Phase Change Material and Controls Study

Project ID: ET16SDG1061 and DR15SDGE0003

Prepared for:

Emerging Technologies Program

San Diego Gas & Electric

October 20th, 2016

Prepared by:

John Baffa, PE

ASWB Engineering

http://www.aswb-engineering.com/

A Sempra Energy utility®

Acknowledgements

San Diego Gas and Electric's Emerging Technologies (SDG&E's ET) group is responsible for this project, developed under internal project numbers ET16SDG1061 and DR15SDE0003. ASWB Engineering conducted this technology evaluation and reporting with overall guidance and management from Chris Roman.

SDG&E and ASWB would like to thank the host customers for their assistance and cooperation. Without their gracious volunteering, this study would not have been possible. Additionally, thanks and acknowledgements are due to the technology vendor for their support, dedication to energy conservation, and ongoing efforts to provide energy efficiency products to the marketplace.

Contact ETinfo@sdge.com for more information on this project.

Disclaimer

EXECUTIVE SUMMARY

The purpose of this study is to determine the effectiveness of passive Phase Change Materials (PCMs) in cold storage freezer applications. The PCM technology is designed to melt and freeze at a specified temperature based on the specific needs of a particular freezer. By increasing the thermal storage capacity of the freezer, refrigeration load is able to shift to periods where energy is cheaper, while simultaneously improving system efficiency. This report is necessary to help determine if the technology is resulting in a significant energy savings and benefits worthy of adoption into SDG&E's Energy Efficiency Program.

The demonstration project was to evaluate the energy saving, demand shifting, and demand response applications of the PCM and control system across two different walk-in freezers in SDG&E Territory. These two locations were a mess hall facility on Camp Pendleton, and the San Diego Food Bank. The technical approach for this field test ensured that any environmental or loading differences between the two cases, baseline and retrofit, be identified and accounted for in order to effectively compare the performance data of the two cases on an equitable basis.

The first testing location, the mess hall on Camp Pendleton, is a 301 square foot walk-in freezer in a cafeteria kitchen that operates from 5:00 AM to 2:00 PM Monday through Thursday, and 5:00 AM to 11:00 AM on Friday. The freezer door is lined with strip curtains and the freezer is entered regularly during business hours by employees. When the mess hall is not open, the freezer is locked shut. The freezer space is served by a Bohn refrigeration unit, model number LET2401F. The PCM and control strategy for the mess hall was to optimize the refrigeration system through the use of controls, sensors, and increased thermal capacity to reduce the energy consumption without modifying refrigeration system hours of operation. Additionally, Demand Response testing was performed at this site to evaluate the "coasting" potential of the PCM for withstanding power outages and voluntary load curtailment.

The second testing location, the San Diego Food Bank, has a large walk-in freezer warehouse of 3,419 square feet and a target temperature of -2°F. Forklifts often enter the freezer throughout the day, and the amount of product varies greatly from month to month depending on the duration and frequency of different food drives. The food bank's receiving operation is open from Monday to Friday, 9:00 AM to 4:00 PM, closing for lunch from noon to 1:00 PM. However, there are often forklifts going in and out of the freezer as early as 7:00 AM. The freezer door is equipped with strip curtains to minimize the heat loss while employees go in and out. The freezer space is served by two Keeprite systems, model number KVD044L6. The PCM and control strategy for San Diego Food Bank was to shift their overnight refrigeration load to the daytime, when their solar generation output exceeds their total facility consumption in order to utilize what might be called "free energy". The PCM and control system allows for the freezer temperature to stay within the target range throughout the duration of the evening and early morning hours.

It should be noted that the two facilities utilized very different control strategies tailored to their individual needs, emphasizing different capabilities of the PCM technology and control system.

Table-ES 1 summarizes the energy savings results obtained by this study.

TABLE-ES 1. SUMMARY OF ENERGY SAVINGS AND DEMAND REDUCTION FOR REFRIGERATION SYSTEMS

LOCATION	ANNUAL ENERGY BASELINE KWH	ANNUAL ENERGY POST KWH	ANNUAL KWH SAVINGS	BASELINE PEAK KW	POST PEAK KW	PERMANENT PEAK REDUCTION KW
Mess Hall	27,142	18,976	8,166	7.4	7.2	0.2
SDFB	130,909	80,045	50,864	108	96	12*

*Note: It may be possible to reduce this peak further by starting the refrigeration process later in the day. Refer to figure 22 of this report for further detail.

