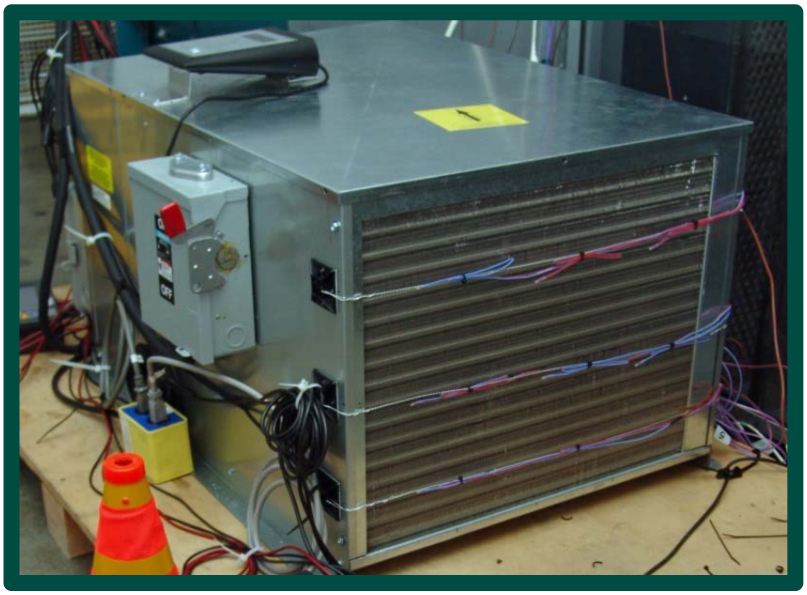
Demand Defrost Controls for Walk-in Freezers

LABORATORY ASSESSMENT

ET14SCE1030 Report



Prepared by:

Emerging Products
Customer Service
Southern California Edison

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SOUTHERN CALIFORNIA EDISON
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Acknowledgments

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EXECUTIVE SUMMARY

The refrigeration systems of walk-in coolers and freezers operate continuously to maintain proper food product temperatures within the conditioned space. One primary heat gain constituent in walk-ins is the infiltration of warm and moist air from the adjacent space. A key factor associated with infiltration in walk-ins is the opening and closing of the walk-in doors. Ultimately, the added moisture due to infiltration leads inevitably to frost formation on evaporator coils.

Frost formation occurs when the moist air comes in contact with a surface temperature that is below the dew point temperature of the air. Hence, frost accumulates on the evaporator coil. The insulating properties of frost slow down the heat transfer and impede airflow through the evaporator coil, thereby decreasing the refrigeration capacity. Therefore, the evaporator coils need to be defrosted in order to maintain performance and product temperatures within the refrigerated zones.

The most common defrost methods are off-cycle and electric defrost. Generally, off-cycle is used for medium-temperature (cooler) and electric defrost is used for low-temperature (freezer) application. In both methods, the refrigeration compressor shuts off, stopping the flow of refrigerant to the evaporator, while the evaporator fan motors stay running. Fan motors blow air over the evaporator coil surface, melting the frost. In electric defrost, electrical heating elements are energized to warm the circulating air over the coil. The conventional defrost method for walk-ins is time initiated and temperature terminated. The consequence of defrost, however, is an increase in the energy usage of the refrigeration system. Hence, defrost technologies that can detect frost on the evaporator and accordingly initiate and terminate defrosts can greatly improve the efficiency of defrost cycles.

The purpose of this project is to investigate the viability of a demand defrost technology compared to a conventional defrost method for a walk-in freezer application. The study focuses on the technology’s capability to initiate defrost based on ice or frost build-up on the evaporator coil. For defrost termination, the technology relied on conventional temperature termination method during the evaluation. The system evaluated in the laboratory was comprised of a condensing unit, an evaporator coil assembly, and all the necessary controls associated with a programmable controller.

According to the manufacturer, refrigerant temperature at the inlet and outlet of the evaporator coil, as well as refrigerant pressure at the outlet of the evaporator, are measured to calculate the degradation in refrigeration capacity for initiating defrost. When the system performance or capacity drops below a predetermined efficiency, defrost is triggered to initiate.

Tests intended to isolate the performance of the demand defrost technology with respect to conventional defrost at outdoor dry-bulb temperatures (DBTs) of 75°F, 90°F, and 110°F. For all 6 test runs, the adjacent space DBT and relative humidity (rh) were maintained fixed at 80°F and 60%, respectively, representing kitchen environment. Additionally, the interior walk-in freezer box temperature was set at 0°F. All tests were performed under controlled laboratory setting at Southern California Edison’s (SCE’s) Technology Test Centers (TTC) controlled environment chambers.

Overall, results indicated that the demand defrost technology under evaluation had no or little impact on the power demand and energy usage of the refrigeration unit. For all three test conditions, the demand defrost technology underwent less defrost cycles per day

compared to conventional four defrost per day schedule. The impact of reduced defrost frequency was evident on the product temperatures, especially for test runs at higher outdoor ambient DBTs.

Ultimately, data obtained here suggests no tangible power demand and energy benefits associated with the evaluated demand defrost technology. A properly commissioned walk-in freezer with time initiated, temperature terminated defrost controls will have similar energy impacts as demand defrost controls. A recommended next step would be to broaden the evaluation to control systems that optimize the refrigeration system beyond demand defrost.

