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Comparison of Vertical Display Cases: Energy and Productivity Impacts of Glass Doors Versus Open Vertical Display Cases

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This paper is based on findings resulting from ASHRAE Research Project RP-1402.

ABSTRACT

The objective of this project was to compare a typical open refrigerated display case line-up to a typical glass-doored refrigerated display case line-up with the aim of quantifying the difference in overall energy consumption and the difference in food product sales for each case type. For this research project, two supermarkets were identified as test sites: one supermarket received a new, open refrigerated display case line-up and the other supermarket received a new, doored refrigerated display case line-up. Per unit length of case line-up, the open display case line-up consumed approximately 1.3 times more energy than the doored display case line-up. Comparison of product sales between the open and doored display case line-ups showed that "doored versus open" had no effect on product sales. Finally, the door opening duration data collected in this study from the doored display case line-up validate the door opening procedure used in the method of test described in ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005).

INTRODUCTION

Refrigerated display cases are utilized by retail food stores to store and display food products in a manner that extends food shelf life and ensures food safety. Retail food stores and supermarkets operate their refrigeration systems continuously to maintain proper food storage conditions, and the continual operation of this equipment accounts for approximately 50% of the total electrical energy consumption of a typical supermarket (Westphalen et al. 1996). Clearly, an increase in the energy efficiency of refrigerated display cases will result in significantly reduced energy consumption and operating cost of supermarkets.

Infiltration accounts for over 70% of the refrigeration load in open refrigerated display cases (Faramarzi 1999). Other contributions to the refrigeration load are minor in comparison and include radiation and conduction heat gain as well as heat gain from lighting, fans, defrost, and anti-sweat heaters. Thus, reducing the infiltration into open display cases will lead to a significant reduction in the overall refrigeration load, thereby reducing the overall energy consumption.

One technique to reduce infiltration is to utilize refrigerated display cases with glass doors. Under controlled laboratory conditions, Faramarzi et al. (2002) found that installing glass doors on an open vertical refrigerated display case reduced the refrigeration load by 68%, resulting in an 87% reduction in compressor power demand. Furthermore, the average temperature of the food products was reduced by 6°F. Thus, energy savings from doors may be achieved both from the smaller cooling loads and from the ability to use higher evaporating temperatures to achieve the same product temperature. Therefore, a significantly large-scale reduction in national annual energy usage could be realized if the nation's supermarkets adopted the use of glass-doored refrigerated display cases. On a nationwide scale, DOE (2002) estimates total supermarket refrigeration energy usage is about 0.33 quads/yr. Assuming that 80% of the nation's supermarkets adopted the use of glass-doored refrigerated display cases, the savings would be about 0.04 quads/yr. This savings would be a significant contribution toward ASHRAE's goal of reducing supermarket energy use by 30%.

In addition to the infiltration energy savings, glass-doored refrigerated display cases offer several other advantages. Due to their design, glass-doored vertical cases allow for more

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product facings using less floor space. Another benefit is that, due to the reduced refrigeration load of glass-doored cases, the medium temperature compressor rack size can be reduced by about 15%, resulting in a lower first cost to the supermarket; however, doored cases are more expensive than open multi-deck cases. Glass-doored cases also improve food safety by reducing the wide variations in product temperatures that are observed in open cases. Reduced product temperature ranges can bring about easier compliance with the 41°F (5°C) product temperature requirements of ANSI/NSF Standard 7-2001 (NSF 2001) and the FDA Food Code (FDA 2009). Doors also reduce cold air spillage into shopping aisles, resulting in increased shopper comfort, which may translate into increased sales. Furthermore, doors will prevent partial cooling and dehumidification of the store by the refrigeration system, thus allowing the HVAC system, which operates at a higher evaporator temperature and COP, to cool and dehumidify the store more efficiently. On the other hand, the capacity of the HVAC system may have to be increased if the case credits for the open display cases are eliminated.

However, in spite of these advantages, the fear of a possible reduction in product sales prevents supermarkets from implementing glass-doored cases (Walker et al. 2004). Unfortunately, the available information regarding the merchandising productivity of display cases is vague and anecdotal.

Thus, there is clearly a need to compare a typical open refrigerated display case to a typical glass-doored refrigerated display case. The objectives of this project were to quantify the difference in overall energy consumption for each case type under actual operating conditions and to quantify the difference in food product sales for each case type. By comparing the advantages and disadvantages of medium-temperature refrigerated cases with and without doors, ASHRAE will encourage the supermarket industry to shift toward more sustainable options.

Furthermore, the results of this study will be used to validate testing procedures given in *ANSI/ASHRAE Standard 72-2005*, *Method of Testing Commercial Refrigerators and Freezers* (ASHRAE 2005).

TEST PLAN

The following test plan was developed in an effort to compare a typical glass-doored refrigerated display case line-up to a typical open refrigerated display case line-up with the aim of quantifying the difference in overall energy consumption for each case type and the difference in food product sales for each case type. For this research project, two supermarkets were identified as test sites: one supermarket received a new doored refrigerated display case line-up, and the other supermarket received a new open refrigerated display case line-up.

The general test plan for this project included a "before-and-after" comparison of selected product sales. An existing display case line-up was identified in each store, and the sales data of the products from that display case line-up were collected for a period of approximately two months. The existing display case line-up in each store was then replaced with a new display case line-up. Each new case line-up was then stocked with the same products in the same location within the new case, as they appeared in the old case line-up. The sales data of these products from each new display case line-up were then collected for a period of approximately two months. Thus, a comparison between sales data was made before and after installation of the new display case line-ups to determine the effect that new case line-ups had on product sales.

The products studied in the two supermarkets were different. In order to account for random and uncontrolled effects in product sales, sales data for all the test products were collected from both supermarkets. Thus, sales data from one supermarket were used as a control to adjust the sales data of products studied in the other supermarket (and vice versa).

