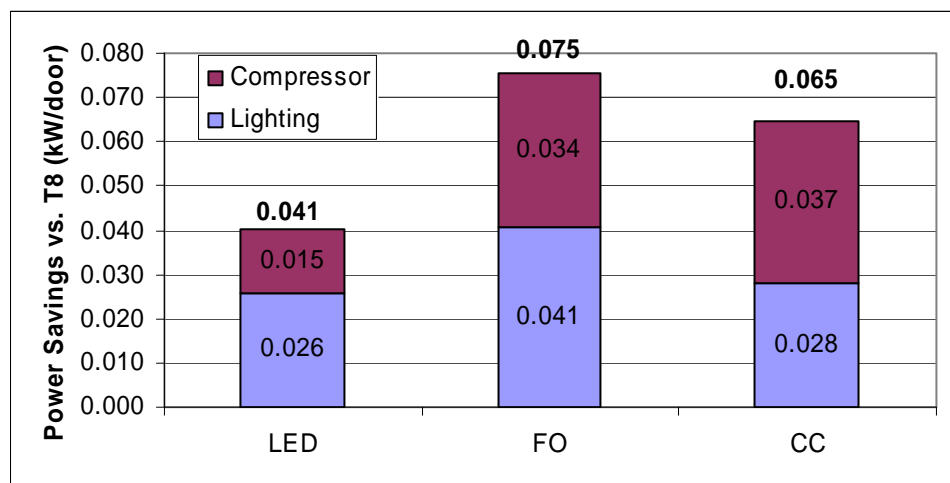


Glare is a measure of the visibility of light sources in a display case to an observer walking down the aisle. Low levels of glare make the product stand out and look more attractive to customers. High levels of glare tend to distract shoppers from the products on display and also waste energy because the light generated is not focused on the products. Fluorescent lamps exhibit high glare because they are completely visible at full brightness to an observer looking down the aisle. The LED and FO manufacturers both claim to reduce glare. Quantification of glare is difficult, but FO provided significantly less glare than fluorescent and LED nearly eliminated it. A pronounced difference in the amount of light spilling onto the floor between the fluorescent and other technologies was also observed.

Power savings. For this type of retrofit measure savings are typically calculated on a “per door” basis. However, each of the different technologies has a slightly different configuration, which complicates direct comparison of power performance. In order to circumvent this issue, each system was analyzed and the results were normalized based on a 5-door display case. This is the most popular size display case and also provides a conservative estimate of savings since the reportable savings per door decreases as the number of doors increases.

On top of the direct lighting savings, there are savings on the refrigeration system due to decreased cooling load on the case. The refrigeration compressor power and energy savings depend on ambient conditions as well as other factors. A combination of numerical modeling and test results was used to calculate these savings (SCE 2008). The calculations performed considered the refrigeration system to be a multi-plex unit, commonly found in large grocery stores. Figure 4 depicts the direct lighting power savings and compressor power savings over T8 fluorescent for California Climate Zone (CTZ) 9 for all three technologies. In this figure, the direct lighting power savings are shown as the lower portion of the bar and the compressor power savings as the upper portion.

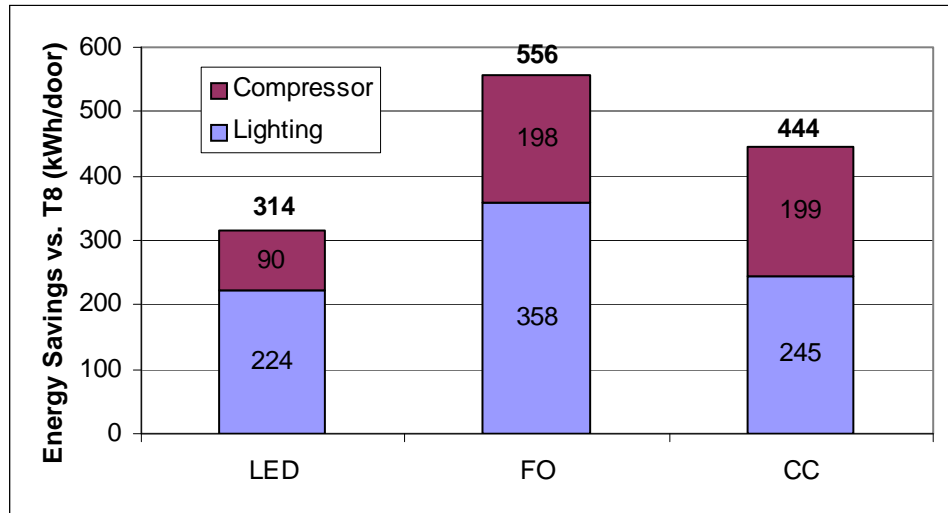
Figure 4. Power Consumption of the Three Lighting Technologies (at Full Output)