ABBREVIATIONS AND ACRONYMS

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
C&S	Codes and Standards
DBT	Dry-bulb temperature
DR	Demand Response
EE	Energy Efficiency
F	Fahrenheit
IDSM	Integrated Demand Side Management
LT	Low-temperature
MT	Medium-temperature
RH	Relative humidity
RTTC	Refrigeration Technology Test Center
SCE	Southern California Edison
Sq.	Square-feet
TTC	Technology Test Centers

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INTRODUCTION

Walk-ins are typically found in restaurants (fast food and sit-down restaurants), grocery stores, and supermarkets. Walk-ins are room-sized partitions that achieve temperature-controlled storage conditions using thermal insulation and refrigeration system. By definition, the floor area of a walk-in is equal or less than 3,000 square feet (SF). Walk-ins are used to provide short-term storage for perishable food products and maximize food safety and shelf life. The walk-ins are classified either as coolers or freezers. Walk-in coolers are for medium-temperature (MT) applications, above 32 degrees Fahrenheit (ºF), such as fresh fruits and melons, fresh vegetables, fresh meat, and dairy products. Walk-in freezers are for low-temperature (LT) applications, below 32ºF, such as frozen-packed fruits and vegetables, frozen meat, and dairy products.

The refrigeration system of walk-ins operate continuously to maintain proper food product temperatures within the walk-ins. One primary heat gain constituent in walk-ins is the infiltration of warm and moist air from the adjacent space. One of the key factors associated with infiltration in walk-ins is the opening and closing of the walk-in doors. Infiltration can also occur through the door gaskets even when the door is closed, especially if the gaskets are in a bad condition. Other contributing factors to infiltration in walks-ins are cracked and not properly joined walk-in panels.

Frost formation occurs when the moist air comes in contact with a surface temperature that is below the dew point temperature of the air. Hence, frost accumulates on the evaporator coil. The insulating properties of frost slow down the heat transfer and impede airflow through the evaporator coil, thereby decreasing the refrigeration capacity. Hence, the evaporator coils need to be defrosted in order to maintain performance and product temperatures within the refrigerated zones.

Off-cycle and electric defrost are the most common methods of defrosting the evaporator coils. Generally, off-cycle is used for MT (cooler) and electric defrost is used for LT (freezer) application. 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. Fan motors blow air over the evaporator coil surface, melting the frost. In electric defrost, electrical heating elements are energized to warm the circulating air over the coil. The conventional defrost method for walk-ins is time initiated and temperature terminated. The consequence of defrost, however, is an increase in the energy usage of the refrigeration system. Therefore, defrost technologies that can detect frost on the evaporator and accordingly initiate and terminate defrosts can greatly improve the efficiency of defrost cycles.

The objective of this project is to investigate the viability of a demand defrost technology compared to a conventional defrost method for a walk-in freezer application. The study focuses on the technology's capability to initiate defrost based on ice or frost build-up on the evaporator coil. For defrost termination, the technology relied on conventional temperature termination method during the study. The evaluation consisted of testing the technology in a laboratory environment. The technology evaluated is comprised of a condensing unit, an evaporator coil assembly, and all the necessary controls along with a programmable controller.

ASSESSMENT OBJECTIVES

The primary objective of this assessment project is to evaluate the energy and power demand performance of a demand defrost technology in walk-in freezer applications in laboratory conditions. The study also examines the impacts on the product temperatures. The power demand, energy, and product temperature implications were obtained under three outdoor conditions while maintaining adjacent space and box temperature set point at a fixed level.

TECHNOLOGY EVALUATION

This study evaluated a demand defrost technology for walk-in freezers in a laboratory environment. The team evaluated a new refrigeration system fully outfitted with demand defrost controls for a walk-in freezer. The system comes with a condensing unit, an evaporator coil, and all the necessary controls with programmable controller (Figure 1). The system uses R-404A refrigerant and electronic expansion valve.

The controller measures the entering and leaving refrigerant temperature at the evaporator and the leaving refrigerant pressure at the evaporator in order to calculate the degradation in capacity for initiating defrost. Per manufacturer recommended settings, when the performance of the system drops below 35%, defrost initiates. Defrost is terminated based on temperature and/or time. For the product tested in the lab, defrost is terminated at 50°F or 45 minutes, whichever occurs first. The manufacturers' certified contractors installed and set up the refrigeration system and the controller.

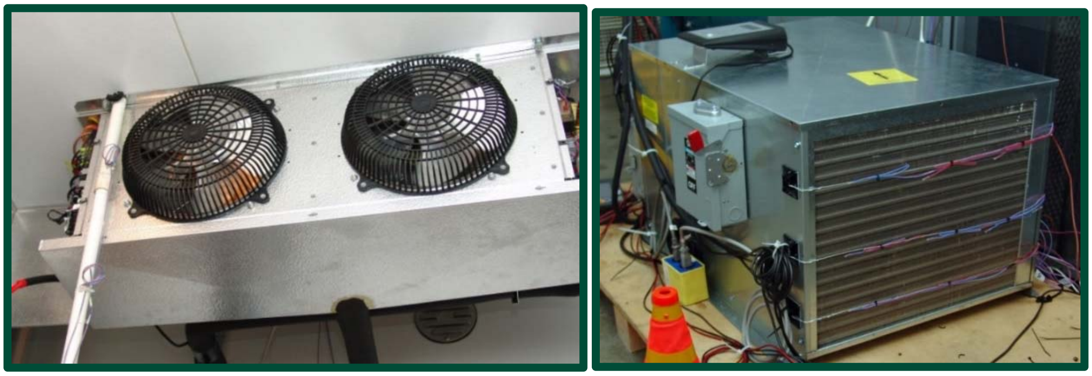


FIGURE 1. LABORATORY ASSEMBLY OF THE EVAPORATOR COIL (LEFT) AND CONDENSING UNIT ALONG WITH THE CONTROLLER (RIGHT)

