Medium-Temperature Display Case Demand Defrost Control

ET11SCE1020 Report

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EXECUTIVE SUMMARY

BACKGROUND

In supermarkets and grocery stores, the refrigeration system operates continuously to maintain proper food product temperatures within the refrigerated display cases. The most important constituent of the cooling load of these display cases, and particularly of open cases, is the infiltration of warm and moist air from the neighboring space. When this moist air contacts the evaporator coil, which has a surface temperature below the dew point temperature of the air, formation of frost on the coil is inevitable. The coil then requires defrosting to maintain system performance and product temperature within the cases.

However, conventional defrost processes add to the energy usage of the refrigeration system. In this context, conventional defrost refers to off-cycle defrosts that are initiated on a preset time cycle, normally every six to eight hours, and terminated when either the evaporator temperature reaches a predetermined temperature or the defrost cycle reaches a predetermined duration, whichever takes place first.

Demand defrost technologies—technologies that can detect ice on the evaporator coil and then optimally initiate and terminate defrosts—have the potential to greatly improve the efficiency of the defrost cycle. According to the manufacturer, demand defrost technology is an ice-sensing component consisting of a line-array of light-emitting diodes (LEDs) and light detectors attached to the evaporator tubes. This component can detect all forms of water (e.g., dew, condensation, and frost) that are in contact with the probe’s surface by the optical opacity and refraction index. That is, the detector senses frost build up as an occlusion of the LED light—which causes the component to initiate a defrost—and the absence of frost as the light expected from the LED—which causes the component to terminate the defrost.

Aligned with its mandate to validate the benefits of emerging energy technologies, SCE undertook an investigation to determine the potential energy and demand reduction possible with demand defrost technology—and to determine if the technology offered performance comparable to conventional technology.

OBJECTIVE

A handful of demand defrost technologies have emerged over the last few years, but little is known about the performance of these technologies. This project sought to help close that gap by evaluating the performance and benefits of a demand defrost technology for a medium-temperature (MT) open vertical refrigerated display case (OVRDC) relative to conventional defrost technology, including any energy and demand reductions. The study focused on the ability of the ice detection technology to recognize frost build-up on the evaporator coil and initiate and terminate defrost cycles in response to this information.

APPROACH

The project team developed a laboratory test plan that called for evaluating the performance of the demand defrost technology under various indoor relative humidity (rh) levels while maintaining a fixed indoor dry-bulb temperature (DBT) of 75^{o}F. Because the amount of frost build-up on the evaporator coil is a function of indoor humidity levels, testing at different rh levels can substantiate the functionality of demand defrost technology.

Before fully executing the assessment plan, the team performed initial tests. These tests involved running the display case with and without the demand defrost technology at an indoor DBT of 75^{o}F and an rh of 45% over an 8-hour period.

FINDINGS

Results revealed that during the conventional defrost run, the refrigeration system underwent one defrost cycle that lasted 28 minutes. In contrast, during the demand defrost test run, the refrigeration system underwent 25 defrost cycles that lasted between 1 to 3 minutes each, for a total defrost time of about 41 minutes. The frequent short defrosts resulted in higher compressor power and energy usage because of high compressor power demand right after defrost cycles. In addition, for both test runs, the product temperatures stayed about the same.

CONCLUSIONS AND RECOMMENDATIONS

Overall, initial testing showed that demand defrost technology was able to detect frost or ice on the coil and initiate defrost. However, the technology terminated defrost cycles before ice was completely melted on the evaporator coil. The premature termination indicates the need to improve the current technology’s ability to detect the amount of ice removed from the coil. Therefore, testing the technology under different rh levels was deemed unnecessary and unbeneficial at this time. The findings of this project were communicated to the manufacturer and improvement opportunities were discussed.

Our plan is to continue providing the necessary technical information to the manufacturer so that a more robust version of the technology can be developed. However, this demand defrost technology at its current state is not recommended for the refrigerated display case application.

ABBREVIATIONS AND ACRONYMS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal unit
DAT	discharge air temperature
DAV	discharge air velocity
DBT	dry-bulb temperature
hr	hour
kW	kilowatt
kWh	kilowatt-Hour
lb	pound
LED	Light-emitting diode
LT	low-temperature
MT	medium-temperature
OVRDC	open vertical refrigerated display case
psig	pounds per square inch gauge
RAG	return air grille
rh	relative humidity
SCE	Southern California Edison
SCT	saturated condensing temperature
TTC	Technology Test Centers
W	watt

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INTRODUCTION

In supermarkets and grocery stores, the refrigeration system operates continuously to maintain proper food product temperatures within the refrigerated display cases. The most important constituent of the cooling load of these display cases, and particularly of open cases, is the infiltration of warm and moist air from the neighboring space. When this moist air contacts the display case evaporator coil—which typically has a surface temperature below 32°F and hence below the dew point temperature of the air—formation of frost on the coil is inevitable. Because excessive frost growth on the coil deteriorates the performance of the refrigeration system, periodic defrosting of the evaporator coil is required to maintain system performance and product temperature within the cases.

This defrost cycle increases the energy usage of the refrigeration system. Demand defrost technologies—that is, technologies that can detect ice on the evaporator coil and then optimally initiate and terminate defrosts only in response to need—have the potential to greatly improve the efficiency the defrost cycle. A handful of demand defrost technologies have emerged over the last few years, but little is known about the performance of these technologies.

Off-cycle and electric defrost are the most common methods of defrosting the evaporator coil of refrigerated cases. Largely, off-cycle is used for medium-temperature (MT) cases and electric defrost is used for low-temperature (LT) cases. In both off-cycle and electric defrosts, the refrigeration compressor shuts off, stopping the flow of refrigerant to the evaporator, while the evaporator fan motors stay running. These motors blow warm air over the evaporator coil surfaces, melting the frost. In the off-cycle defrost, the warm air comes from the adjacent space; in the electric defrost, the warm air is created by energizing electric heating elements located in front of the evaporator.

According to the manufacturer, the demand defrost technology under investigation is an ice-sensing component that can detect all forms of water (e.g., dew, condensation, and frost) that are in contact with the probe’s surface by the optical opacity and refraction index. That is, the detector senses frost build up as an occlusion of the LED light—which causes the component to initiate a defrost—and the absence of frost as the light expected from the LED—which causes the component to terminate the defrost.

In contrast, under the conventional off-cycle defrost method, defrosts are initiated on a preset time cycle and are normally scheduled to occur every six to eight hours. Defrost cycles are terminated when either the evaporator temperature reaches a predetermined temperature or the defrost cycle reaches a predetermined duration, whichever takes place first.

This laboratory assessment project was conducted at Southern California Edison’s (SCE’s) Technology Test Centers (TTC) controlled environment test chambers, which are described in Appendix A. The assessment investigated the performance and benefits of a demand defrost technology relative to the conventional off-cycle defrost for an MT open vertical refrigerated display case (OVRDC). Specifically, the study focused on the capability and feasibility of a frost/ice detection technology in recognizing frost/ice build-up on the evaporator coil and subsequently initiating and terminating defrost cycles.

The project team developed a test plan that called for evaluating the performance of the demand defrost technology at various indoor relative humidity (rh) levels while maintaining a fixed indoor dry-bulb temperature (DBT) of 75°F. Testing of a defrost technology at different rh levels can substantiate its functionality because the amount of frost build-up on the evaporator coil is a function of indoor humidity levels. Prior to fully executing the assessment plan, the team conducted initial tests that involved running the display case with and without the demand defrost technology at an indoor DBT of 75^{o}F and rh of 45%.

These initial tests showed that the demand defrost technology was able to detect frost/ice on the coil and initiate defrost. However, the technology terminated the defrost cycle before the ice melted entirely. This finding indicated a need to improve the current technology's ability to detect the amount of ice removed from the coil. Therefore, additional testing of the technology under various indoor rh levels was deemed unnecessary and unbeneficial at this time. Our plan is to continue providing the necessary technical information to the manufacturer so that a more robust version of the technology can be developed.