Energy savings. Direct lighting energy consumption is calculated by multiplying the measured power by the lighting on time. The anticipated annual lighting energy consumption was calculated assuming 24-hour operation at full power. Compressor energy savings is estimated using the calculation methodology and assumption previously stated. Figure 5 gives the annual

energy savings over T8 for each technology, with the two areas of savings presented the same as in Figure 4.

Figure 5. Estimated Annual Lighting and Compressor Energy Consumption



Anti-Fog Film

Background

A persistent problem with putting glass doors on refrigerated display cases has been maintaining visibility through the doors. Temperature and humidity differences between the inside of the case and the ambient conditions tend to cause fogging or sweating on the glass surface as condensation builds up. If shoppers can not clearly view products, sales of those products are likely to be reduced. In addition to hampering sales and increasing the energy consumption of the display case, condensation dripping to the floor can cause a slip hazard for shopper traffic. The following technologies address energy efficiency opportunities that are intended to mitigate fog formation on reach-in glass doors.

Anti-Sweat Heater (ASH). To prevent condensation on the glass, display cases typically have three types of electric resistance ASHs ranging from 100-200 W/door:

- Case mullion heaters – located inside the case frame to keep the doors from freezing shut.
- Door frame heaters – located in the door frame to keep the doors from freezing shut and provide some heat to the glass.
- Glass heaters – located on the glass itself to raise its surface temperature and prevent condensation.

Anti-Fog Film (AFF). AFF is applied to the inner surface of glass doors to prevent condensation and fog formation. By installing this film, some portion of the glass and/or door mullion heaters can be removed while maintaining fog-free operation. Removal of ASHs also reduces the

amount of heat added to the case, resulting in lower compressor run time and energy consumption.

A project was conducted to investigate the energy savings potential and fog-clearance implications of using AFF to replace ASH. It involved laboratory testing of several different door construction/ASH/AFF combinations. In addition to the ASHRAE-prescribed test conditions, data was also collected at room conditions of 75°F and 60% Rh Table 1 details the different door constructions, AFF, and ASH scenarios investigated in this project.