Table-ES 2 summarizes the results of the Demand Response testing at the mess hall facility. The refrigeration system was able to shed load when instructed by the control system as intended.

TABLE-ES 2. SUMMARY OF MESS HALL DEMAND RESPONSE TESTING

LOCATION	2 HOUR DR SIMULATION AVERAGE LOAD SHED KW	4 HOUR DR SIMULATION AVERAGE LOAD SHED KW	7 HOUR DR SIMULATION AVERAGE LOAD SHED KW
Mess Hall DR Testing	1.89	1.72	0.54*

*Note: The system was unable to remain offline for the full 7 hour test, as the freezer temperature increased too high and the controls system overrode the DR signal to maintain freezer temperature within the allowable range.

Based on the results of this assessment, the new technology had a positive impact on both freezer systems and was able to produce savings. In order to determine if the technology was cost effective, the energy savings were converted into dollar figures using estimated $/kWh rates, and then compared to the project implementation costs. Table-ES 3 summarizes the financial analysis results obtained by this study.

TABLE-ES 3. SUMMARY OF FINANCIAL ANALYSIS

LOCATION	PROJECT IMPLEMENTATION COST	ANNUAL COST SAVINGS	SIMPLE PAYBACK
Mess Hall	$19,723.00	$816.70	24.1 Years
SDFB	$47,039.43	$8,154.93	5.8 Years

A life expectancy of 20 years was assumed for this analysis, which was taken directly from Viking Cold Solutions product literature. An energy cost of $0.13/kWh and a demand charge of $11.34/kW per month were assumed for the food bank, and an energy cost of $0.10/kWh was assumed for the mess hall. Based on these simple playbacks, the San Diego Food Bank was an ideal candidate for the installation of PCM and the control system, while the mess hall resulted in a significantly less attractive investment opportunity mainly due to the small freezer and refrigeration system size and the fixed costs for adding the controls optimization with the installation of the PCM. However, it is important to note that Viking Cold Solutions' costs have dropped dramatically since the time of installation, and cost effectiveness will improve as a result. Further explanation of each site's cost effectiveness can be found in the results section of this report. Viking Cold Solutions product literature can be found at http://www.vikingcold.com/cold-storage/.

When taking into consideration the projected drop in costs, as well as incentives from the Energy Efficiency Business Incentives (EEBI) Program and Technology Incentives (TI) Program (for mess hall only), the results of the financial analysis improve significantly, as seen in Tables ES 4 and ES 5 below. Refer to Appendix C for further information about these programs.

TABLE-ES 4. MESS HALL FINANCIAL ANALYSIS

SCENARIO	IMPLEMENTATION COST	INCENTIVE	TOTAL COST	ANNUAL COST SAVINGS	SIMPLE PAYBACK
Current Installation, no incentive	$19,723.00	$0.00	$19,723.00	$816.70	24.1 Years
Current Installation, with incentive	$19,723.00	$1,822.05	$17,900.95	$816.70	21.9 Years
Forecasted 2017 Installation, with incentive	$6,000.00	$1,822.05	$4,177.95	$816.70	5.1 Years

TABLE-ES 5. SDFB FINANCIAL ANALYSIS

SCENARIO	IMPLEMENTATION COST	INCENTIVE	TOTAL COST	ANNUAL COST SAVINGS	SIMPLE PAYBACK
Current Installation, no incentive	$47,039.43	$0.00	$47,039.43	$8,154.93	5.8 Years
Current Installation, with incentive	$47,039.43	$7,525.35	$39,514.08	$8,154.93	4.8 Years
Forecasted 2017 Installation, with incentive	$24,000.00	$7,525.35	$16,474.65	$8,154.93	2.0 Years

ABBREVIATIONS AND ACRONYMS

CBP	Capacity Bidding Program
CPP	Critical Peak Pricing
DR	Demand Response
EEBI	Energy Efficiency Business Incentives
EEM	Energy Efficiency Measure
HVAC	Heating, Ventilation, and Air Conditioning
OBF	On-Bill Financing
OSAT	Outside Air Temperature
PCM	Phase Change Material
SDFB	San Diego Food Bank
TES	Thermal Energy Storage
TI	Technology Incentives
TSC	Thermal Storage Cells
ZNE	Zero Net Energy