BACKGROUND

Refrigerated display cases are widely used in grocery stores to merchandise perishable food products. To meet the different temperature requirements of different types of product, display cases are designed to offer either medium-temperature (MT) or low-temperature (LT) storage. In general, MT cases are used to merchandise fresh meat, deli, dairy, produce, and beverages, while LT display cases are used to merchandise frozen food and ice cream. Display cases rely on the temperature of the air discharged into the case, or the discharge air temperature (DAT), to maintain proper and desired product temperatures. The DAT for MT cases can range from +24°F to +38°F and the DAT for LT cases can range from -24°F to -5°F.[1] In a typical supermarket, about half of the total refrigerated display cases are MT open vertical or multi-deck.[1,2]

Figure 1 is the side view schematic of an MT open vertical refrigerated display case (OVRDC) and its air circulation pattern. As shown, cold air is provided through an inlet jet called the discharge air grille located at the top front of the case and through a set of slots located on the back panel of the case. The air circulates back to the evaporator for cooling through an outlet located at the bottom front of the case called the return air grille (RAG).

This top-down flow of cold air creates an invisible barrier, known as the air curtain, between the refrigerated space and the warm and moist adjacent space. Mixing between the cold and warm air cannot be avoided as part of the cold air spills over the case and is replaced by the warm air. The continuous flow of adjacent warm air into the air curtain and its subsequent mixing with the cold air is called the entrainment. A portion of the entrained air spills over after some mixing with the cold air and the rest is infiltrated into the RAG. The infiltration, or the amount of warm and moist air that moves into the thermodynamic cooling cycle of the case through the RAG, is responsible for most of the cooling load, and thereby the power and energy consumption, of an OVRDC. Prior research has proven that infiltration constitutes roughly 80% of the total cooling load of an OVRDC.[1,2]

More significantly, infiltration of warm and moist air into OVRDCs results in ice formation or frost accumulation on the cold surfaces of the evaporator coil. Therefore, a defrost period is essential to melt the ice or frost build-up on the coil. Typically, the OVRDCs rely on the conventional off-time or off-cycle defrost method. In this method, defrost cycles are initiated based on a prescribed time schedule and are terminated based on a preset evaporator coil outlet temperature combined with a fail-safe time period. It is common for OVRDCs to undergo four or six scheduled defrost periods per day.

When the defrost cycle is initiated, the refrigeration compressor stops operating, and the evaporator fan motors continue operating. Consequently, warm and humid indoor air infiltrates and comes into contact with the evaporator coil, causing the frost or ice build-up on the coil to melt. Previous studies have established that defrost periods are responsible for product temperature fluctuations and high temperature swings. In addition, power demand and energy usage of refrigeration compressors increase during post-defrost periods.

Defrost technologies that can detect ice or frost on the evaporator coil and initiate and terminate the defrost cycles at an ideal point or time can decrease the post-defrost product temperature swings and compressor power demand and energy usage, thereby improving the efficiency of the defrost cycle.

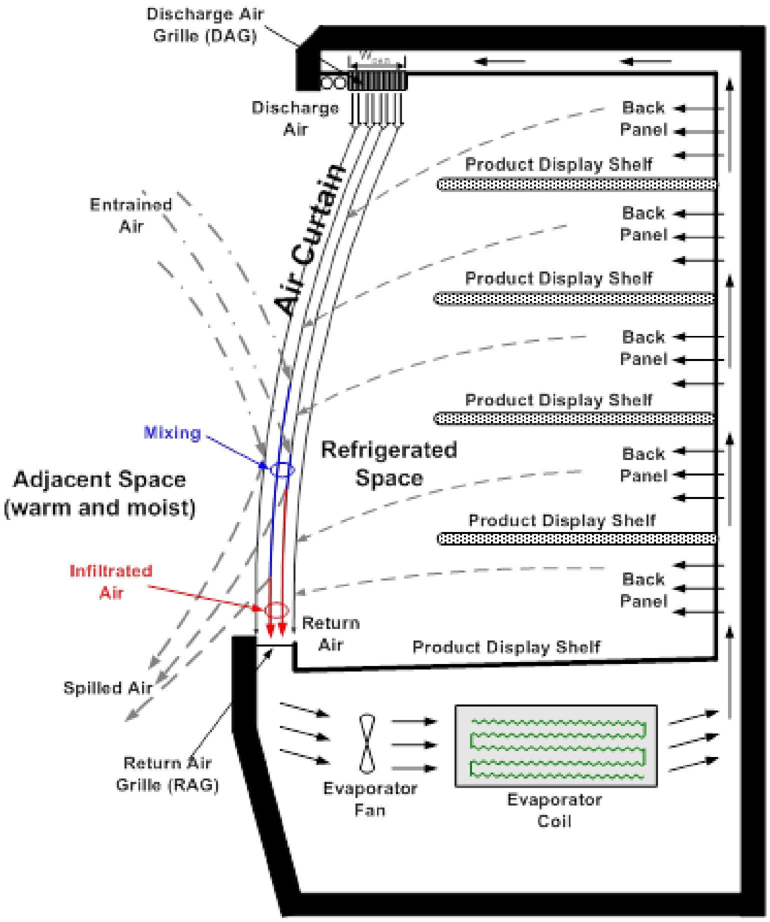


FIGURE 1. SIDE VIEW OF A MEDIUM-TEMPERATURE OPEN VERTICAL REFRIGERATED DISPLAY CASE AND ITS AIR CIRCULATION PATTERN

DESCRIPTION OF DEMAND DEFROST TECHNOLOGY

Assessment of the technology in a laboratory setting allowed evaluation of the differences in performance between the traditional off-cycle defrost and demand defrost technology. Fundamentally, the technology evaluated, IceMeister™, model 9734-REFR, is an ice sensing element. It senses all forms of water, such as dew, condensation, and frost, that are in contact with the probe surface by the optical opacity and refraction index. The sensor attaches directly to evaporator tubes and is constructed of a line-array of light-emitting diodes (LEDs) and light detectors. When the light from the LEDs is occluded, the sensor detects rime ice or frost by optical opacity. When the light from the LEDs is as expected, the sensor detects clear ice by optical refraction. Figure 2 illustrates the ice detecting probe (left photograph), and the probe installed in the rear top section of the evaporator coil (right photograph).

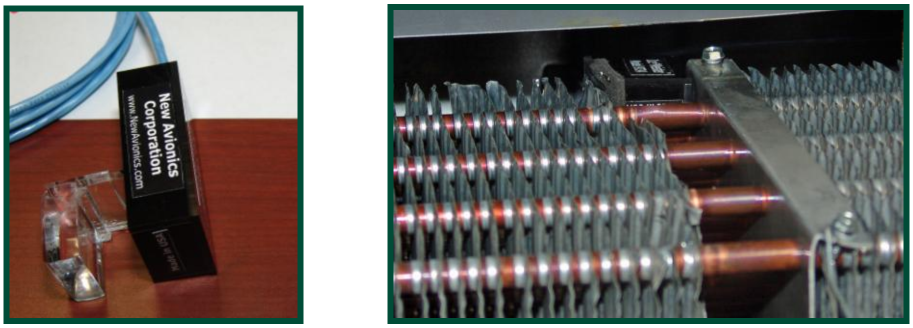


FIGURE 2. ICE DETECTING PROBE (LEFT) AND THE PROBE INSTALLED ON THE EVAPORATOR COIL (RIGHT)

TEST DESIGN

The demand defrost technology was installed on an eight-foot five-deck MT OVRDC. Figure 3 shows the display case installed in the test chamber. The specifications for the display case are in Appendix B. Appendix C lists the instrumentation used in this project, and Appendix D outlines location of sensors.

FIGURE 3. THE DISPLAY CASE IN THE TEST CHAMBER

METHODOLOGY

Tests were performed under steady-state conditions following the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 72-05.[3] For all tests, the refrigeration system was charged with a hydrofluorocarbon refrigerant, R-404A, and the refrigeration system controller was set to maintain a fixed saturated condensing temperature (SCT) of 95°F ± 0.5°F. To comply with the manufacturer's specifications, the average DAT was maintained at the specified temperature of 30°F, which was the critical control point.