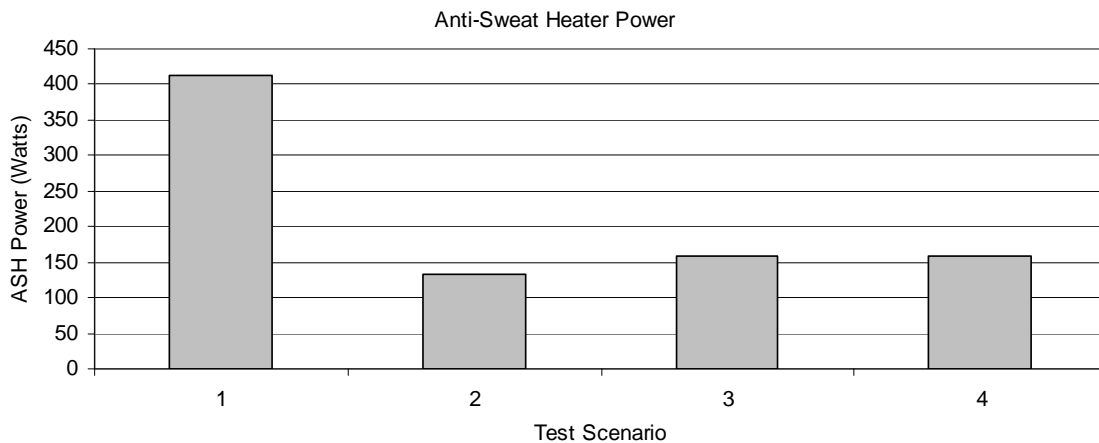
Table 1. Summary of AFF Test Scenarios

Scenario	Door Construction	AFF	Mullion Heat	Glass Door Heat	Door Frame Heat
1	Baseline	None	Low	Yes	No
2	Baseline	Field Installed	Low	No	No
3	Advanced	None	High	No	No
4	Advanced	Factory Installed	High	No	No

Analysis

The total ASH power measured for each scenario is shown in Figure 6. These heaters are typically on 24 hours per day, 7 days per week. Much of the heat generated by the ASHs ends up as a cooling load on the refrigeration system, but the magnitude is relatively small compared to the total cooling load. This can significantly increase the power and energy consumption required by the refrigeration compressors.

Figure 6. Anti-Sweat Heater Power for Each Test Scenario



Following ASHRAE 72 standards, the doors were opened, allowing moisture to enter and condense on the doors. A video camera was set up to allow a comparison of fog clearance times between the various scenarios. Table 2 lists the fog clearance times for each test scenario and room condition. A fog clearance time of 0:00 means that no detectable fog formed on the glass.

Table 2. Fog Clearance Times

Scenario	Room Condition	Fog Clearance Time	Room Condition	Fog Clearance Time
Scenario 1	75°F / 55%Rh	1:35	75°F / 60%Rh	1:56
Scenario 2*	75°F / 55%Rh	Failed	72°F / 40%Rh	0:00
Scenario 3	75°F / 55%Rh	2:40	75°F / 60%Rh	3:18
Scenario 4	75°F / 55%Rh	0:00	75°F / 60%Rh	0:00

Note: for scenario 2 severe sweating occurred on the outside of the door at the 75°F/55%Rh condition. Rather than continue to 60% humidity, it was decided to run the second test at 72°F/40% humidity which is more representative of supermarket conditions. No sweating occurred at this condition.

A significant discovery of these tests was that the AFFs are highly susceptible to damage after returning to room temperature. After being cycled from freezer temperatures to room temperature and back to freezer temperatures, both the field-installed and factory-installed AFF technologies began to delaminate from the glass. This is believed to be due to moisture migrating underneath the coating, then freezing and separating it from the glass surface. The resulting delamination permanently obscured the view of the products worse than any fogging observed.

Door Gaskets

Background

Gaskets on glass doors of reach-in display cases often become damaged due to the harsh treatment by shoppers. Tight-fitting gaskets inhibit infiltration of warm and moist air from the surrounding environment into the cold refrigerated space, thereby reducing the cooling load. They also prevent moisture that enters the refrigerated space from ending up as frost on the cooling coils, reducing heat transfer effectiveness. As a result of these two factors, compressor run time and energy consumption are reduced with “good” gaskets. Although decreased infiltration load will reduce defrost energy, this study does not take such a reduction into account. Additionally, the increased infiltration can cause fog to form on the glass surface, with similar problems as detailed in the AFF section.

The nature of door gaskets is such that part of the gasket will wear out or become damaged before other parts. However, a single gasket is designed to fit a specific-sized door, requiring the entire gasket, including some parts which are functioning properly, to be replaced at the same time. Therefore, a correlation must be made between the length of gasket replaced and the length of gasket which was actually in need of repair.

Unfortunately, there is very little survey data on the amount and degree of damaged gaskets in the field today. To conduct the laboratory test comparison, the “damaged” gasket condition was created by completely removing one foot of gasket (Figure 7), out of 45 total feet for the 3-door case, and comparing it to the display case with all gaskets in “normal” condition. The damaged condition was based on field observations of refrigeration service personnel and field auditors. Greater lengths of missing gasket were also attempted, but frost built up on the coil to the point that the case could not properly operate. The analysis includes both LT and MT applications and provides estimates of energy and demand savings on a “per linear-foot (ln ft) of door gasket replaced” basis.