CONTENTS

FIGURES

TABLES

INTRODUCTION

ASWB was selected by SDG&E ETP to conduct the Measurement and Verification (M&V) analysis for a Phase Change Material (PCM), produced by Viking Cold Solutions, to determine if the technology is viable as a possible energy efficiency measure and/or an effective load shifting measure when implemented in walk-in freezers. SDG&E worked with the PCM technology vendor, Viking Cold Solutions, and originally arranged for field testing at three sites within their service territory. One of the sites went out of business approximately midway through their individual project timeline, so the project had to be cancelled. As a result of the facility closure, the analysis shown here is only for the two remaining sites: The San Diego Food Bank and a USMC Camp Pendleton mess hall.

Phase Change Material technology utilizes a material that changes phase at or near the operating point of the particular refrigerated facility under study. Heat is absorbed by the material as it changes phase from a solid to a liquid-like gel during those times when the air temperature in the refrigerated environment rises to the material's design point. This undesirable heat gain in the refrigerated spaces is due to a number of sources, from conductive heat gain through the building envelope to heat gained due to air infiltration through doorways and other envelope openings as well as heat that is transferred from any non-frozen products that are introduced to the refrigerated environment in the course of business. The PCM acts to maintain the refrigerated facility at or near the designed target temperature by providing what can be thought of as "thermal ballast", which absorbs heat as it "melts" and then releases that heat as the temperature in the space is reduced and the material "freezes". In addition to maintaining space temperature, this "thermal ballast" also serves to keep the space at temperature during short-term power interruptions. In theory, the PCM provides a function similar to that of a battery for Thermal Energy Storage (TES) and Permanent Load Shift (PLS) applications. It can be cooled and then frozen by the refrigeration system when energy costs are lower (or provided for free by photovoltaics), and then provide that stored cooling capacity to the space in place of the mechanical refrigeration system at times when the energy costs are higher or renewable sources are not available.

The PCM was installed above the top layer of product per the manufacturer's design in both walk-in freezers where the supply air fans were able to recharge, or freeze, the material after the stored product depleted, or melted, the material via convection when the evaporator fans were not operational. Once the thermal capacity was reached, or the melting cycle completed, the evaporator fans could operate and return the PCM back to its solid, or frozen, state. The melting cycle was designed to shift a specific load at each site for a specific duration of time.

There is no incumbent technology equivalent to this product and is considered a passive retrofit add-on. The alternative to this product is not having any phase change materials installed in the freezer area. The base case for the analysis in this report assumes a regular walk-in freezer with no heat transfer material in the space.

BACKGROUND

HISTORY

While PCMs are relatively new, the concept of passively storing heat in a building has been around since the 1800s[1]. One of the earliest iterations of this technology is referred to as a Trombe wall. The Trombe wall is a wall that has an external layer of glass and a high heat capacity internal layer separated by a layer of air. Heat from the sun penetrates the glass in the form of ultraviolet radiation and is absorbed by the internal layer of the wall. The heat is then re-emitted from the wall as infra-red radiation, which does not pass back through the glass layer as easily and becomes trapped. Upper and lower vents are located in the internal wall layer to allow the air between the wall and glass to flow into the building space. This technology was first created in 1881 by Edward Morse, and was fully developed by Felix Trombe in 1964. The main drawback of the Trombe wall is that it is not very functional in the summer when cooling is required. PCMs however have both heating and cooling applications, and are more versatile as they can be placed in both walls and ceilings. In addition, the PCMs can be designed to an ideal melting/freezing temperature for most applications.

Over the years several materials have been considered and tested as applications for PCM in buildings. Some notable materials are eutectic salts, paraffin wax, and bio-based organic materials. The material under study in this report is a PCM designed for cold storage application. These PCMs maintain their melting temperatures at very low temperatures adjustable by their internal chemistry. This makes them ideal for cold storage applications.