In addition, the energy usage of each new display case line-up was monitored. Thus, comparisons could be made between the energy usage of a new open display case line-up versus that of a new doored display case line-up.

Outline of the Test Procedure

A detailed outline of the test procedure used in this project is given as follows:

For Store #1:

1. An old open case was replaced with a new glass-doored case.
2. The new case was in the same location as the old case.
3. The new case was stocked with the same product as the old case.
4. The sales of the product were studied before and after the case was replaced.

For Store #2:

1. An old open case was replaced with a new open case.
2. The new case was in the same location as the old case.
3. The new case was stocked with the same product as the old case.
4. The sales of the product were studied before and after the case was replaced.

In both stores:

1. The product studied in Store #1 was different than the product studied in Store #2, although sales data from Store #1 were used to adjust the sales data of products studied in Store #2 (and vice versa).
2. The arrangement of the product in the new case was as identical as possible to the product arrangement in the old case, and both the old and new product arrangements were recorded so that anomalies in sales data could be compared to any differences in the arrangements.
3. The studied products were not duplicated elsewhere in the store.
4. The location of the case in Store #1 was different than the location of the case in Store #2.

5. Energy consumption of the new cases was measured.
6. The “before-and-after” test in Store #1 occurred simultaneously to the “before-and-after” test in Store #2.

Instrumentation Plan

The following detailed instrumentation plan was used to determine the energy use and thermal performance of the new refrigerated display case line-ups in each supermarket.

Two pressure transducers and two thermocouples were used to monitor the pressures and temperatures of the refrigerant entering and exiting the refrigerated display cases. The pressure and temperature sensors were installed in the inlet and outlet refrigeration lines as close as possible to the display case line-ups in an effort to comply with the specifications given in ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005), which states that the pressure and temperature sensors should be no more than 6.1 in. (155 mm) from the refrigerated display case. A coriolis mass flowmeter was installed in the refrigerant line entering each display case to determine the refrigerant mass flow rate.

Air discharge and return temperatures within the display case line-ups were measured with thermocouples. In addition, the surface temperatures of the evaporators within the display case line-ups were measured with a thermocouple mounted on a return bend of the evaporators and insulated from the air around it.

Electrical energy consumption of the refrigerated cases was determined through the use of kWh transducers. Separate kWh transducers and current transformers were installed in the electrical lines leading to the fans, lighting, and anti-sweat heaters to determine the individual electrical loads produced by these components.

Shopper traffic at the new doored refrigerated display case line-up in Store #1 was estimated by the number of door openings. The number of door openings and duration were determined from the open/shorted status of contact switches installed on each door. Customer traffic at the new, open display case line-up at Store #2 was monitored and recorded via a surveillance video camera and a time-lapse video cassette recorder. The number of “reach-in” events, or the number of times a person reached into the case through the air curtain to make contact with product in the case, was determined by viewing the surveillance video.

Store ambient dry-bulb temperature and relative humidity were measured with a thermocouple and a humidity sensor. The temperature/humidity sensors were located near the refrigerated display case line-ups, sufficiently far from heat and cold sources, at an elevation of approximately 10 ft (3 m), so as to measure the representative ambient conditions of the store.

Local outdoor dry-bulb temperature and relative humidity were measured with a thermocouple and a humidity sensor. The temperature/humidity and sensors were located in such a manner as to minimize the effects of radiation from direct sunlight.

All measurements discussed above were recorded using a one-minute sample rate.

Product sales for each refrigerated display case, as well as total store product sales, were tracked with the aid of stock keeping units (SKUs). For each week of the study, the following data were obtained from the electronic point-of-sales system in each supermarket, and exported to a file in comma separated values (CSV) file format: the universal product code (UPC) of the product, a description of the product, the quantity of product sold, the actual sales price of the product, and the regular sales price of the product.

IDENTIFY AND SECURE TEST SITES

For this research project, two supermarkets were identified as test sites: one supermarket received a new, doored refrigerated display case line-up and the other supermarket received a new, open refrigerated display case line-up. These two test sites were large public supermarkets with footprints of approximately 25,000 ft^2 (2300 m^2), located in the Midwestern United States. The two supermarkets were similarly situated to ensure that climate, weather, time of year, and economic conditions of the shoppers were comparable. Testing was performed at both stores simultaneously.

Store #1

Store #1 is located in Osawatomie, KS, a community of 4600 people, which is located approximately 50 miles (80 km) south west of Kansas City, MO. Store #1 has average retail sales of $80,000 per week, and the store size is 23,000 ft^2 (2140 m^2).

Store #2

Store #2 is located in Wamego, KS, a community of approximately 4000 people, which is about 10 miles (16 km) east of Manhattan, KS (pop. 50,000), and approximately 100 miles (160 km) west of Kansas City, MO. Store #2 has average retail sales of $140,000 per week and the store size is 30,200 ft^2 (2810 m^2).

DISPLAY CASES AND PRODUCTS TO BE STUDIED

At Store #1, it was agreed that dairy products, including yogurt, prepackaged cheese, butter, and sour cream, would be used in this study. The dairy products initially resided in a 44 ft (13.4 m) open, multi-deck case line-up, shown in Figure 1a. This case was replaced with a new, medium-temperature, 20-doored case line-up, nominally 48 ft (14.6 m) in length, shown in Figure 1b.

During the test period, sales of the selected dairy products were monitored for a period of two months in the original case line-up. The original open case line-up was then replaced with

(a) *(b)*

Figure 1 *(a) Initial open and (b) new, doored display case line-ups at Store #1, Osawatomie, KS.*

a new, 20-doored, medium-temperature case line-up. After installation of the new case line-up, the sales of the selected products were monitored for a period of two months. The selected dairy products were only merchandised in the refrigerated display case line-up under study and did not appear anywhere else in the store.