The intensity of ambient lighting in the controlled environment room was 115 foot-candles, in compliance with the ASHRAE standard, which requires a minimum of 74.4 foot-candles. The entering liquid refrigerant temperature and pressure was measured at 6.1 feet of pipe length from the display case. The liquid temperature was maintained at 80°F, and the pressure was maintained at 214 pounds per square inch gauge (psig), which corresponded to an SCT of about 94°F. These parameters meet the ASHRAE standard, which requires the entering liquid temperature to be 80.6°F ± 5°F and SCT to be maintained between 89.6°F and 120.2°F. Refrigerant mass flow rates were measured by using a coriolis mass flow meter installed in the liquid line. Power measurements included input to the compressor, evaporator fan, and other items required as part of the system for normal operation. Instrumentation was installed at locations set by test procedures.

MONITORING POINTS

The core monitoring points are listed below:

- Compressor power – kilowatt (kW), watt (W)
- Condensor energy – kilowatt-hour (kWh)
- Total system power and energy (less condenser) – kW, kWh
- Evaporator fan motors power and energy – kW, kWh
- Display case lighting power and energy – kW, kWh
- Refrigeration energy – British thermal unit (Btu)
- Case total cooling load – Btu/hr
- Condensate quantity – lb/hr, lb
- Product temperatures – °F

DATA ACQUISITION

The National Instruments SCXI data acquisition system was used to log the test data. The data acquisition system was set up to scan and log 77 data channels in 10-second intervals. The data acquisition unit was designed to be entirely independent of the supervisory control computer. This ensured that the data collection was not compromised by the control sequence's priority over data acquisition.

Collected data was screened to ensure the key control parameters were within the acceptable ranges. In the event that any of the control parameters fell outside the acceptable limits, the problem was flagged, and a series of diagnostic investigations were conducted. Corrections were then made, and tests were repeated, as needed. After the data passed the initial screening process, it was imported to a customized refrigeration analysis model, where detailed calculations were performed.

RESULTS

This section discusses the main findings from testing the display case with and without the demand defrost technology at an indoor DBT of 75°F and rh of 45%. Additional test data are provided in Appendix E.

DISCHARGE AIR TEMPERATURE AND VELOCITY

Figure 4 shows the 10-second profile of DAT for both the conventional defrost (base case) and demand defrost technology over an 8-hour test run. The average DAT was maintained around 30°F as specified by the manufacturer. The rise in DAT indicates the defrost periods. As shown, during conventional defrost test run, the refrigeration system underwent one defrost cycle; this defrost cycle lasted 28 minutes. During the demand defrost test run, however, the refrigeration system defrosted 25 times. The defrost durations ranged between 1 to 3 minutes, totaling about 41 minutes.

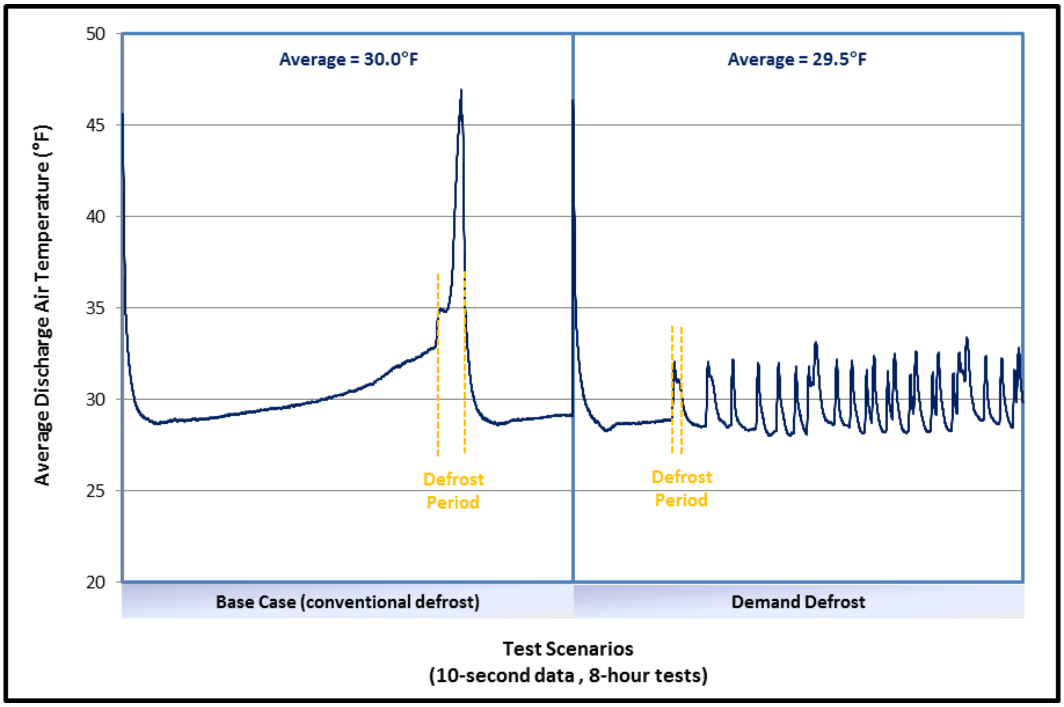


FIGURE 4. 10-SECOND PROFILE OF DISCHARGE AIR TEMPERATURE

The effect of frost build-up on the evaporator coil can be observed on the profile of discharge air velocity (DAV)—or the velocity of cold air leaving the discharge air grille of the display case—shown in Figure 5. Since the frost accumulation on the evaporator coil blocks the air passage, the DAV profile coincides with the number of defrosts. The DAV decreases as the cycle approaches defrost, and the maximum drop occurs just prior to the initiation of defrost. The drop in the DAV was more noticeable for the base case test than for the demand defrost run due to numerous short defrosts during the demand defrost test. The frequent short defrosts resulted in a gradual drop in DAV over an 8-hour test run. The gradual drop in DAV indicated that defrost cycles did not completely remove the ice or frost from the evaporator coil because the peak velocities did not reach their maximum values observed at the beginning of the test.

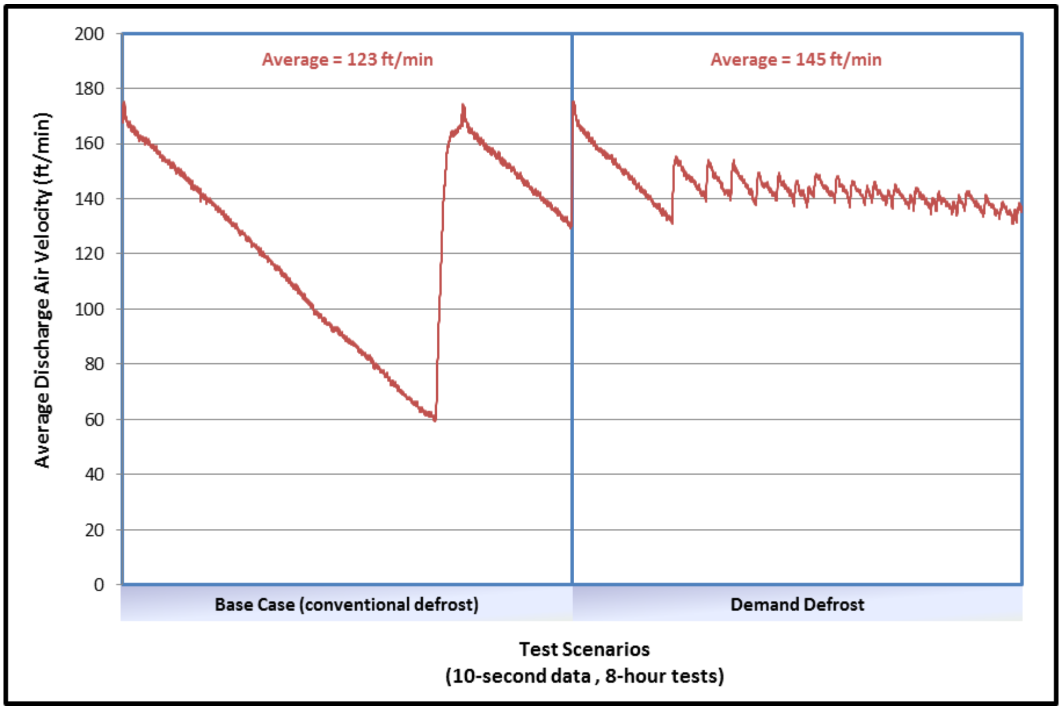


FIGURE 5. 10-SECOND PROFILE OF DISCHARGE AIR VELOCITY

MASS OF CONDENSATE

Figure 6 is the 10-second profile of condensate mass collected. The stepped profiles indicate the mass of condensate for each defrost cycle. The total condensate mass collected in the base case run (16.8 lb) was about 50% more than that in the demand defrost test run (8.6 lb). This finding confirmed the previous observation of incomplete removal of ice build-up on the evaporator coil during the demand defrost test run. As noted earlier, short and frequent defrost cycles during the demand defrost run were not sufficient to entirely melt the ice/frost on the evaporator coil.