The earlier versions of PCM technology used macro-encapsulation, which reduced the surface area contact to the PCM. As a result, when it was time to regain the heat from the liquid phase, the PCM would solidify only on the edges, and prevent effective heat transfer from the rest of the material in the capsule. At the time, the material available was also either toxic or flammable, which posed unsafe conditions and possible health risks for the buildings they were used in. The PCM technology has since evolved to incorporate micro-encapsulation as opposed to macro-encapsulation. This increases the overall surface area and allows for superior effective heat transfer. Non-toxic and ignition resistant PCMs have also been developed.

[1] Introduction to Phase Change Materials: Building Applications, Theo Pacson, 2011

SITE DESCRIPTIONS

MESS HALL:

The mess hall on USMC Camp Pendleton used for this study has a 301 square foot walk in freezer having a target temperature of 5°F. The mess hall operates Monday from 5:00 AM to 2:00 PM Mondays through Thursdays and 5:00 AM to 11:00 PM on Fridays. The door is opened frequently during working hours as mess hall staff go in and out as needed. Outside of operating hours, the door to the freezer is locked and can only be accessed by the manager. The freezer door is equipped with strip curtains in order to minimize heat loss while employees go in and out. The freezer space is served by a Bohn refrigeration unit, Model LET2401F.

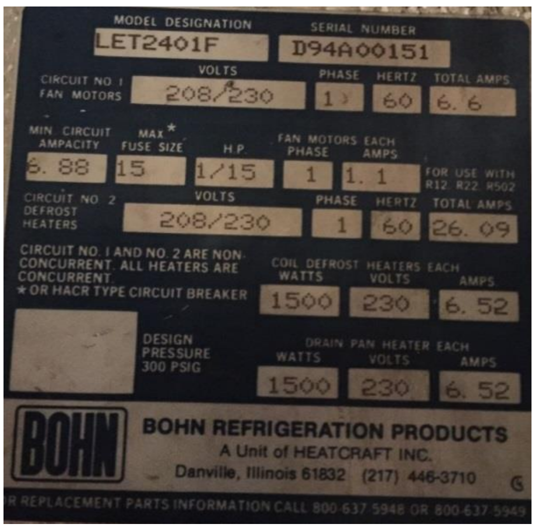


FIGURE 1. – MESS HALL REFRIGERATION UNIT NAMEPLATE

FIGURE 2. – MESS HALL REFRIGERATION UNIT

SAN DIEGO FOOD BANK:

The San Diego Food Bank has a large walk-in freezer warehouse of 3,419 square feet and a target temperature of -2°F. Forklifts often enter the freezer throughout the day, and the amount of product varies slightly from month to month depending on the duration and frequency of different food drives. The food bank's receiving operation is open from Monday to Friday, 9:00 AM to 4:00 PM, closing for lunch from Noon to 1:00 PM. However, there are often forklifts going in and out of the freezer as early as 7:00 AM. The freezer door is equipped with strip curtains to minimize the heat loss while employees go in and out. The freezer space is served by two Keeprite systems, Model KVD044L6.

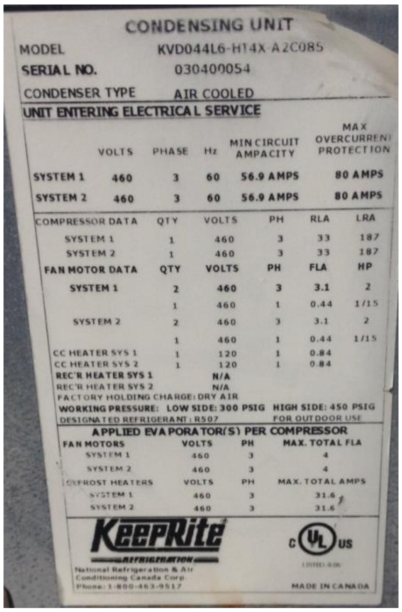


FIGURE 3. – FOOD BANK REFRIGERATION UNIT NAMEPLATE

FIGURE 4. – FOOD BANK GOOGLE EARTH VIEW

EMERGING TECHNOLOGY/PRODUCT

The Phase Change Material technology being assessed uses Thermal Storage Cells (TSC) filled with a substance that has a melting point equivalent to the desired temperature in order to store or release latent heat to achieve that temperature.