The laboratory evaluation tested the walk-in freezer refrigeration system with and without the demand defrost capability at the outdoor dry-bulb temperatures (DBTs) of 75°F, 90°F, and 110°F. Testing with the demand defrost technology represents "measure runs" and testing without demand defrost technology represents "baseline runs." Similar to conventional refrigeration units, defrost for the baseline scenarios were set to four defrosts per day. For both measure and baseline runs, defrost terminated on temperature. For all test runs, the walk-in (box) temperature was set at 0°F. The adjacent space DBT was kept at 80°F and relative humidity (RH) at 60%, demonstrating a typical kitchen environment. The controlled environment test chambers of the Technology Test Center (TTC) were used to control and keep tight key test parameters. After testing, the performance data of the refrigeration unit with and without the demand defrost technology was compared to assess the impact of the technology on power demand, energy, and product temperatures.

TEST DESIGN

The following section provides information on the test unit and protocols. It also addresses the performed testing and key monitoring points.

TEST UNIT

Test unit was a new refrigeration system designed for a walk-in freezer application. It was comprised of a condensing unit (PCI99LOP-3E, Figure 2) and evaporator coil assembly (EL26-92-BDE) along with all the necessary controllers. It uses R-404A refrigerant and an electronic expansion valve (SER-C 3/8” x 3/8” ODF).

FIGURE 2. CONDENSING UNIT

TEST METHODOLOGY

Because there were no established standards for testing the performance of walk-in coolers and freezers, the performance testing relied primarily on best engineering practices. Whenever applicable, though, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI, 2009) Standard 1250 as well as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2005) Standard 72 were used. For example, the measurements for DBT and RH of air entering the evaporator coil followed AHRI (2009) Standard 1250, whereas the type of filler products and product simulators followed ASHRAE (2005) Standard 72.

All instruments were calibrated before the test. Careful attention was paid to the design of the monitoring system, with the objective of minimizing instrument error and maintaining a high level of repeatability and accuracy in the data.

LABORATORY TEST SCENARIOS

A set of six tests were designed to compare the performance of the refrigeration unit with and without demand defrost technology. The tests were run under two scenario types:

- Baseline scenarios (without demand defrost technology): These scenarios consisted of tests with defrost cycles initiated based on time and terminated based on temperature.
- Measure scenarios (with demand defrost technology): These scenarios consisted of tests with defrost cycles initiated by the controller and terminated on temperature.

Table 1 summarizes all six test runs. Tests were done for three sets of outdoor conditions at a constant adjacent space condition, 80°F and 60% RH, representing a typical commercial kitchen environment.

TABLE 1. LABORATORY TEST SCENARIOS

DEFROST TECHNOLOGY	TEST NAME	DESCRIPTION	ADJACENT SPACE TEMP. (DBT)	ADJACENT SPACE HUMIDITY (RH)	OUTDOOR AMBIENT TEMP. (DBT)	FREQUENCY OF DEFROST PER DAY
Conventional	A	Baseline A	80°F	60%	75°F	4/day
	B	Baseline B			90°F	
	C	Baseline C			110°F	
Demand Defrost	A1	Measure A	80°F	60%	75°F	Determined by the controller
	B1	Measure B			90°F	
	C1	Measure C			110°F	

MONITORING POINTS

The core monitoring points are listed below. (Refer to Appendix B for the schematic diagrams of sensor location.)

- Refrigeration side:
    - Compressor discharge temperature and pressure
    - Compressor suction temperature and pressure
    - Liquid line temperature and pressure across before and after the mass flow meter
    - Refrigerant temperature and pressure entering the evaporator coil
    - Refrigerant temperature and pressure leaving the evaporator coil
    - Refrigerant mass flow rate
- Air side:
    - Air DBT and RH in the walk-in
    - Air DBT and RH in the adjacent space
    - Air DBT and RH entering the evaporator coil – return air

  - Air DBT and RH leaving the evaporator coil – supply or discharge air
  - Air DBT entering the condenser coil – outdoor ambient DBT
- Condensate mass
- Product temperatures
- Electrical data:
  - Compressor power
  - Evaporator fan power
  - Condenser fan power
  - Defrost heater power
  - Total unit power, amperage and voltage

DATA ACQUISITION

National Instruments™' SCXI data acquisition system was used to log test data. The data acquisition system was set up to scan and log 124 data channels in 20-second intervals.

Screening of collected data ensured the key control parameters were within the acceptable ranges. When any of the control parameters fell outside the acceptable limits, a series of diagnostic inspections was carried out. Corrections were then made and tests were repeated, as necessary.

After the data passed the initial screening process, data was imported to customized refrigeration analysis model where detailed calculations were performed. Appendix B provides list of sensor specifications for the instruments used in this project along with schematic diagrams of test set-up.

RESULTS

This section summarizes key laboratory test results. It includes defrost frequency and duration, power and energy, as well as the product temperatures observed for all six test runs. Test control parameters, walk-in interior temperatures during refrigeration and defrost periods, and key refrigeration parameters are presented in **APPENDIX C. KEY DATA PLOTS**. As shown in **APPENDIX C. KEY DATA PLOTS** (Figure 13), the average outdoor DBT were maintained for each test condition. Additionally, adjacent space temperature was maintained at 80°F and RH at 60% for all six test runs.