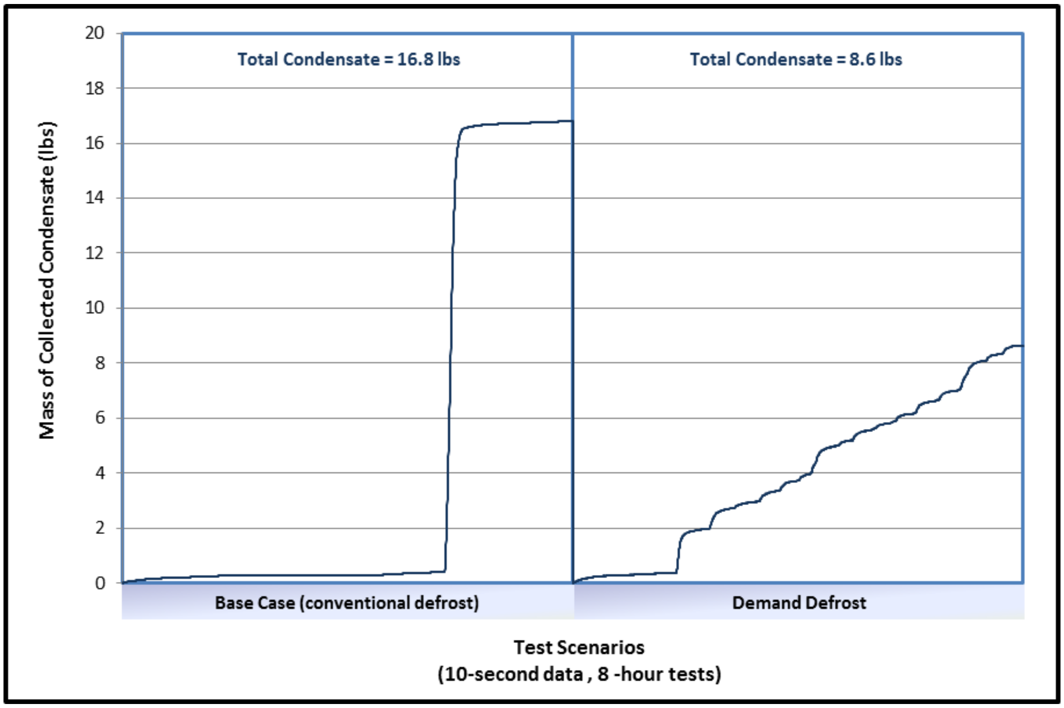


FIGURE 6. 10-SECOND PROFILE OF COLLECTED CONDENSATE MASS

POWER AND ENERGY

Figure 7 depicts the 10-second compressor power profile. As shown, compressor power is highest right after defrosts when the refrigeration cycle starts and lowest prior to the initiation of defrosts. As shown in Figure 8, this profile resulted in higher compressor power during the demand defrost test run (2,402 W), than in the base case run (2,264 W). The type of run did not affect the power draw of the display case lighting system and evaporator fan motors. Therefore, the total power load was dependent on the compressor power. Accordingly, total power was higher by 138 watts (W) during the demand defrost run than in the base case run.

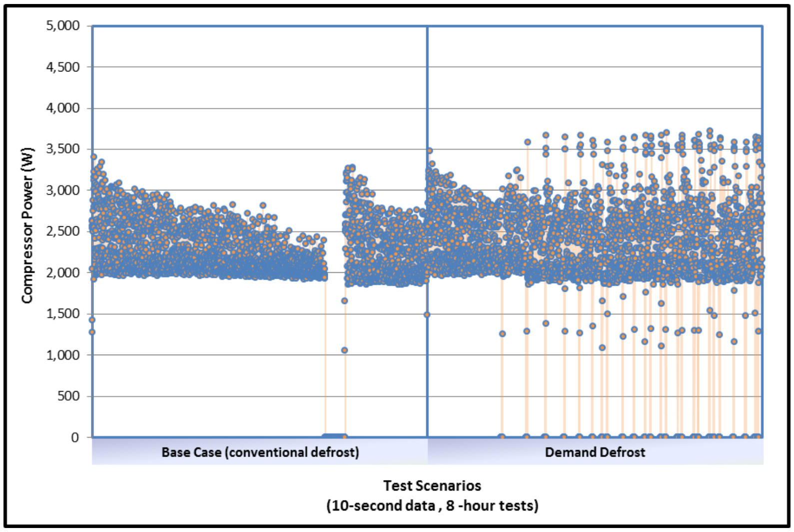


FIGURE 7. 10-SECOND PROFILE OF COMPRESSOR POWER

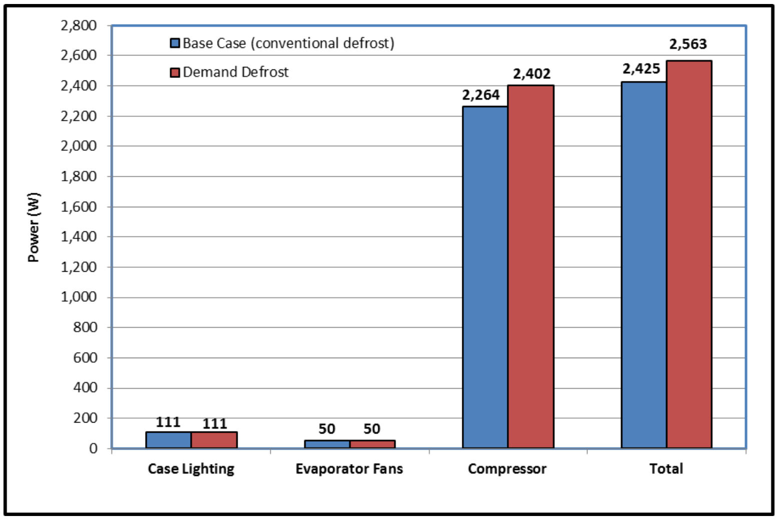


FIGURE 8. AVERAGE POWER BY COMPONENT AND TOTAL

The increase in compressor power for the demand defrost run resulted in slightly higher compressor energy use compared to the base case over an 8-hour period (Figure 9), although its run time was shorter than that for the base case. As expected, the display case lighting and evaporator fan energy usage remained unchanged.