Furthermore, the energy consumption of a 10-doored portion of the 20-doored case line-up was measured for a period of two months. This 10-doored portion of the case line-up was nominally 24 ft (7.3 m) in length, and contained refrigeration and electrical circuitry that was separate from the remaining 10 doors of the line-up. This was done so that a comparison of energy usage could be made with the similarly sized 24 ft (7.3 m) open case line-up installed in Store #2.

The new, doored, reach-in cooler case line-up used in this study was manufactured by Zero Zone, Inc., Model Number RVCC30. The 10-doored portion of the case line-up was nominally 24 ft (7.3 m) in length and had interior dimensions of 306.75 in. (7.79 m) (length) by 64.5 in. (1.64 m) (height). This 10-doored case line-up provided 19,785 $in.^2$ (12.76 m^2) of product facing and 251.8 ft^3 (7.13 m^3) of capacity. The new doored display case line-up is shown in Figure 1b.

Furthermore, at Store #1, a 12 ft (3.7 m) open, multi-deck case line-up merchandising beer and various alcoholic beverages (wine coolers, hard lemonade, etc.) was replaced with a 6-doored case line-up merchandising beer and alcoholic beverages. Thus, while beer and alcoholic beverages were not originally intended to be primary products studied at this supermarket, the replacement of the old, open beer case line-up with a new, doored beer case line-up provided an additional opportunity to collect beer and alcoholic beverages sales data for an old, open case line-up versus a new, doored case line-up.

At Store #2, it was agreed that beer and various alcoholic beverages (wine coolers, hard lemonade, etc.) would be used in the study. These products initially resided in an open, multi-deck case line-up, nominally 24 ft (7.3 m) in length, shown in Figure 2a. During the test period, sales of the beer and various alcoholic beverages were monitored for a period of two months in the original case line-up. This original open case line-up was then replaced with a new, medium-temperature, open, multi-deck case line-up, nominally 24 ft (7.3 m) in length, shown in Figure 2b. After installation of the new case, the sales of the selected products and the energy consumption of the new case were monitored for a period of two months. The selected products were only merchandised in the refrigerated display case line-up under study and did not appear anywhere else in the store.

The new, open, multi-deck beverage line-up used in this study was manufactured by Tyler Refrigeration, Model Number N6DHP, and was nominally 24 ft (7.3 m) in length and had interior dimensions of 288 in. (7.32 m) (length) by 60.25 in. (1.53 m) (height). This case line-up provided 17,352 $in.^2$ (11.19 m^2) of product facing and 224.2 ft^3 (6.35 m^3) of capacity. The new open case line-up is shown in Figure 2b.

The refrigerated display case line-ups used in this study were selected to represent current, mainstream models. These display cases did not include the most recent energy enhancements, such as electronic fans, LED lighting, high-efficiency air curtains, or low-energy doors. It was intended that these display cases should represent the typical cases that a supermarket operator would consider when choosing between new open cases and new glass-doored cases, thereby providing the economic basis for the typical decision in terms of sales and energy.

Control Variables

In order to account for random and uncontrolled effects in product sales, sales data for dairy products and beer and alcoholic beverages were collected from both supermarkets. Thus, dairy sales data from the supermarket receiving the new, open display case line-up (in which beer and alcoholic beverages were the test products) served as a control for the dairy sales data from the supermarket receiving the new, doored display

(a) (b)

Figure 2 *(a) Initial open and (b) new, open display case line-ups at Store #2, Wamego, KS.*

case line-up. Conversely, beer and alcoholic beverages sales data from the supermarket receiving the new, doored display case line-up (in which dairy was the test product) served as a control for the beer and alcoholic beverage sales data from the supermarket receiving the new, open display case line-up.

Summary of Test Configurations

The combination of old and new display case line-ups at the two supermarkets resulted in the following four test configurations to be studied:

- Old, open dairy case at Store #1
- New, doored dairy case at Store #1
- Old, open beer case at Store #2
- New, open beer case at Store #2

Furthermore, an opportunity arose to study the following two additional configurations when a new, doored beer case line-up was also installed at Store #1:

- Old, open beer case at Store #1
- New, doored beer case at Store #1

ANALYSIS OF ENERGY AND SALES DATA

Using the instrumentation plan described previously, energy-related data were collected and analyzed for the two new display case line-ups for the period April 21, 2009, through June 1, 2009. In addition, beer and dairy sales data from both stores were collected and analyzed before and after installation of the new display case line-ups for the period January 4, 2009, through June 6, 2009.

Analysis of Energy-Related Data

For the test period April 21, 2009, through June 1, 2009, daily energy consumption of the new, open and new, doored display case line-ups were determined from the measured energy-related data using the methodology described in *ANSI/ASHRAE Standard 72-2005*, *Method of Testing Commercial Refrigerators and Freezers* (ASHRAE 2005), and *ANSI/ARI Standard 1200-2006*, *Performance Rating of Commercial Refrigerated Display Merchandisers and Storage Cabinets* (ARI 2006).

The daily refrigerator load, Q, for both the open and doored display case line-ups were determined as follows (ASHRAE 2005):

$$Q = \frac{m(h_v - h_l)}{(t - t_{dt})} \qquad (1)$$

where

m	=	total refrigerant mass flow for the 24-hour test period
h_v	=	enthalpy of the refrigerant suction vapor
h_l	=	enthalpy of the refrigerant liquid
t	=	length of the test period (24 h)
t_{dt}	=	is the total defrost period during the test period

Enthalpies were determined using the average refrigerant temperature and pressure during the period when refrigerant was flowing through the evaporator. The mean daily refrigerator load during the 42-day test period for the open display case line-up was 25,082 Btu/h (7.351 kW), which is significantly greater than that of the doored display case line-up, which was found to be 7027 Btu/h (2.059 kW).