To understand the application of PCM in a refrigeration application, it is necessary to understand the difference between sensible and latent heat. When temperatures increase and decrease in the stored product, the measurable difference is called sensible heat. Sensible heat can be measured using a conventional thermal measuring device. Latent heat is the heat energy that is required to change the material from a solid to a liquid or 'Phase Change'. During this transformation, the material does not become measurably warmer or cooler. After the Phase Change is complete, the heat gain becomes measureable again, or sensible.

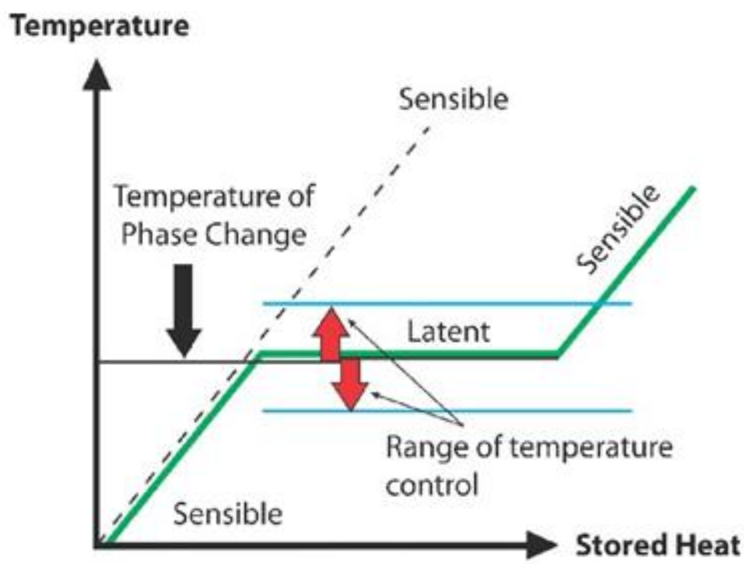


FIGURE 5. – PHASE CHANGE DIAGRAM

(Figure 5 from http://www.rgees.com/technology.php)

The phase change material is designed to operate, or phase change, within a precise range of temperature control. This allows the material to have a specific phase change design point that is targeted to absorb heat loads that are introduced into the refrigerated space without allowing the stored material to increase in temperature outside the specifically designed range of control temperature. This design temperature is maintained while the PCM transitions through phase change process (latent mode) since it can absorb many times the thermal energy in the latent mode, at a constant temperature than a 1°F temperature change in the sensible mode. This application is possible because the PCM is designed to phase change at a temperature that is just below the freezing control point of the stored product. By designing the PCM to phase change below the freezer control point, the PCM can absorb thermal energy entering the refrigerated space and maintain the product temperature at the desired setpoint without the aid of mechanical cooling. When depleted, the mechanical systems can recharge the PCM and prepare it for use in the next cycle.

A significant added benefit to this technology is that it can be combined with sophisticated controls which can facilitate demand shifting and demand response. The increase in thermal mass associated with adding PCMs to a space allows for the facility to temporarily shut down some or all of the refrigeration equipment and then "coast" on the cooling provided from the PCM, which can maintain the ideal temperature range for hours at a time. When a demand response event is known in advance, the system can precool and charge the PCM system to prep it for a refrigeration system shut down. For demand shifting applications, the refrigeration system can work extra hard on a daily basis during times when the electricity is cheaper, and then rely on the PCM to maintain the space temperature during the hours where electricity is most expensive. These strategies would not be as easily implementable without the PCM technology.

There are also significant energy efficiency applications for the PCM and controls system. Much of the freezer's heat gained through its exterior envelope can be absorbed by the PCM. This is because when compared to the product, the PCM has a larger surface area per pound, is more heat absorbent, and has a lower R-value. Likewise, the refrigeration system is able to remove heat more easily from the PCM material than it can from the stored frozen product, which results in shorter compressor run times. The PCM also reduces the need to cool space temperature as far below the target temperature for the freezer than was the case in the original condition. The slight average temperature increase results in somewhat warmer evaporator temperatures overall, which in turn correlate to a higher evaporator pressures. By keeping the freezer temperature relatively warmer on average than was possible before PCM installation, the compressor can operate at somewhat higher suction temperatures, gaining between 2 to 3 percent of thermal capacity for each degree of suction temperature relief. This increase in thermal capacity as a function of suction temperature relief is well known and can be used as a "rule of thumb". In this case, the mess hall condensing unit's capacity data was available. This data was used to calculate this percentage efficiency improvement at 0°F and -5°F suction temperatures, with this refrigerant and compressor. This data can be located in the Appendix A.