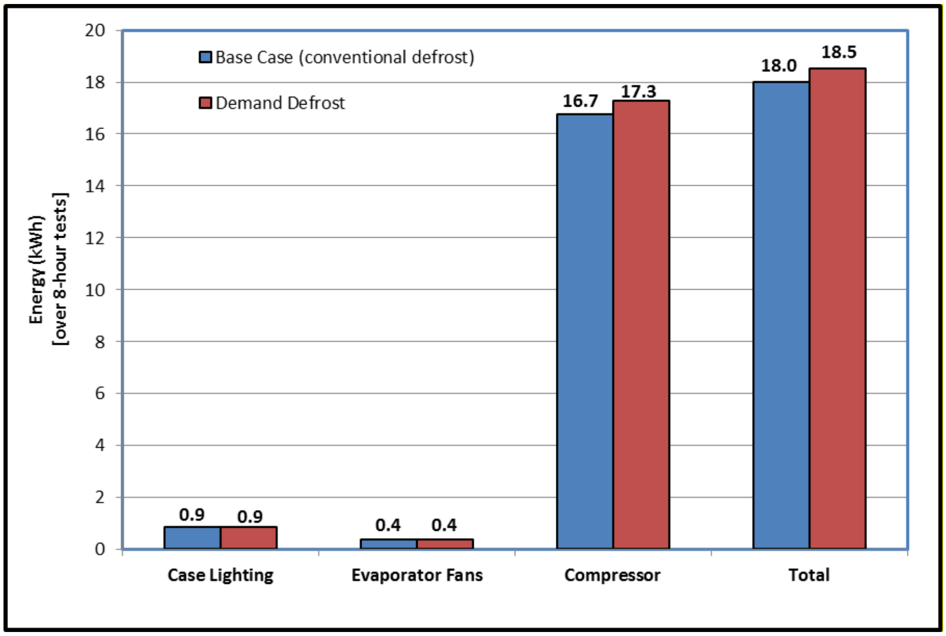


FIGURE 9. TOTAL ENERGY BY COMPONENT AND TOTAL

CONCLUSIONS

Testing revealed that the demand defrost technology was able to detect frost or ice on the evaporator coil and initiate defrosts. However, because the technology was unable to detect the amount of ice removed from the evaporator coil, it did not allow sufficient to melt the ice build-up on the evaporator coil completely. In other words, the technology was unable to terminate the defrost cycles at an optimum period.

RECOMMENDATIONS

The demand defrost technology with its current functionality is not recommended for the refrigeration application because of its deficiency in terminating defrost cycles at an ideal period. The manufacturer has been advised on the limitation of the technology. Once this limitation has been addressed, a new generation of the technology can be tested.

APPENDIX A – TECHNOLOGY TEST CENTERS

Southern California Edison's (SCE) Technology Test Centers (TTC) are a collection of technology assessment laboratories specializing in testing the performance of integrated demand side management (IDSM) strategies for SCE's energy efficiency (EE), demand response (DR), and Codes and Standards (C&S) programs. Located in Irwindale, CA, TTC is composed of three main centers focused on distinct energy end uses: Heating, Ventilating, and Air Conditioning Technology Test Center (HTTC), Refrigeration Technology Test Center (RTTC), and Lighting Technology Test Center (LTTC).

By conducting independent lab testing and analysis, TTC widens the scope of available IDSM solutions with verified performance and efficiency. TTC tests are thorough and repeatable, and conducted in realistic, impartial, and consistent laboratory environments to ensure the best quality results and recommendations.

RTTC is described in more detail below.

REFRIGERATION TECHNOLOGY TEST CENTER

Founded in 1996, RTTC combines state-of-the-art research facilities with staff expertise to promote IDSM in refrigeration and other thermal technology applications. RTTC is responsible for sharing the EE benefits of thermal technologies with SCE customers and other public entities through technical test reports, workshops, publications, seminars, and presentations.

RESPONSIBILITIES

RTTC's key responsibilities include:

- **Testing:** Globally recognized for its scientific simulation and testing capabilities, RTTC tests existing and emerging IDSM technologies. Many test projects are conducted in support of California's statewide Emerging Technologies, Codes and Standards, and Demand Response efforts. Testing includes the following:
  - Equipment testing in accordance with the standards provided by industry and regulatory organizations:
    - Air Conditioning and Refrigeration Institute (ARI)
    - American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE)
    - National Sanitary Foundation (NSF)
    - American National Standard Institute (ANSI)
    - United States Department of Energy (DOE)
    - California Energy Commission (CEC)
  - Supermarket and cold storage refrigeration equipment testing
  - Calorimetric testing
  - Refrigerant testing

    - Fluid flow visualization and quantification experiments using Laser Doppler Velocimetry and Digital Particle Image Velocimetry techniques
    - Development of end-use monitoring plans for evaluations conducted at customer sites
  - **Technical analysis:** Using results from test projects and various other sources of industry data, RTTC can provide the following detailed technical analyses to customers:
    - Computer modeling of energy systems in supermarkets and cold storage facilities
    - Infiltration and air curtain modeling and analysis
    - Computational fluid dynamics modeling
    - Refrigeration load analysis
- **Evaluation:** RTTC helps customers make informed purchasing decisions regarding refrigeration equipment. RTTC employees work to provide expert, unbiased performance evaluations of energy-efficient technologies.
- **Trusted Energy Advisor:** RTTC uses its knowledge of customer operations and needs, alliances with leading industry manufacturers, and expertise in thermal science to transform theory into practical applications. Energy-efficiency consulting is available to SCE customers at no cost.
- **Collaborative Studies:** Results obtained from RTTC research are available at no cost to SCE customers and other interested parties. This research plays an instrumental role in evaluating and promoting energy-efficient technologies in collaboration with the CEC's codes and standards initiatives and statewide EE incentive programs.
- **Equipment Efficiency Enhancement:** With funding support from statewide programs and research grants, RTTC works with manufacturers, state, and federal agencies to improve EE regulations addressing refrigeration equipment.

TEST CHAMBERS AND EQUIPMENT

Several test chambers are present to serve the RTTC's testing needs. Each is equipped with state-of-the-art data acquisition equipment as well as comprehensive supervisory control systems to maintain test conditions:

- **Supermarket Test Chamber:** This 300-square-foot isolated controlled environment room is served by independent heating, cooling, and humidification systems. It is used to test self-contained refrigeration equipment as well as remotely fed low- and medium-temperature display cases via refrigerant feeds from the neighboring mechanical room. Condensing pressures for remotely fed equipment can be held constant through the use of a separate heat rejection loop.
- **Walk-in Cooler Test Chambers:** Two 284-square-foot test chambers are capable of maintaining a wide range of indoor conditions found in walk-in coolers. They generally operate in the +15 - +40° Fahrenheit (F) range. One of these chambers can also be used to simulate various outdoor conditions for typical loading dock configurations.
- **Walk-in Freezer Test Chamber:** This 90-square-foot test chamber can maintain temperatures as low as -40°F.

APPENDIX B – DISPLAY CASE SPECIFICATIONS

The following are the specifications for the Hill Phoenix's eight-foot five-deck display case tested in this project.

Display Case Data

Evaporator coil:	One coil per case 8.66" deep x 7.5" tall x 129" wide 6 circuits 8 tubes per circuit, smooth copper tube, 0.016" tube wall thickness 0.375" tube nominal outside diameter Corrugated fins, 0.0075" fin thickness, 4 fins/inch
Evaporator fan motor:	Three high-efficiency fans (ECM), 9 watt
Evaporator fan blade:	8" diameter, 5 blades, 37° pitch
Air curtain:	Single band
Honeycomb:	4" wide, 1" deep, 1/8" holes
Number of shelves:	Five
Expansion valve:	Sporlan ESX electronic expansion valve
Defrost type:	Off-cycle
Defrost frequency:	Four times per day
Defrost length:	42 minutes (fail-safe)
Defrost termination temp:	47°F
Refrigerated volume:	92.11 ft^3

Refrigeration Data

Refrigerant:	R-404A
Discharge air:	30°F
Discharge air velocity:	270 fpm
Return air:	44°F
Evaporator:	22°F
Conventional capacity:	1,570 BTUH @ 22°F
Superheat set point:	6–8°F

Electrical Data

Fans:	120 volts, 0.70 amps (high-efficiency fans, ECM)
Lighting:	120 volts, 0.47 amps per light row (two 4-foot T8s with electronic ballast per light row)

APPENDIX C – INSTRUMENTATION

Table 1 provides the specifications and calibration dates for all sensors used in this project. All instruments were calibrated before conducting any tests.