Figure 3 compares defrost frequency and duration for baseline and measure runs under three test conditions. As scheduled, the baseline system went to defrost four times per day for all three test conditions. Under Test Condition A and B, the system defrosted once per day for the measure run. Under Test Condition C, the measure system went to defrost three times per day. Nonetheless, daily aggregate defrost duration for baseline and measure runs were about the same, indicating longer defrost durations for measure runs. Longer defrost durations were also observed for the measure run under Test Condition A and B.

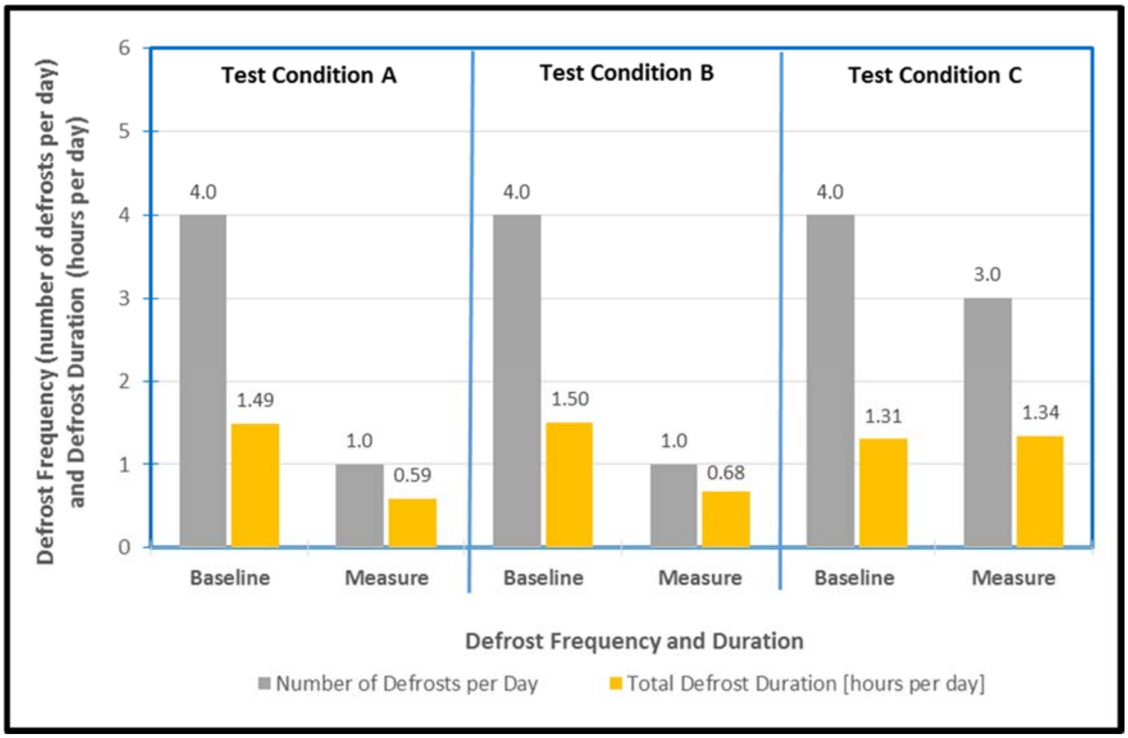


FIGURE 3. DEFROST FREQUENCY AND DURATION – ALL TESTS

Figure 4 shows the power by each component and total power over the entire test period for all six test runs. There was no significant variation in power either by component or total for both the baseline and measure runs under three test conditions. In other words, under all test conditions, the power demand remained about the same for the baseline and measure runs. As expected, however, the power demand increased as the ambient DBT was increased from 75°F (Test Condition A) to 110°F (Test Condition C).