In order to determine the compressor energy consumption for both the new, open and new, doored display case line-ups, the energy-efficiency ratios (EER) of the refrigeration systems were estimated. The energy-efficiency ratio is the ratio of cooling capacity (in Btu/h) divided by the power input (in W). From the methodology presented in ANSI/ARI Standard 1200-2006 (ARI 2006), the EER may be determined from the display case adjusted dew-point temperatures. Per ANSI/ARI Standard 1200-2006, the adjusted dew-point temperature was determined as the saturated temperature of the refrigerant at the evaporator pressure minus 2°F (1.1°C).

For both refrigerated display case line-ups, daily average values of the adjusted dew-point temperature and EER were determined. For the doored display case line-up at Store #1, the mean adjusted dew-point temperature was found to be 27.0°F (–2.8°C), resulting in a mean EER value of 14.21. For the open display case line-up at Store #2, the mean adjusted dew-point temperature was found to be 25.9°F (–3.4°C), resulting in a mean EER value of 13.94.

Based on the techniques given in ANSI/ARI Standard 1200-2006 (ARI 2006), the daily compressor energy consumption, *CEC*, for both the open and doored display case line-ups were estimated as follows:

$$CEC = Q(t - t_{dt})/(1000 \cdot EER) \quad (2)$$

where

Q = refrigerator load of the display case line-up

EER = energy efficiency ratio

As shown in Table 1, the average compressor energy consumption during the 42-day test period for the open display case line-up was found to be 42.20 kWh/day, while for the doored display case line-up, the average compressor energy consumption was found to be 11.70 kWh/day.

The daily fan energy consumption, *FEC*, for both the open and doored display case line-ups were determined as follows:

$$FEC = P_f t_f \quad (3)$$

where

P_f = the average fan power

t_f = length of time the fans operate during a 24-hour period

Similarly, the daily lighting energy consumption, *LEC*, for the both the open and doored display case line-ups were determined as follows:

$$LEC = P_l t_l \quad (4)$$

where

P_l = the average lighting power

t_l = the length of time the lights operate during a 24-hour period

For the doored display case line-up, the daily anti-sweat heater energy consumption, *AHEC*, was determined as follows:

$$AHEC = P_{ah} t_{ah} \quad (5)$$

where

P_{ah} = the average anti-sweat heater power

t_{ah} = the length of time the anti-sweat heaters operate during a 24-hour period

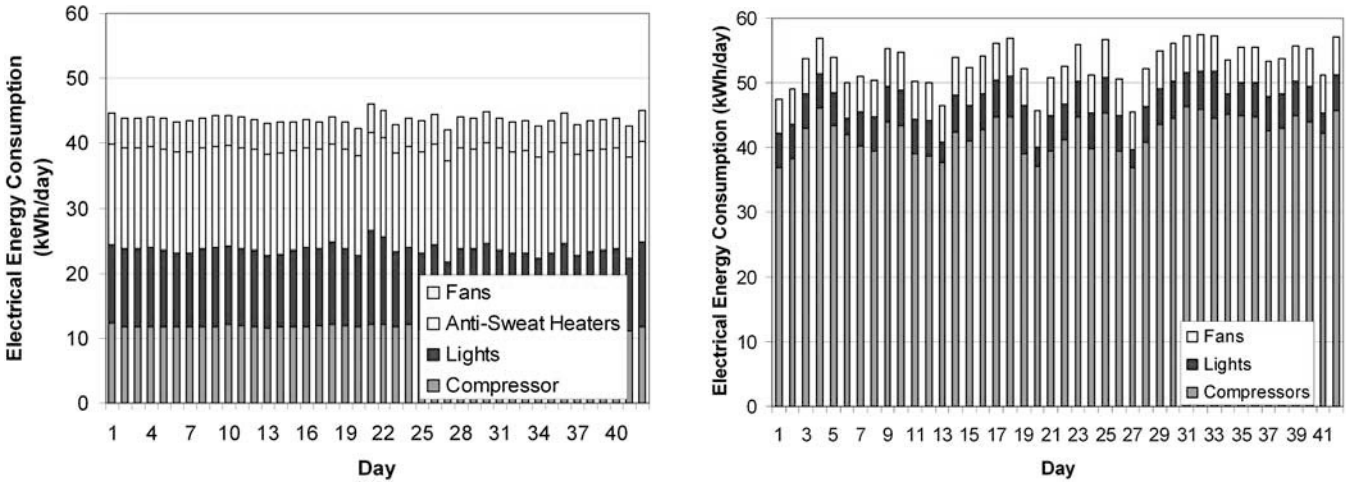
The mean auxiliary electrical energy consumption, which includes fans, lighting, and anti-sweat heaters, for both the open and doored display case line-ups are summarized in Table 1. It can be seen that the mean auxiliary electrical power consumption of the doored case line-up was greater than that of the open case. The lighting, fans, and anti-sweat heaters of the doored case consumed an average of 32.0 kWh/day. The mean auxiliary electrical power consumption of the open case, which consisted only of lighting and fan loads, was found to be 10.9 kWh/day.