TABLE 1. SPECIFICATIONS, CALIBRATION DATES, LOCATIONS, AND CORRESPONDING MONITORING POINTS FOR SENSORS

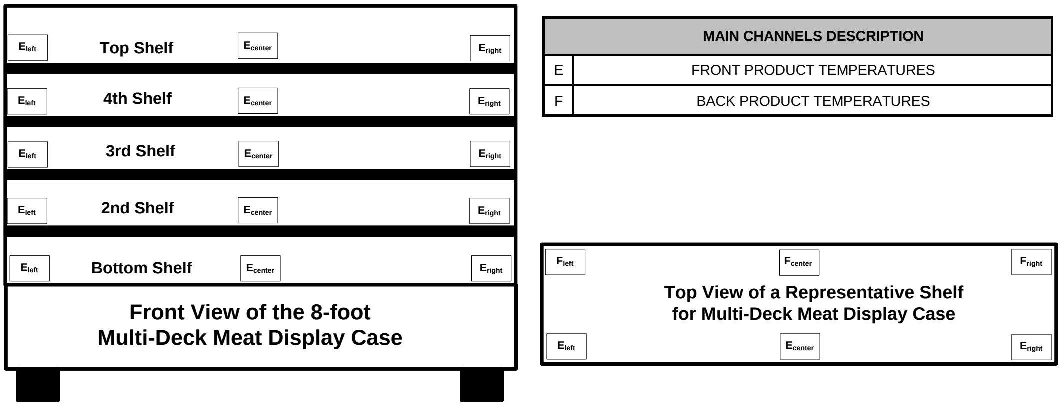
SENSOR TYPE	MAKE/MODEL	ACCURACY (NIST TRACEABLE)	CALIBRATION DATE (LOCATION)	CORRESPONDING KEY MONITORING POINTS
Temperature (type-T thermocouples)	Masy Systems, Ultra-Premium Probe	± 0.18°C [at 0°C] (± 0.32°F)	6-4-2013 (In-house)	• Indoor room • Case interior • Product temps • All air temps • All refrigerant temps
Relative Humidity (RH)	Vaisala, HMP 247	± (0.5 + 2.5% of reading)% RH	6-19-2013 (SCE's Metrology Lab)	• Indoor room • Case interior
Dew Point	Edgetech, Dew Prime DF Dew Point Hygrometer	± 0.2°C (± 0.36°F)	6-25-2013 (SCE's Metrology Lab)	• Inlet of evaporator • Outlet of evaporator
Pressure (0-1000 psi)	Setra, C207	± 0.13% of full scale	6-10-2013 (In-house)	• Discharge • Inlet TXV
Pressure (0-500 psi)	Setra, C207	± 0.13% of full scale	6-10-2013 (In-house)	• Suction • Outlet evaporator
Power	Ohio Semitronics, GW5-002C	± 0.2% of reading ± 0.04% of full scale	6-12-2011 (In-house)	• Compressor • Evaporator fan
Refrigerant Mass Flow Meter	Endress-Hauser, (Coriolis meter) 80F08-AFTSAAACB4AA	For liquids, ± 0.15% of reading For gases, ± 0.35% of reading	6-20-2013 (Homer R. Dulin Co.)	• Refrigerant flow rate
Scale	HP-30K	± 0.1 gram (± 0.0035 ounces)	6-12-2013 (In-house)	• Mass of condensate

APPENDIX D – SENSOR LOCATIONS

To simulate the presence of food products in the display case, ASHRAE 72-05 requires food product zones be filled with test packages and dummy products (Figure 10). Based on the ASHRAE standard, the food products comprise 80% to 90% water, fibrous materials, and salt. Accordingly, plastic containers entirely filled with a sponge material soaked in a 50% ± 2% by volume solution of propylene glycol and distilled water were used to simulate products during the tests. The spaces in the test display case where temperature measurement was not required were stocked with dummy products to stabilize the temperature in the case and account for transient heat transfer effects.

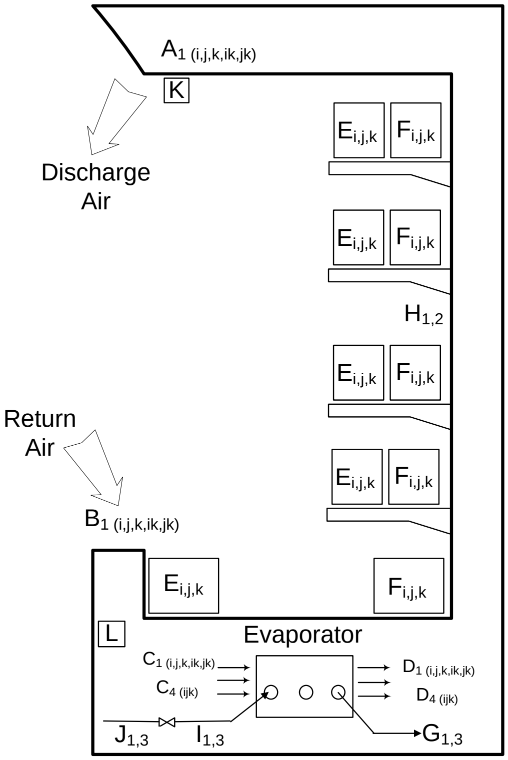
FIGURE 10. SIMULATED AND DUMMY PRODUCTS USED IN THE DISPLAY CASE

For each display shelf, six product simulators were used to monitor product temperatures (Figure 11). Two product simulators were located at the left end, two at the right end and two at the center. At each left, right, and center location, one product simulator was placed on the shelf surface at the front of the shelf and one at the rear edge of the shelf. Figure 12 shows the location of sensors within the display case.



MAIN CHANNELS DESCRIPTION	
E	FRONT PRODUCT TEMPERATURES
F	BACK PRODUCT TEMPERATURES

FIGURE 11. LOCATION OF PRODUCT SIMULATORS INSIDE THE DISPLAY CASE



	MAIN CHANNELS DESCRIPTION
A	DISCHARGE AIR
B	RETURN AIR
C	AIR ENTERING EVAPORATOR **[After Fans]**
D	AIR LEAVING EVAPORATOR
E	FRONT PRODUCT TEMPERATURES
F	BACK PRODUCT TEMPERATURES
G	REFRIGERANT AT COIL EXIT
H	AIR INSIDE CASE CAVITY
I	REFRIGERANT AT EXPANSION VALVE EXIT
J	REFRIGERANT AT EXPANSION VALVE INLET
K	CASE LIGHT - POWER
L	CASE FAN MOTORS - POWER
	SUBSCRIPTS (numerical)
1	TEMPERATURE
2	RELATIVE HUMIDITY
3	PRESSURE
4	DEWPOINT TEMPERATURE
	SUBSCRIPTS (roman)
i	LEFT
j	MIDDLE
k	RIGHT
ik	BETWEEN RIGHT AND MIDDLE
jk	BETWEEN LEFT AND MIDDLE
ijk	COMBINATION OF RIGHT, MIDDLE, AND LEFT

FIGURE 12. LOCATION OF SENSORS FOR THE DISPLAY CASE

APPENDIX E – ADDITIONAL DATA

ROOM CONDITIONS

Figure 13 is the 10-second profile of the test chamber’s DBT and rh. As shown, the room conditions were maintained fixed for both test scenarios.