ASSESSMENT OBJECTIVES

This project is a technology assessment that ultimately aims to analyze the potential demand, energy savings, and TES/PLS potential for PCMs. Specifically, the assessment objectives are:

- Using temperature loggers, monitor the temperature at various heights throughout the refrigerated space.
- Using ampere loggers, monitor the run time of each of the refrigeration units pre and post PCM installation for a noticeable difference in the run time.
- Analyze the interval data for noticeable changes in energy use between pre and post installation timeframes.
- Ensure that the PCM can maintain space and product at the target temperature for extended periods of time without the refrigeration units running (Demand Response Applications).

TECHNOLOGY/PRODUCT EVALUATION

This technology evaluation project studied the Viking Cold Solutions Phase Change Material and controller refrigeration strategy as installed in two frozen food storage applications. By use of the phase change materials, the refrigerated space's thermal capacity was increased significantly, allowing for mechanical cooling energy to be stored as latent heat within the phase change material. By implementing a sophisticated control system along with the phase change material, new operational strategies arise that may not have been possible previously due to the risk of product temperature increasing beyond the desired limits. With the PCM and controller set up, the freezers are capable of operating compressors during hours when electricity is cheaper, and then using the PCM to store that additional cooling to coast through on-peak periods without needing to run the compressors to maintain target product temperature. In addition to permanent load shifting applications, there are also Demand Response possibilities associated with this technology.

ASWB Engineering was selected as the engineering firm to perform the assessment. ASWB has performed multiple Emerging Technology Assessments for various utilities in the past, and has extensive experience planning and implementing Measurement and Verification projects.

TECHNICAL APPROACH/TEST METHODOLOGY

FIELD TESTING OF TECHNOLOGY

SDG&E proposed field verifications for this technology to monitor and evaluate the impact of the PCM and control system on walk-in freezers in SDG&E service territory. Three locations were selected; however one location was forced to close down during the testing procedure, and was omitted from the project. The other two locations tested, Camp Pendleton mess hall and San Diego Food Bank, were selected for the following reasons:

- Both were facilities with cold storage freezers
- Both were located in SDG&E service territory
- An interest in reducing operating costs
- Both were willing to take the risk of allowing refrigeration plants to shut down for significant periods of time
- Each had differing needs, allowing SDG&E to test different PCM product applications

The mess hall on Camp Pendleton has a 301 square foot walk in freezer with a target temperature of 5°F. The mess hall operates Monday from 5:00 AM to 2:00 PM Mondays through Thursdays and 5:00 AM to 11:00 PM on Fridays. The door is opened frequently during working hours as mess hall staff go in and out as needed. Outside of operating hours, the door to the freezer is locked and can only be accessed by the manager. The freezer door is equipped with strip curtains in order to minimize heat loss while employees go in and out. The freezer space is served by a Bohn refrigeration unit, model number LET2401F.

The San Diego Food Bank has a large walk-in freezer warehouse of 3,419 square feet and a target temperature of -2°F. Forklifts often enter the freezer throughout the day, and the amount of product varies greatly from month to month depending on the duration and frequency of different food drives. The food bank's receiving operation is open from Monday to Friday, 9:00 AM to 4:00 PM, closing for lunch from Noon to 1:00 PM. However, there are often forklifts going in and out of the freezer as early as 7:00 AM. The freezer door is equipped with strip curtains to minimize the heat loss while employees go in and out. The freezer space is served by two Keeprite systems, model number KVD044L6. While product level in the freezer space does vary from time to time, this was assumed constant for analysis purposes as it could not be easily tracked.

Data loggers were installed in both facilities, monitoring both refrigeration system current and space temperature. Loggers recorded data throughout the baseline period, and were left in place during the installation and set-up of the PCM and control systems. Once the PCM and control systems were implemented, the loggers were relaunched to collect the post period data.