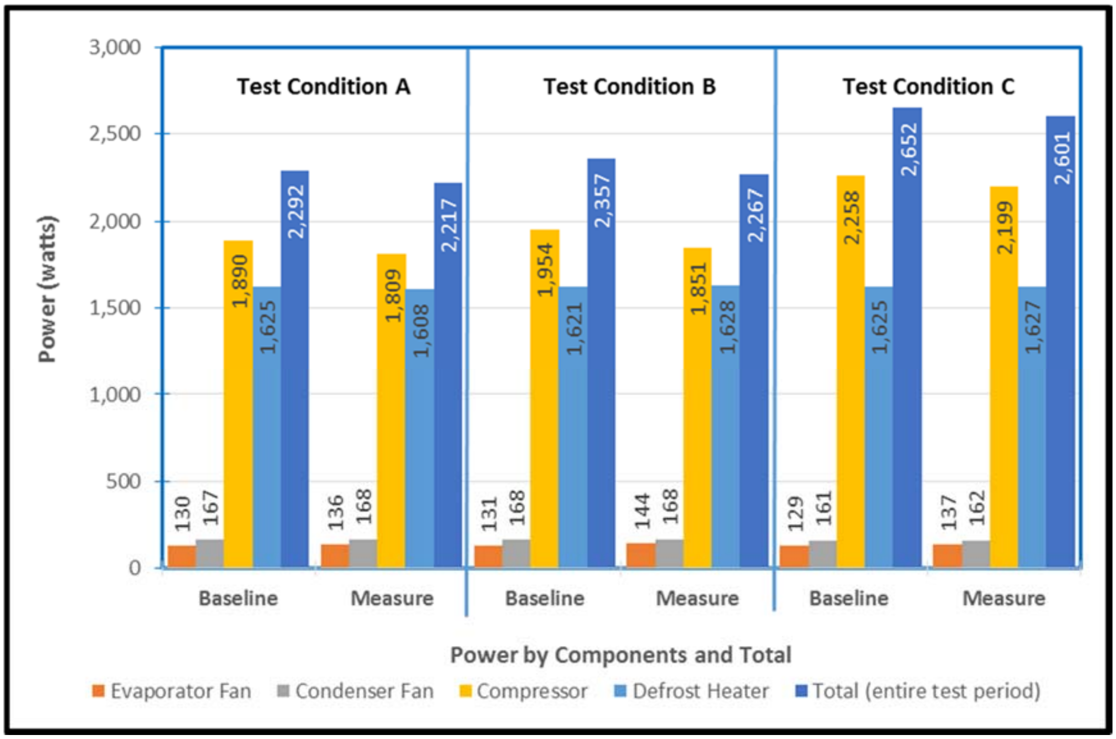


FIGURE 4. POWER BY COMPONENTS AND TOTAL – ALL TESTS

Likewise, the run-time of the evaporator fan, condenser fan, and the compressor did not vary significantly between baseline and measure run under each test condition. (See Figure 5.) However, the refrigeration system ran longer under Test Condition C compared to the other two test conditions.

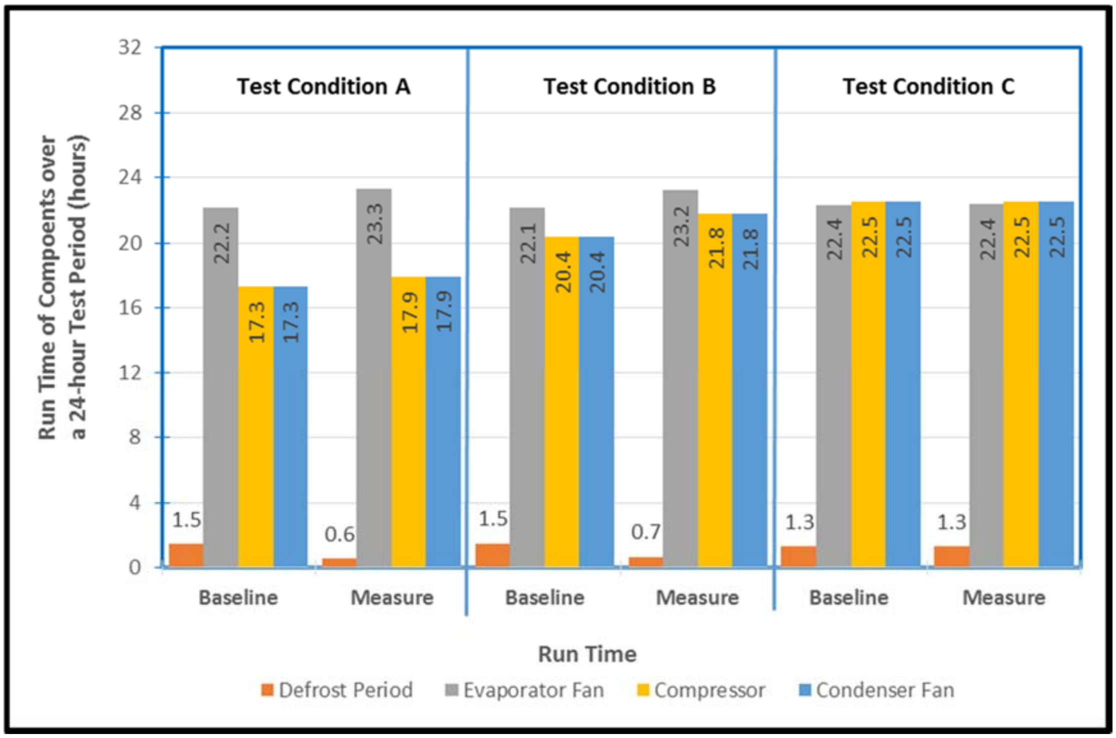


FIGURE 5. RUN TIME FOR COMPONENTS AND DEFROST – ALL TESTS

Figure 6 is the energy usage by each component and total over the entire test period for all six test runs. As shown, the energy either by component or total for both the baseline and measure run under three test conditions remained relatively unchanged. This is because of no significant change in power (Figure 4) and run-time (Figure 5) between the baseline and measure runs. As expected, the energy usage of the refrigeration system was increased as the ambient DBT was increased from 75°F (Test Condition A) to 110°F (Test Condition C).