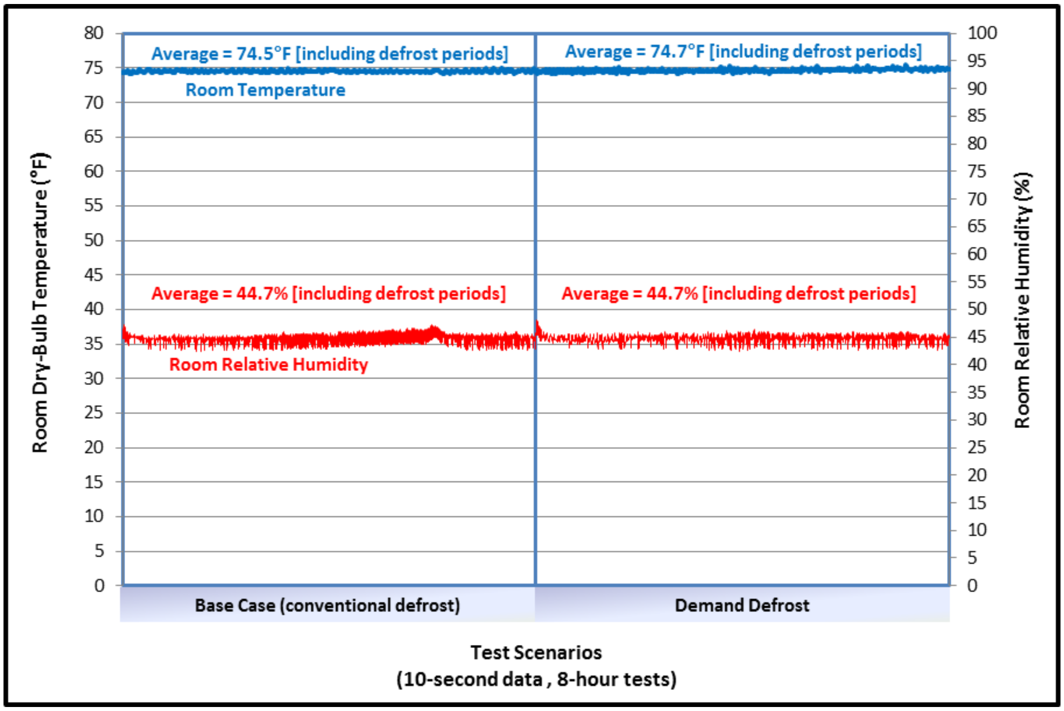


FIGURE 13. 10-SECOND PROFILE OF ROOM DRY-BULB TEMPERATURE AND RELATIVE HUMIDITY

SUCTION AND DISCHARGE PRESSURES

The test rack controller was programmed to run both test scenarios at a fixed target suction pressure to provide a DAT of 30°F, as specified by the manufacturer (Figure 14). In addition, the controller maintained a fixed target discharge pressure of 220 psig, corresponding to a SCT of 95°F.

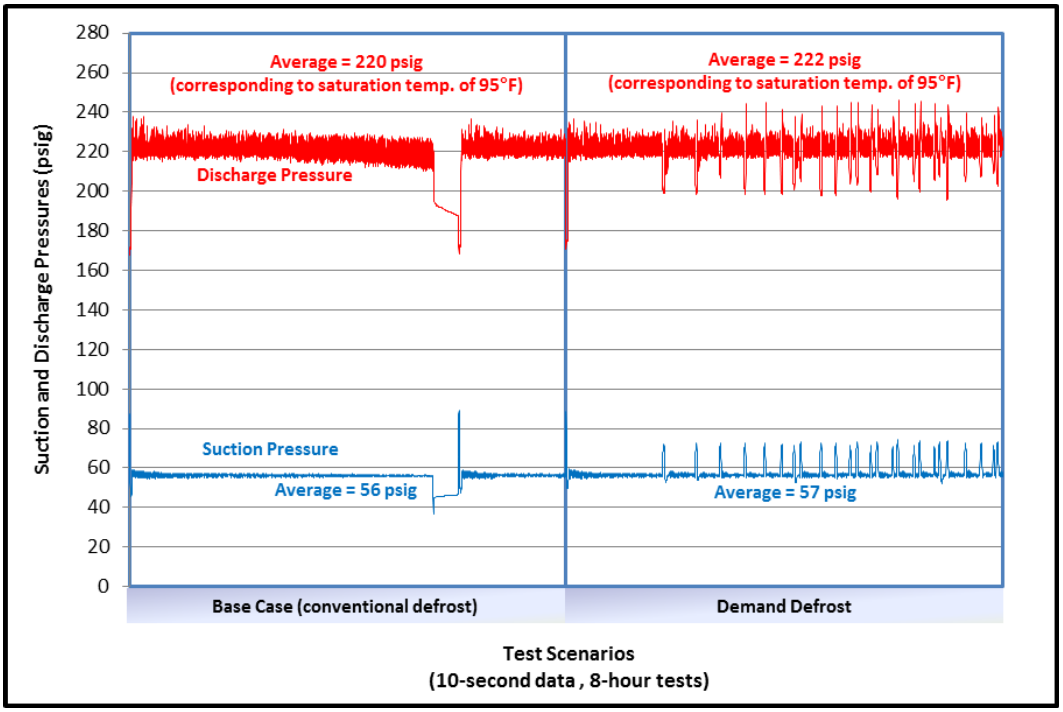


FIGURE 14. 10-SECOND PROFILE OF SUCTION AND DISCHARGE PRESSURE

PRODUCT TEMPERATURES

Figure 15 is the 10-second profile of average product temperatures for every shelf. It shows that products located on the bottom shelf experienced the greatest temperature swings. The overall average product temperatures are in Figure 16. As expected, the product temperatures were highest after defrosts and lowest prior to initiation of defrosts.

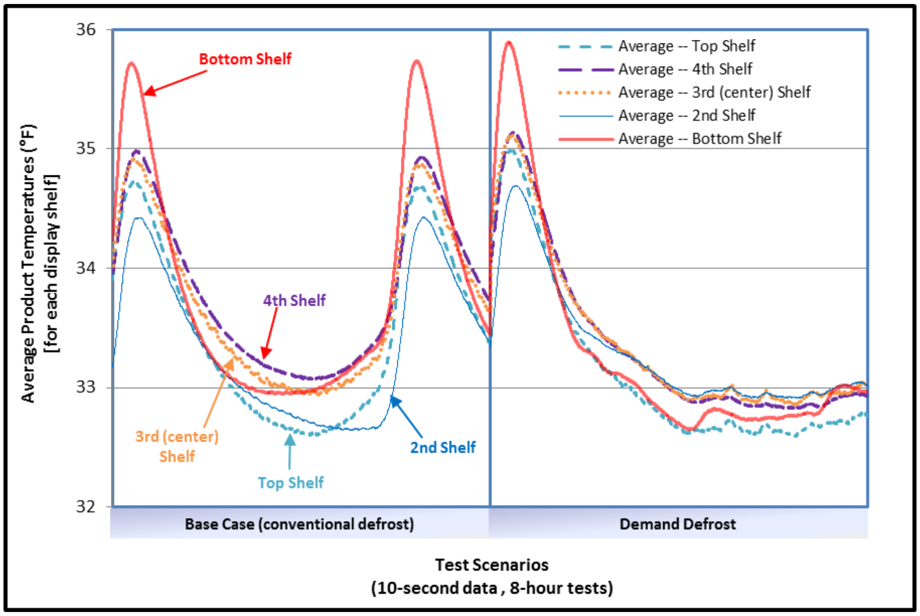


FIGURE 15. 10-SECOND PROFILE OF AVERAGE PRODUCT TEMPERATURE

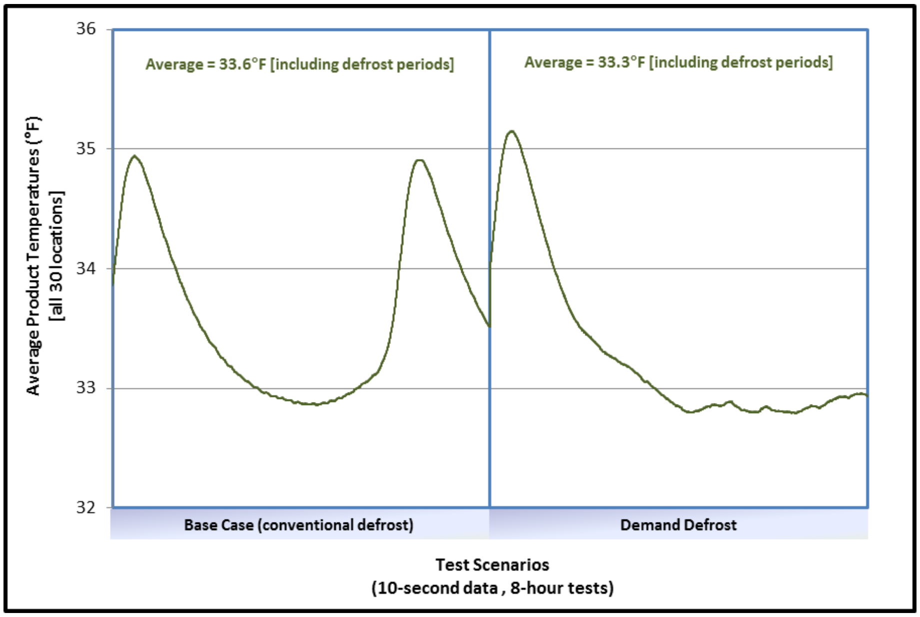


FIGURE 16. 10-SECOND PROFILE OF AVERAGE PRODUCT TEMPERATURE

The average product temperature was below 34°F for both test runs (Figure 17). For both runs, the maximum product temperature reached about 42.5°F (Figure 18). The minimum product temperature, however, stayed below 28°F (Figure 19).