Table 1. Mean Electrical Energy Consumption of the Open and Doored Display Case Line-Ups Calculated Using ANSI/ARI Standard 1200-2006 (ARI 2006)

Electrical Energy Consumption	Doored Display Case (Store #1)	Open Display Case (Store #2)
Compressors (kWh/day)	11.70	42.20
Lights (kWh/day)	11.93	5.18
Fans (kWh/day)	4.58	5.69
Anti-sweat heaters (kWh/day)	15.50	—
Total (kWh/day)	43.72	53.07
Total (kWh/day per ft)	1.71	2.21

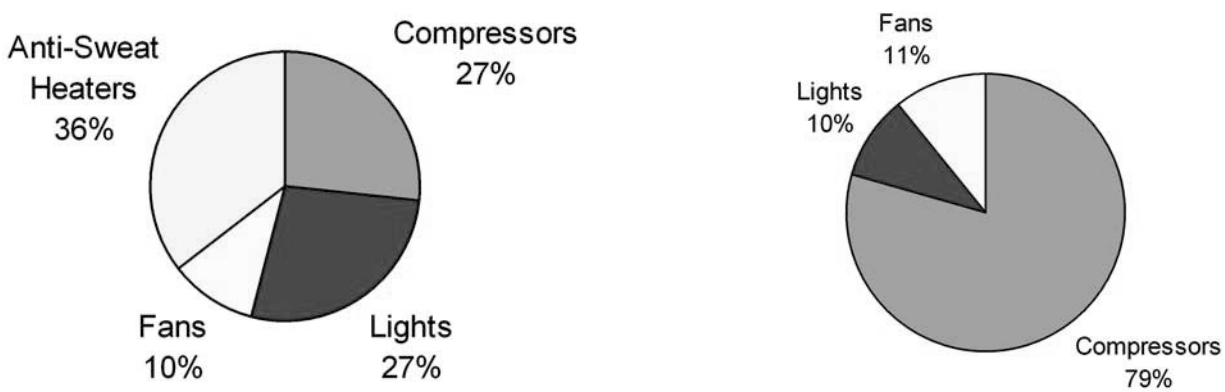
As shown in Table 1, the mean total electrical energy consumption of the open display case line-up was found to be 53.07 kWh/day, while the mean total energy consumption of the doored display case line-up was found to be 43.72 kWh/day. Per unit length of case line-up, the electrical energy consumption of the open display case line-up was found to be 2.21 kWh/day per ft (7.25 kWh/day per m), while the electrical energy consumption of the doored display case line-up was found to be 1.71 kWh/day per ft (5.61 kWh/day per m). This calculation is based upon the 25.56 ft (7.79 m) length of the 10-door line-up and the 24 ft (7.3 m) length of the open case line-up, both measured without ends. Thus, per unit length of case, the open display case line-up consumed approximately 1.3 times more energy than the doored display case line-up.

It can be seen from Table 1 that, while the doored display case line-up had significantly less compressor energy consumption compared to the open display case line-up, the doored case line-up had a substantial anti-sweat heater energy consumption that the open case line-up did not have. Thus, a significant portion of the energy savings gained by reducing the display case infiltration load through the use of doors was offset by the energy requirements of the anti-sweat heaters. However, it should be noted that the energy consumption of the doored case line-up could be substantially reduced by using “no heat” doors and LED lighting. Assuming zero energy consumption for “no heat” doors and 265 watts energy consumption for LED lighting, it is estimated that the 10-doored case line-up could consume as little as 20.5 kWh/day or 0.802 kWh/day per ft (2.63 kWh/day per m).



(a) (b)

Figure 3 *Daily electrical energy consumption, showing the components of the electrical load for the period of April 21, 2009 through June1, 2009, for (a) the new, doored refrigerated display case line-up and (b) the new, open refrigerated display case line-up.*



(a) (b)

Figure 4 *Components of the average daily electrical energy load for (a) the new, doored refrigerated display case line-up and (b) the new, open refrigerated display case line-up.*

For the 42-day test period between April 21, 2009, through June 1, 2009, the daily electrical energy consumption, including the components that make up the electrical load, for the new, doored and new, open display case line-ups are shown in Figures 3a and 3b, respectively. It can be seen that the electrical energy consumption of the open display case line-up exhibited significant variation from day-to-day. This variation is mainly attributed to the difference in compressor energy consumption from day-to-day. The electrical energy consumption of the doored display case line-up was relatively consistent from day-to-day, with all of the components of the electrical load remaining fairly constant.

As shown in Figure 4a, the anti-sweat heaters were the major contributor to the total daily electrical load of the doored refrigerated display case, accounting for 36% of the energy use. The compressors and lights each accounted for 27% of the total daily electrical energy consumption, while fan energy consumption was 10% of the total.

On average, the compressors accounted for approximately 79% of the total daily electrical energy consumption for the open refrigerated display case line up, as shown in Figure 4b. Fans accounted for 11% of the total daily electrical energy consumption, while lighting consumed 10% of the total.

Figure 5 shows the variation in daily electrical energy consumption of the new, open and new, doored display case line-ups versus mean daily indoor relative humidity. It can be seen that as the mean indoor relative humidity increased, the electrical energy consumption of the open display case line-up increased. From Figure 5, it can be seen that the open case line-up consumed approximately 1.25 times as much energy when the indoor relative humidity was 45% as compared to when the mean indoor relative humidity was 20%. However, for the

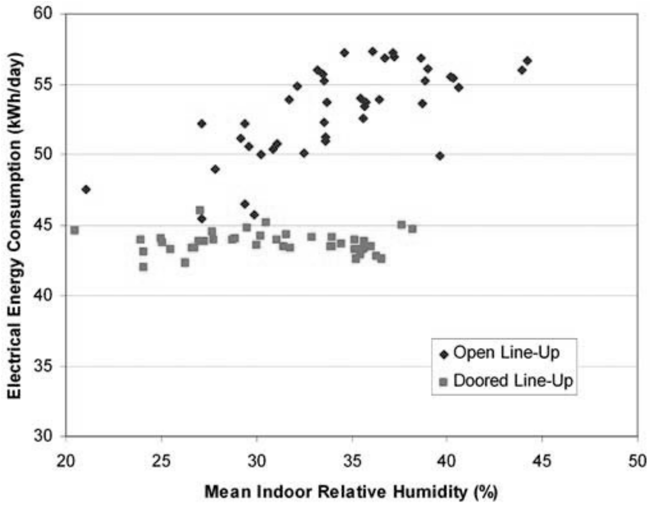


Figure 5 *Variation in electrical energy consumption versus mean indoor relative humidity for the new, open and new, doored display case line-ups.*