Figure 7. One Foot of Missing Gasket Used in Testing LT Display Case Leakage



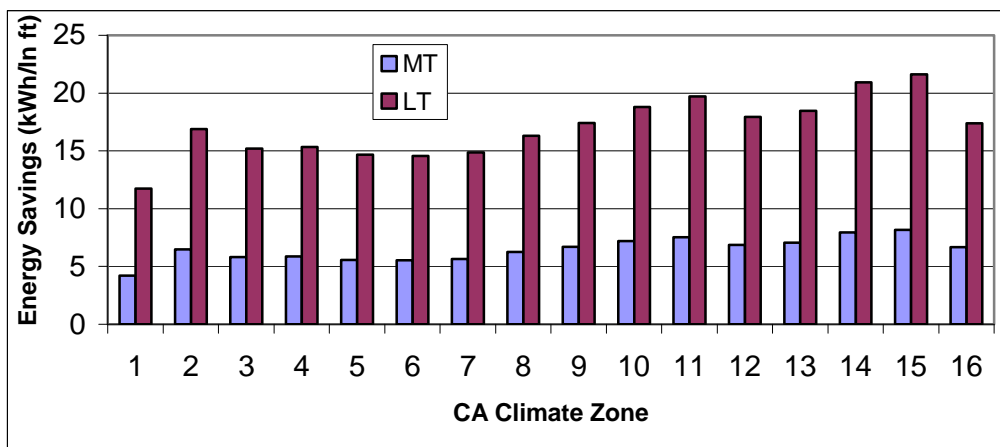
Analysis

The amount of infiltration through the missing one foot of door gasket was calculated using ASHRAE psychrometric software based on the difference in case cooling capacity between the damaged and normal test results, 973 Btu/hr. Gaskets are only effective when the door is actually closed. During normal use, doors are open for a certain percentage of time where poor gaskets will not affect the amount of infiltration into the cabinet. ASHRAE 72-2005 requires doors of display cases to be opened 6 times per hour during 8 hours of a 24-hour test, equating to 99.12% closed time. A field study conducted by RTTC in a supermarket measured average door closed time of 99.5% over a 3-month period. Therefore, using 99.12% as required by the ASHRAE method will provide a slightly conservative estimate of the door closed time when compared with field-monitored data.

Once the gasket infiltration load was determined, the resulting compressor power and energy requirements to provide this additional amount of cooling could be calculated. Again, a combination of numerical modeling and test results was used to perform compressor analysis in deriving the savings values (SCE 2007). Likewise, the retrofit case was again assumed to be served by a multi-plex system. Several additional factors are taken into account, including weather and compressor over sizing, to arrive at the expected savings value.

Figure 8 displays the energy savings associated with the replacement of a “damaged” door gasket on a reach-in display case, for both LT and MT applications. These savings range from a high of 22 kWh/yr/ln ft for CTZ 15 for a LT case, to a low of 4 kWh/yr/ln ft in CTZ 1 for a MT case. Demand savings are not shown, but follow the same trend. The demand savings range from 0.78 W/ln ft in CTZ 1 (MT case) to 4.09 W/ln ft in CTZ 15 (LT case).

Figure 8. Door Gasket Replacement Projected Annual Energy Savings for All 16 CA Climate Zones in a Reach-In Display Case



Conclusion

Each technology examined in the laboratory tests was found to have a beneficial impact on electric demand and energy consumption of refrigerated display cases. Annual savings for the lighting technologies are estimated to be 314 to 556 kWh per door. For AFF technologies, demand savings are more than 90 W/door, with additional improvements in fog clearing time. Maintaining proper door gaskets is estimated to save between 4 and 22 kWh/ln ft depending on climate zone and application. Though these tests revealed that there may be some areas for improvement, especially for anti-fog films, all of the technologies are promising solutions to improve the performance of display cases. Supermarket operators should further investigate these technologies to determine which ones fit their needs and should also be cognizant of advances in the performance of the various technologies. Additionally, case manufacturers should be encouraged to adopt these technologies into production models.

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