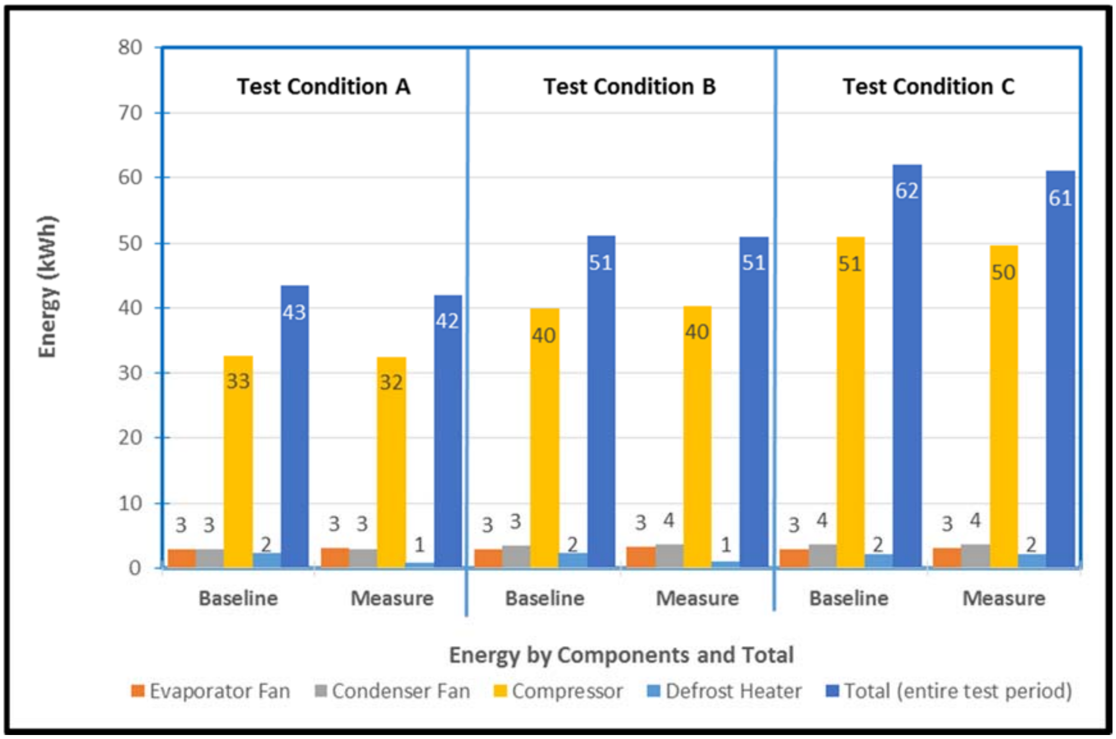


FIGURE 6. ENERGY BY COMPONENTS AND TOTAL – ALL TESTS

Figure 7 shows the average, maximum, and minimum product temperatures observed for all six test runs. The average product temperatures for Test Condition A and B were below 0°F. Under Test Condition C, however, higher average product temperatures were observed for both the baseline and measure runs. This was attributed to a decrease in cooling capacity of the system at higher ambient DBT. The minimum product temperatures for Test Condition A and B were below -6°F. Under Test Condition C, the minimum product temperature remained consistent at approximately -6°F for the measure run, whereas for the baseline run was at approximately -2°F. Under Test Condition A, the difference in the maximum product temperature between baseline and measure run was approximately 1°F. The variation in the maximum product temperature between baseline and measure run was 4°F for Test Condition B and 2°F for Test Condition C. This was attributed to changes in defrost frequency due to change in outdoor DBT.

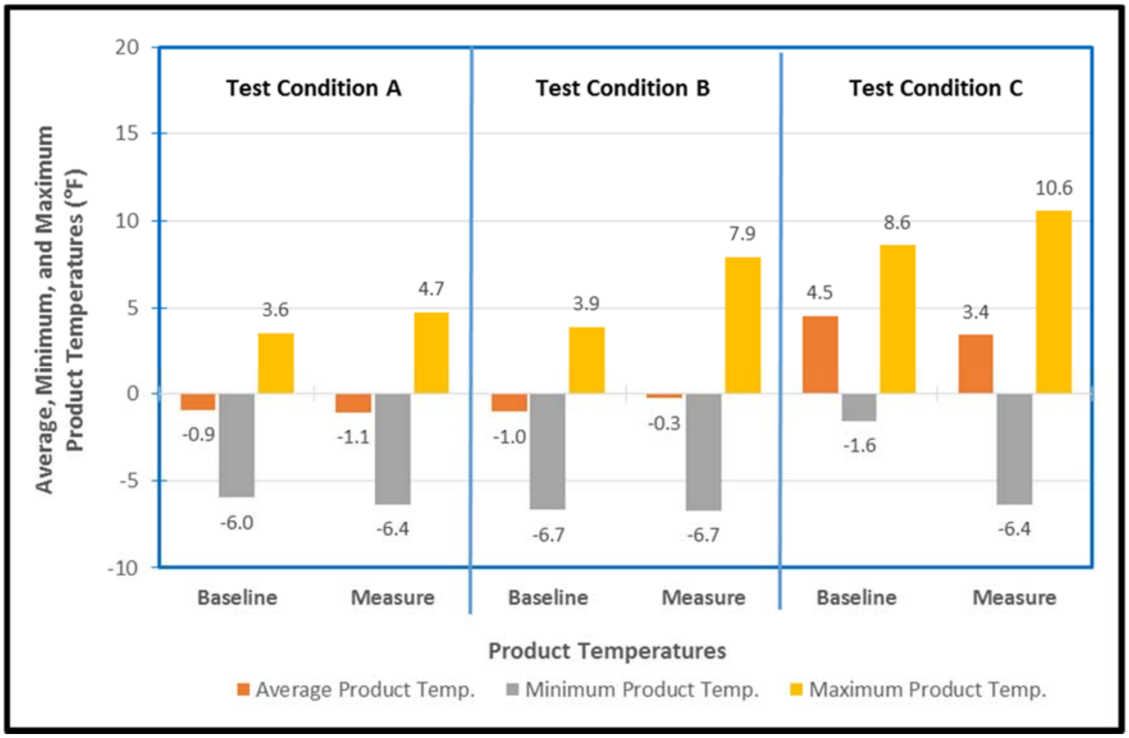


FIGURE 7. AVERAGE, MAXIMUM, AND MINIMUM PRODUCT TEMPERATURES – ALL TESTS

CONCLUSIONS

This laboratory assessment involved conducting 6-test runs to compare the performance of a conventional defrost with a demand defrost technology at three outdoor DBTs. The focus was on the power demand and energy usage. In addition, the impact of the technology on the product temperatures were also was observed.