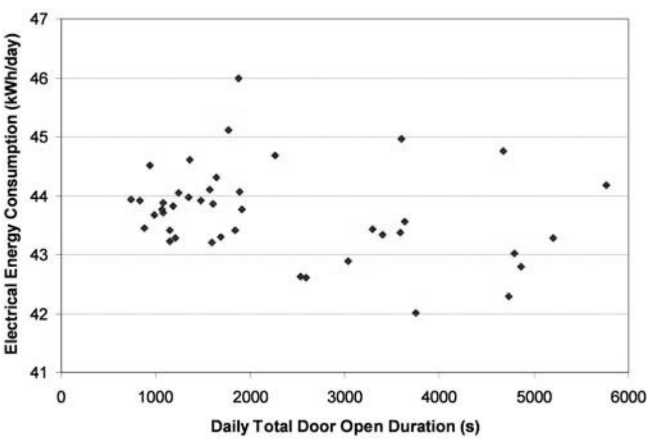


Figure 6 *Variation in electrical energy consumption versus daily door open duration for the new, doored display case line-up at Store #1.*

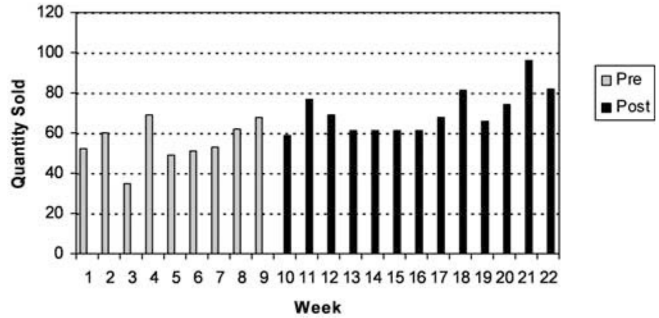


Figure 7 *Weekly beer sales data from the old, open and new, doored display case line-ups in Store #1 for the period of January 4, 2009, through June 6, 2009.*

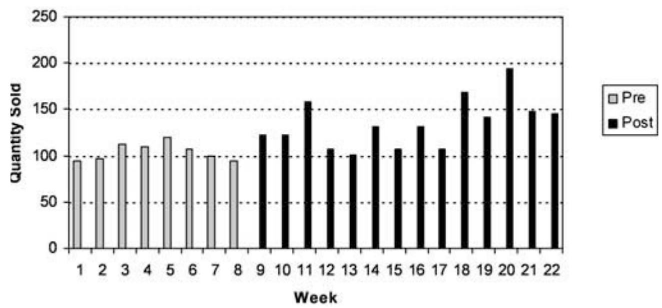


Figure 8 *Weekly beer sales from the old, open and new, open display case line-ups in Store #2 for period of January 4, 2009, through June 6, 2009.*

doored display case line-up, the electrical energy consumption remained relatively constant with increasing mean indoor relative humidity.

Figure 6 shows the variation in daily total energy consumption of the new, doored display case line-up versus daily total door open duration. It can be seen that there is no clear correlation between the door open duration and the corresponding electrical energy consumption of the doored display case line-up.

Analysis of Sales Data

The weekly quantity of beer products sold for the week, starting January 4, 2009, through the week ending June 6, 2009, are shown in Figures 7and 8 for both the doored display case line-up and the open display case line-up, respectively. It should be noted that both supermarkets received new, beer case line-ups. Store #1 received a new, doored display case line-up, which replaced an old, open display case line-up, while Store #2 received a new, open display case line-up, which replaced an old, open display case line-up. Thus, Figures 7 and 8 compare beer sales in old versus new cases for both stores. In both figures, weekly beer sales prior to the installation of the new display case line-ups are shown in grey, while the weekly beer sales after the installation of the new display case line-ups are shown in black.

The mean and standard deviation of the weekly beer sales before and after installation are summarized in Table 2. From Figures 7 and 8 and Table 2, it can be seen that the average weekly quantity of beer products sold increased after the installation of both the new, doored and new, open display case line-ups. Beer sales increased by 27% in the new, doored display case line-up at Store #1, from 55.4 units per week in the old, open case line-up to 70.5 units per week in the new, doored case line-up, and beer sales increased by 29% in the new, open display case line-up at Store #2, from 104.4 units per week in the old, open case line-up to 134.6 units per week

Table 2. Summary of Weekly Beer Sales During Pre-Installation and Post-Installation of the New Doored Displayed Case Line-Up

Beer Sales Statistics	Doored Display Case Line-Up (Store #1)	Open Display Case Line-Up (Store #2)
Mean weekly quantity sold, pre-installation	55.4	104.4
Standard deviation of weekly quantity sold, pre-installation	10.6	9.26
Mean weekly quantity sold, post-installation	70.5	134.6
Standard deviation of weekly quantity sold, post-installation	11.1	26.7
Percentage increase	27%	29%

Table 3. Summary of Weekly Dairy Sales During Pre-Installation and Post-Installation of the New Doored Displayed Case Line-Up

Dairy Sales Statistics	Doored Display Case Line-Up (Store #1)	Open Display Case Line-Up (Store #2)
Mean weekly quantity sold, pre-installation	639.4	3864
Standard deviation of weekly quantity sold, pre-installation	41.3	403.6
Mean weekly quantity sold, post-installation	621.5	3846
Standard deviation of weekly quantity sold, post-installation	152.2	464.5
Percentage increase	–2.8%	–0.47%

in the new, open case line-up. Based on a two-sample, unequal-variance t-test, it was found that these increases in sales were significant at the 0.05 level. Since the rate of increase in beer sales was essentially the same for both the new, doored and new, open display case line-ups, the data show that "doored versus open" had no effect on product sales.