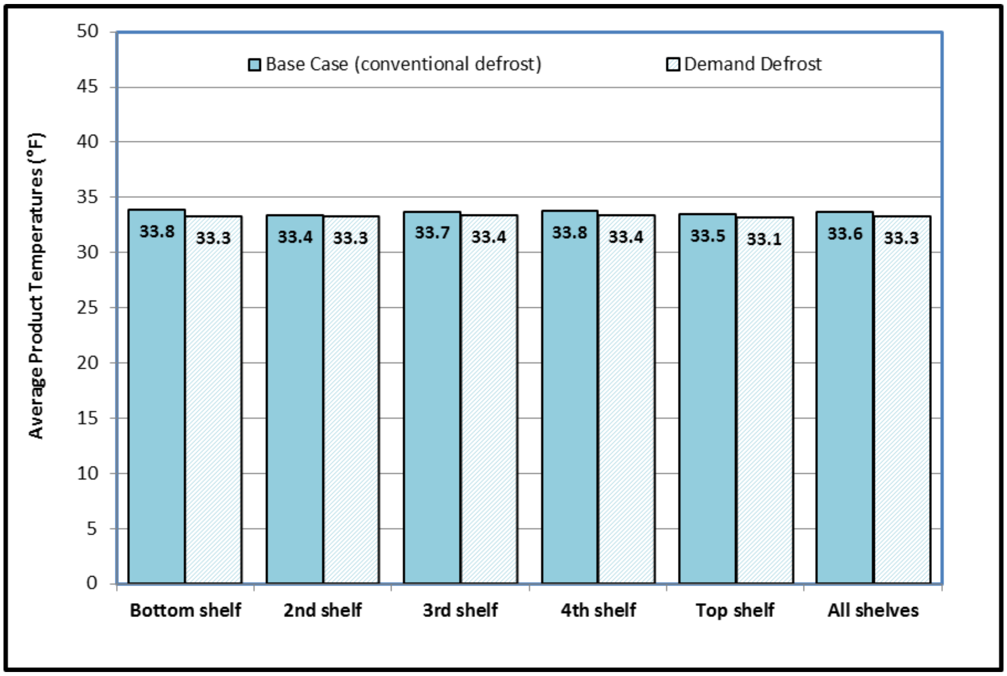


FIGURE 17. AVERAGE PRODUCT TEMPERATURE FOR EVERY SHELF AND ALL SHELVES

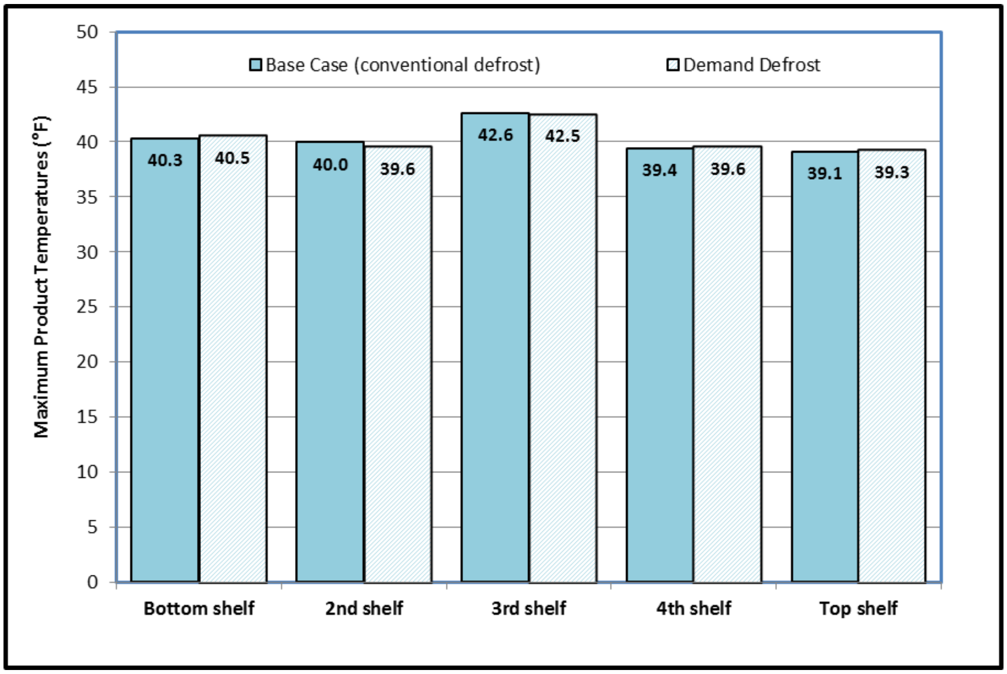


FIGURE 18. MAXIMUM PRODUCT TEMPERATURE FOR EVERY SHELF

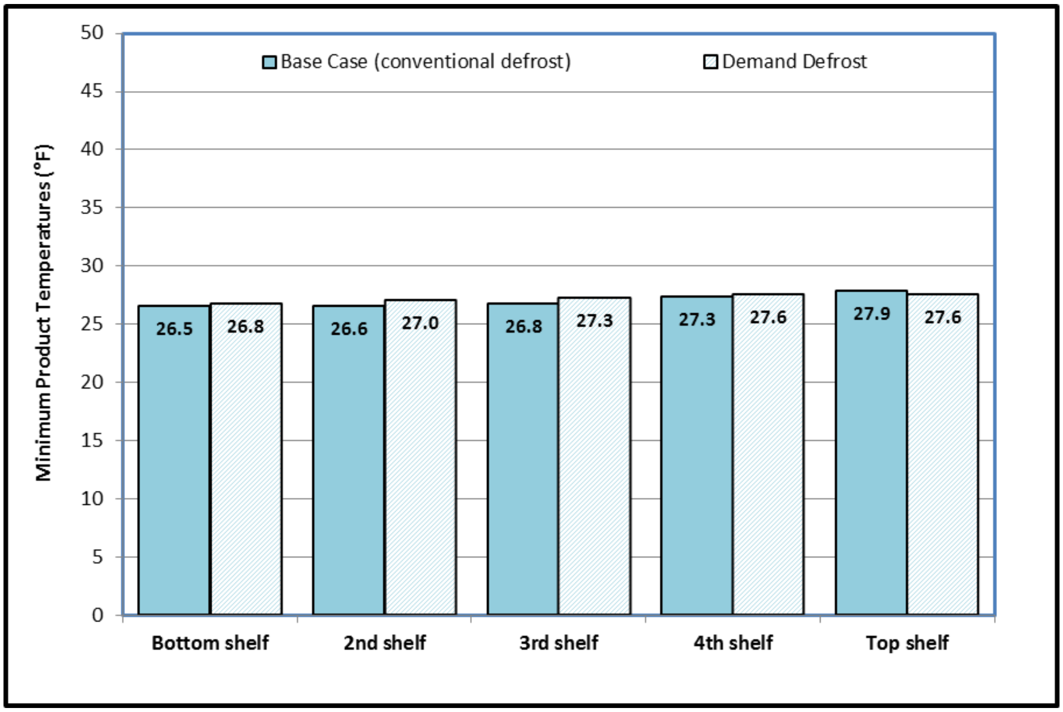


FIGURE 19. MINIMUM PRODUCT TEMPERATURE FOR EVERY SHELF

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1 American Society of Heating, Refrigeration, and Air-Conditioning Engineers (2006). Refrigeration Handbook. Retail Food Store Refrigeration and Equipment, Ch. 46.

2 Baxter, V. D. (2004), Investigation of Energy Efficient Supermarket Display Cases, ORNL/TM-2004/292. Oak Ridge National Laboratory.

3 American Society of Heating, Refrigeration, and Air-Conditioning Engineers (2005). *Methods of Testing Commercial Refrigerators and Freezers*. Standard 72.