The results indicated that the demand defrost technology under evaluation had no or little impact on the overall power demand and energy usage of the refrigeration system. Under all three test conditions, the demand defrost technology underwent less defrost cycles per day compared to conventional four defrost per day schedule. The impact of reduced defrost frequency was more evident on the product temperatures, in particular for Test Condition B and C. Ultimately, a properly commissioned walk-in freezer with time initiated, temperature terminated defrost controls will have similar energy impacts as demand defrost controls.

RECOMMENDATIONS

Data obtained here suggests no tangible power demand and energy benefits associated with the evaluated demand defrost technology. A recommended next step would be to broaden the evaluation to control systems that optimize the refrigeration system beyond demand defrost.

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 comprised of various centers focused on distinct energy end uses.

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.

REFRIGERATION TECHNOLOGY TEST CENTER

Founded in 1996, the Refrigeration Technology Test Center (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

The key responsibilities of the RTTC 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. Testing includes:

    Equipment testing in accordance with the standards provided by industry and regulatory organizations, including:

    - 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, its alliance 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. INSTRUMENTATION AND TEST SETUP DIAGRAM

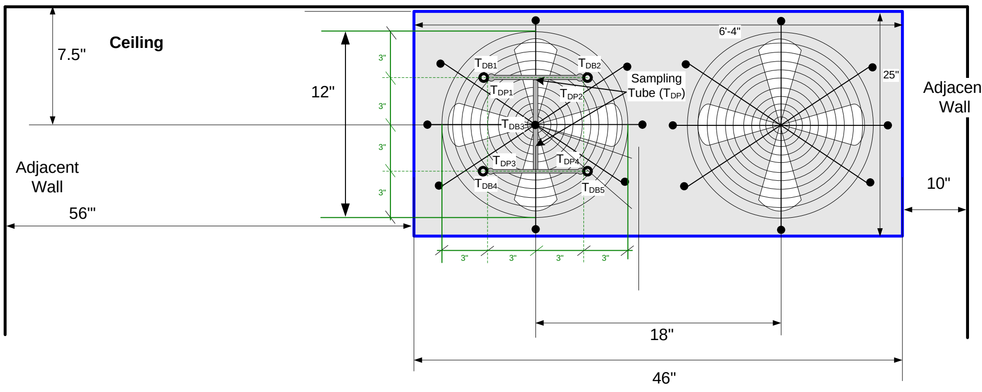
Table 2 lists the specifications for the instruments used in this project. As shown, accuracy relied on National Institute of Standards and Technology (NIST) standards. All the sensors were calibrated in-house prior to installing them on the test equipment and conducting any testing.

TABLE 2. LIST OF SPECIFICATIONS USED FOR INSTRUMENTATION

MEASUREMENT	MAKE/MODEL	ACCURACY (NIST TRACEABLE)
Dry-bulb	Masy Systems, (type-T thermocouples)	± 0.18°F
Dew Point	Edgetech, Dew Prime DF Dew Point Hygrometer	± 0.36°F
Pressure	Setra, C207 (0-1,000 psi)	± 0.13% of full scale
Pressure	Setra, C207 (0-500 psi)	
Power	Ohio Semitronics, GW5-002C	± 0.2% of reading ± 0.04% of full scale
Refrigerant Mass Flow Rate	Endress-Hauser, (Coriolis meter) 80F08-AFTSAAACB4AA	For liquids, ± 0.15% of reading For gases, ± 0.35% of reading
Condensate Mass (using a scale)	HP-30K	± 0.1 gram (± 0.0035 ounces)

Figure 8, not to scale, illustrates the quantity and location of discharge or supply air DBT and dew-point temperature (DPT) sensors. As shown, air DBT were measures at 10 locations. For DBT, sampling tubes were arranged to draw the air from 8 different locations. The sampling points or locations were in close vicinity of the DBT measurements.

Figure 9, not to scale, shows the quantity and location of return air DBT and DPT sensors. The return air DBT was measured at 9 locations. The DPT sampling tubes were arranged to draw air from 6 different locations. Figure 9 also demonstrates the refrigerant temperatures and pressures at the inlet and outlet of the evaporator coil.

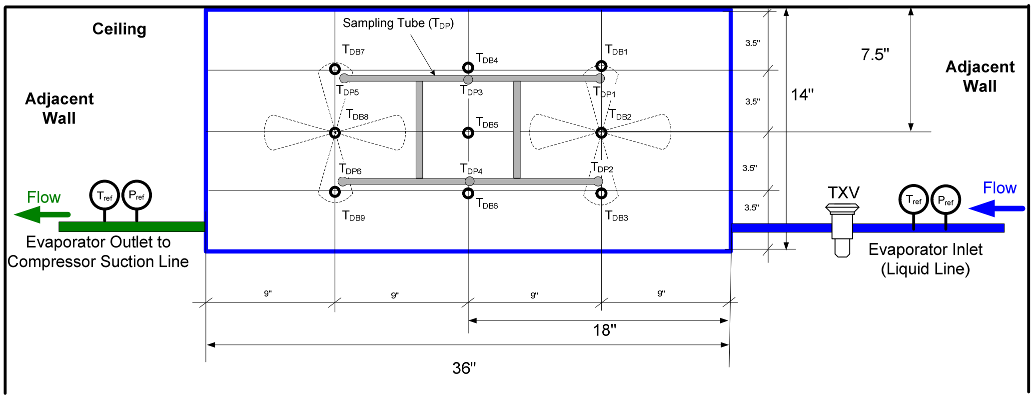


Legend:

T_{DB} = Air dry-bulb temperature (10 sensors , 5 each fan)
T_{DP} = Air Dew-point temperature (8 samples, 4 each fan)

Evaporator Coil – Front View
SCALE: NONE

FIGURE 8. SCHEMATIC DIAGRAM OF SENSORS FOR MEASURING EVAPORATOR DISCHARGE OR SUPPLY AIR DRY-BULB AND DEW-POINT TEMPERATURES



Legend:

P_{ref} = Refrigerant pressure (2 sensors; 1 at inlet, 1 at outlet)
T_{DB} = Air dry-bulb temperature (9 sensors)
T_{DP} = Air Dew-point temperature (6 samples)
T_{ref} = Refrigerant temperature (2 sensors; 1 at inlet, 1 at outlet)

Evaporator Coil -- Rear View
SCALE: NONE

FIGURE 9. SCHEMATIC DIAGRAM OF SENSORS FOR MEASURING EVAPORATOR RETURN AIR DRY-BULB AND DEW-POINT TEMPERATURES, AND REFRIGERANT PRESSURES AND TEMPERATURES AT THE INLET AND OUTLET OF THE EVAPORATOR

Figure 10 shows the quantity and location of condenser inlet air DBT sensors. As shown, 9 sensors were used to measure the air temperature at the inlet of the condenser, which represented the outdoor DBT. Figure 10 also shows the refrigerant temperature and pressure at the inlet and outlet of the condensing unit. As shown in Figure 10, the refrigerant mass flow meter was installed at the liquid line.

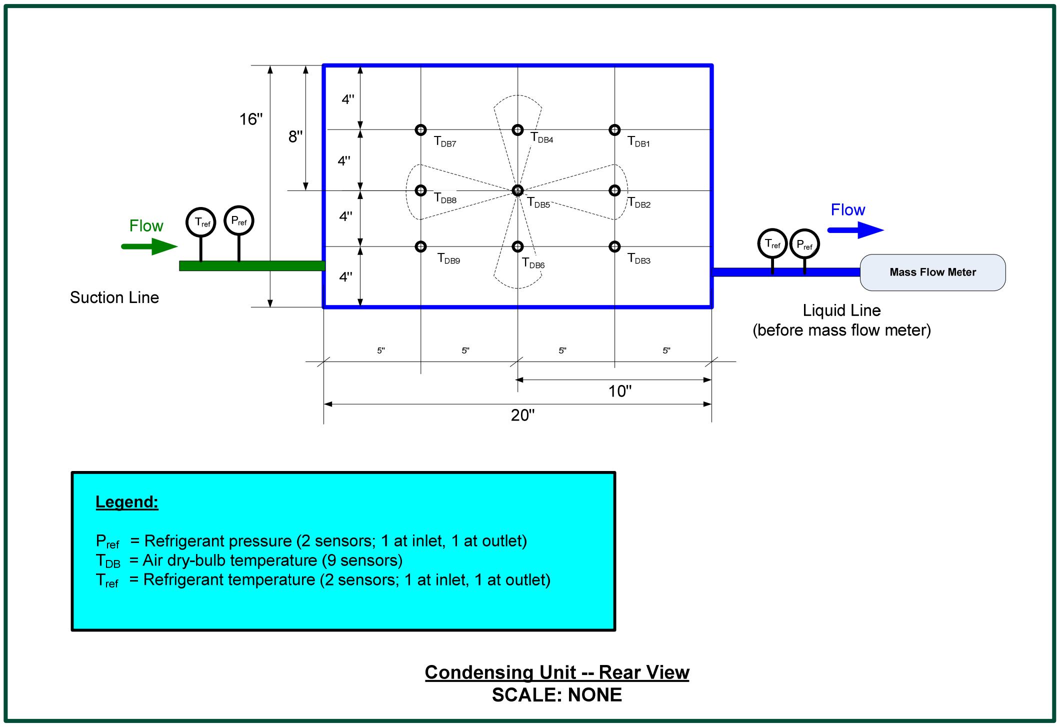


FIGURE 10. SCHEMATIC DIAGRAM OF SENSORS FOR MEASURING CONDENSER INLET AIR DRY-BULB TEMPERATURES, REFRIGERANT MASS FLOW METER, AND PRESSURE AND TEMPERATURES AT THE INLET AND OUTLET OF THE CONDENSING UNIT

Figure 11 depicts the location of DBT and RH sensors used to measure the walk-in's interior and exterior (adjacent space) air temperature and humidity. Inside the walk-in, a pole was set up to measure the walk-in's interior DBT and RH. On the pole, 10 temperature sensors at one-foot increments and 1 RH sensor at the six-foot level were installed. Similar set up was used to measure temperature and humidity in the adjacent space.

Figure 12 shows a photograph of filler products and product simulator. A total of four racks were used to capture the product temperatures along each side of the walk-in. Each rack had four shelves, and on each shelf three product simulators were used. Overall, 48 product simulators were used to measure product temperatures.