The weekly quantity of dairy products sold for the week starting January 4, 2009, through the week ending June 6, 2009, are shown in Figures 9 and 10 for both the doored display case line-up and the open display case line-up, respectively. It should be noted that Store #1 received a new, doored

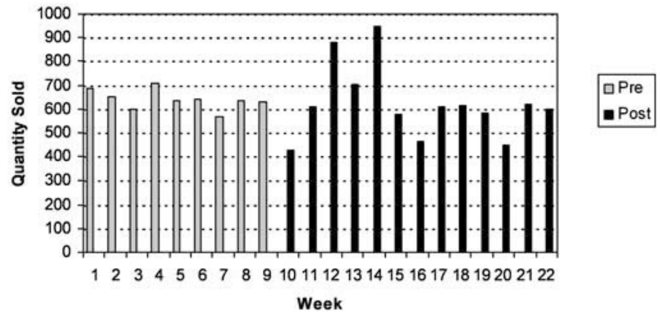


Figure 9 *Weekly dairy sales data from the doored display case line-up in Store #1 for the period of January 4, 2009, through June 6, 2009.*

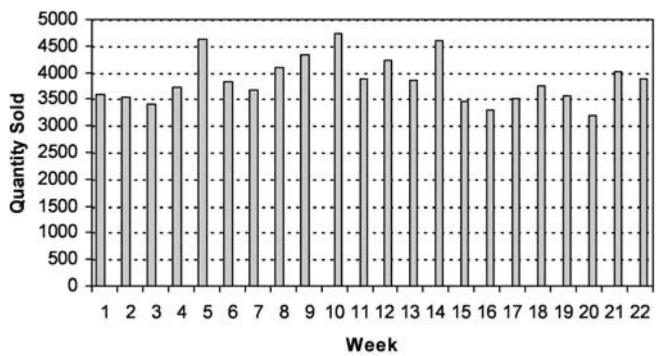


Figure 10 *Weekly dairy sales data from the open display case line-up in Store #2 for the period of January 4, 2009, through June 6, 2009.*

up, while the open dairy case line-up at Store #2 remained the same during the test period. Thus, Figure 9 compares dairy sales in an old, open case line-up versus a new, doored case line-up during the test period, while Figure 10 shows dairy sales from the same open display case line-up during the entire test period. In Figure 9, weekly dairy sales prior to the installation of the new display case line-up are shown in grey, while the weekly dairy sales after the installation of the new display case line-up are shown in black.

The mean and standard deviation of the weekly dairy sales before and after installation are summarized in Table 3. From Table 3 and Figures 9 and 10, it can be seen that before and after the installation of the new, doored display case line-up, the average weekly quantity of dairy products sold remained the same in both supermarkets, although Figure 9 shows a temporary up-tick in dairy sales immediately following the installation of the new, doored case line-up. Based on a two-sample, unequal-variance t-test, it was found that there was no significant difference (at the 0.05 level) in dairy product sales in either store before and after installation of the new, doored display case line-up in Store #1. Since the rate of dairy sales remained essentially the same in both stores before and after the installation of the new, doored display case line-up, the data show that "doored versus open" had no effect on product sales.

Customer Traffic at the New Display Case Line-Ups

During a 51-day test period from April 13, 2009, through June 3, 2009, a total of 4792 door openings were logged for the new doored display case at Store #1. The mean door opening duration was found to be 31 seconds, with a standard deviation of 87 seconds. The longest door opening duration was 1842 seconds, while the shortest door opening duration was 1 second.

The vast majority, or 90%, of the door opening durations were less than 60 seconds. A histogram of all door openings with a duration of less than 60 seconds is shown in Figure 11. The mean of all door openings with a duration of less than 60 seconds was found to be 12 seconds, with a standard deviation of 11 seconds. Furthermore, from Figure 11, it can be seen that the mode of the door opening durations (the duration that occurs the most frequently) was 5 seconds. Finally, for the new 10-doored display case line-up, it was found that the daily mean door opening frequency was 6.3 door openings per hour.

In ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005), it is stated that for doored display cases, each door should be in the fully open position for six seconds, six times per hour, for eight consecutive hours. Thus, the door opening duration data collected in study from the doored display case line-up validate the door opening procedure used in the method of test described in ANSI/ASHRAE sStandard 72-2005 (ASHRAE 2005).

Customer traffic at the new, open beer display case line-up at Store #2 was monitored and recorded via a surveillance video camera and a time-lapse video cassette recorder. The number of "reach-in" events, or the number of times a person reached into the case through the air curtain to make contact with product in the case, was determined by viewing the surveillance video. It was found that, on average, there were 1.7 "reach-in" events per hour for the new 24 ft (7.3 m) open beer display case line-up. In addition, approximately 80% of all "reach-in" events for the new 24 ft (7.3 m) open beer display case line-up occurred between 4:00 p.m. and 10:00 p.m.

CONCLUSION

The objective of this project was to compare a typical open refrigerated display case line-up to a typical glass-doored refrigerated display case line-up with the aim of quantifying the following:

- The difference in overall energy consumption for each case type
- The difference in food product sales for each case type

Furthermore, the results of this study were used to validate testing procedures given in ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005).

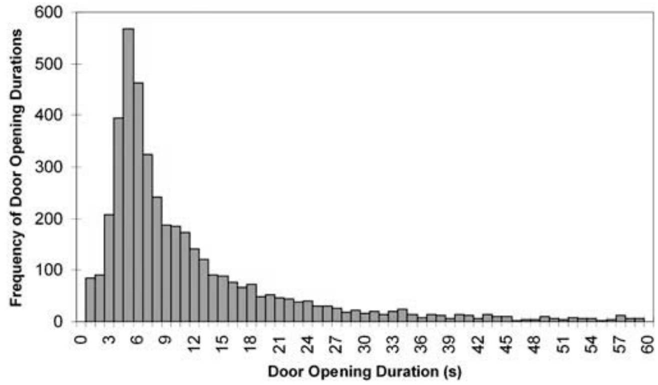


Figure 11 *Histogram of door opening durations for the new, doored display case line-up during the period of April 13, 2009, through June 3, 2009.*

The general test plan for this project included a "before-and-after" comparison of selected product sales in two supermarkets. An existing display case line-up was identified in each store, and the sales data of the products from that display case line-up were collected for a period of approximately two months. The existing display case line-up in each store was then replaced with a new display case line-up. Each new case line-up was then stocked with the same products in the same location within the new case, as they appeared in the old case line-up. The sales data of these products from each new display case line-up were then collected for a period of approximately two months. Thus, a comparison between sales data was made before and after installation of the new display case line-ups to determine the effect that new case line-ups had on product sales.

The products studied in the two supermarkets were different. In order to account for random and uncontrolled effects in product sales, sales data for all the test products were collected from both supermarkets. Thus, sales data from one supermarket were used as a control to adjust the sales data of products studied in the other supermarket (and vice versa).

In addition, the energy usage of each new display case line-up was monitored. Thus, comparisons were made between the energy usage of a new, open display case line-up versus that of a new, doored display case line-up.

For this research project, two supermarkets were identified as test sites: one supermarket received a new, doored refrigerated display case line-up and the other supermarket received a new, open refrigerated display case line-up. These two test sites were large public supermarkets with footprints of approximately 25,000 ft^2 (2300 m^2), located in the Midwestern United States. The two supermarkets were similarly situated to ensure that climate, weather, time-of-year, and economic conditions of the shoppers were comparable. Testing was performed at both stores simultaneously.

At Store #1, it was agreed that dairy products, including yogurt, prepackaged cheese, butter, and sour cream, would be used in this study. The dairy products initially resided in a 44 ft (13.4 m) open, multi-deck case line-up. This case was replaced with a new, medium-temperature, 20-doored case line-up, nominally 48 ft (14.6 m) in length, that included an instrumented 10-door section with refrigeration and electrical circuitry that was separate from the remaining 10 doors of the line-up. In addition, in this same supermarket, a 12 ft (3.7 m) open, multi-deck case line-up merchandising beer and various alcoholic beverages (wine coolers, hard lemonade, etc.) was replaced with a 6-doored case line-up merchandising beer and alcoholic beverages. Thus, while beer and alcoholic beverages were not originally intended to be primary products studied at this supermarket, the replacement of the old, open beer case line-up with a new, doored beer case line-up provided an additional opportunity to collect beer and alcoholic beverages sales data for an old, open case line-up versus a new, doored case line-up.

At Store #2, it was agreed that beer and various alcoholic beverages (wine coolers, hard lemonade, etc.) would be used in this study. These products initially resided in an open, multi-deck case line-up, nominally 24 ft (7.3m) in length. This original open case line-up was replaced with a new, medium-temperature, open, multi-deck case line-up, nominally 24 ft (7.3 m) in length.

Per unit length of case line-up, the electrical energy consumption of the new, open display case line-up was found to be 2.21 kWh/day per ft (7.25 kWh/day per m), while the electrical energy consumption of the new, doored display case line-up was found to be 1.71 kWh/day per ft (5.61 kWh/day per m). While the doored display case line-up had significantly less compressor energy consumption compared to the open display case line-up, the doored case line-up had a substantial anti-sweat heater energy consumption that the open case line-up did not have. Thus, a significant portion of the energy savings gained by reducing the display case infiltration load through the use of doors was offset by the energy requirements of the anti-sweat heaters.

The electrical energy consumption of the open display case line-up exhibited significant variation from day-to-day. This variation was mainly attributed to the difference in compressor energy consumption from day-to-day. The electrical energy consumption of the doored display case line-up was relatively consistent from day-to-day, with all of the components of the electrical load remaining fairly constant. It was found that as the mean indoor relative humidity increased, the electrical energy consumption of the open display case line-up increased. However, for the doored display case line-up, the electrical energy consumption remained relatively constant regardless of changes in mean indoor relative humidity.

Beer sales increased by 27% in the new, doored display case line-up at Store #1, from 55.4 units per week in the old open case line-up to 70.5 units per week in the new, doored case line-up, and beer sales increased by 29% in the new, open display case line-up at Store #2, from 104.4 units per week in the old, open case line-up to 134.6 units per week in the new, open case line-up. Based on a two-sample, unequal-variance t-test, it was found that these increases in sales were significant at the 0.05 level. Since the rate of increase in beer sales was essentially the same for both the new, doored and new, open display case line-ups, the data show that "doored versus open" had no effect on product sales.

It was found that before and after the installation of the new, doored display case line-up in Store #1, the average weekly quantity of dairy products sold remained the same in both Store #1 and Store #2 (control). Based on a two-sample, unequal-variance t-test, it was found that there was no significant difference (at the 0.05 level) in dairy product sales in either store before and after installation of the new, doored display case line-up in Store #1. Since the rate of dairy sales remained essentially the same in both stores before and after the installation of the new, doored display case line-up, the data show that "doored versus open" had no effect on product sales.

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In ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005), it is stated that for doored display cases, each door should be in the fully open position for six seconds, six times per hour, for eight consecutive hours. Thus, the door opening duration data collected in study from the doored display case line-up validate the door opening procedure used in the method of test described in ANSI/ASHRAE Standard 72-2005 (ASHRAE 2005).

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