TEST PLAN

The monitoring periods for this energy study are as follows:

- Mess Hall Pre Period – 2/29/16 through 3/30/16
- Mess Hall Post Period – 5/25/16 through 6/24/16
- Mess Hall DR Period – 6/30/16 through 7/25/16
- San Diego Food Bank Pre Period – 3/23/16 through 4/22/16
- San Diego Food Bank Post Period – 5/6/16 through 6/5/16

ASWB determined that this measurement and verification project would be best performed utilizing the Retrofit Isolation option (Option B) of the International Performance Measurement & Verification Protocol (IPMVP). This option was the best fit for the proposed project due to the following facts:

- The performance of the systems affected by the energy conservation measure (ECM) is the only area of concern.
- Other systems at the facility were assumed to be unaffected and operated the same during the pre- and post-monitoring periods.
- Interactive effects with other facility equipment were assumed to be immaterial.
- The independent variables that affect energy use are not complex and excessively difficult or expensive to monitor.

The savings associated with the PCM were calculated from the information recorded during the field monitoring periods. The underlying equation to calculate the savings for this Energy Efficiency Measure (EEM) is as follows:

EEM Energy Savings = Baseline Energy Use – Post Installation Use

Baseline Energy Use is the energy performance measured before energy performance improvement actions were implemented. Post Installation Use is the energy performance measured after energy performance improvement actions were implemented. This difference is considered to be the energy savings attributed to the Viking Cold Solutions system.

Compressor amps were recorded over time in order to monitor refrigeration system run times. ASWB installed Onset amp loggers on two of the legs for each unit and programed them to record their amperage every minute. At the time that the amp loggers were installed, simultaneous power readings were taken to correlate the amps to real power. ASWB measured the real RMS power for each AC unit's amp correlation using a PowerSight PS3000 Energy Analyzer.

Temperature measurements were taken pre- and post PCM installation using stratified temperature sensing data loggers. The data was collected using HOBO U12 Data Loggers, with TMC6-HD temperature sensors. These data loggers were set to monitor the temperature inside the space at five minute intervals.

All data was processed through ASWB's rigorous quality control screening to determine if there were any issues with the collected data or any recorded data that did not meet the guidelines for the expectations of the specific point being monitored. The data from both sources, kW derived from calibrated amp measurements and temperatures, were used to perform all of the following actions:

1. Product temperature analysis
2. Regression analysis
3. Annual energy savings analysis
4. Electric load shifting analysis
5. Developing the charts and graphs for this final reporting

In addition to the pre and post PCM installation analysis, a period of demand response testing was also included for the mess hall facility. As part of this testing, ASWB provided a day-ahead notice to Viking Cold Solutions for simulated DR events of varying length. The DR event simulations were scheduled as follows:

- 7/8/16 12:00 PM to 2:00 PM
- 7/12/16 12:00 PM to 4:00 PM
- 7/19/16 11:00 AM to 6:00 PM

ASWB conducted a regression analysis on the collected data against all independent variables, which are those parameters that are expected to change routinely and that have a measureable impact on the energy use of facility's Refrigeration systems. The regression analysis provides the basis to normalize the collected data to annual energy consumption for the pre- and post-installation condition.

INSTRUMENTATION PLAN

The instrumentation for this energy study consisted of:

Mess Hall:

- 6 HOBO Data Loggers (U12-001)
- 6 Temperature Probes TMC6-HD
- 2 CTV-A 20 A Current Transducers
- 1 CTV-B 50 A Current Transducers
- 1 Three-Phase Power Meter (Summit PowerSight 3000)

San Diego Food Bank:

- 8 HOBO Data Loggers (U12-001)
- 8 Temperature Probes TMC6-HD
- 4 CTV-B 50 A Current Transducers
- 1 Three-Phase Power Meter (Summit PowerSight 3000)

Temperature measurement accuracy: ±0.25°C from 0° to 50°C (±0.45°F from 32° to 122°F) with 5 minute sample times. Two temperature sensors were attached per HOBO logger, allowing for 75 days of continuous data collection without needing to be reset.

Current measurement accuracy: ±4.5% of Full Scale with 1 minute sample times. Current measurements are calibrated against instantaneous RMS real power meter readings. One current transducer was attached per HOBO logger, allowing for 30 days of continuous data collection without needing to be reset.

The HOBO loggers were launched and retrieved using HOBOware 3.7.1 through a USB cable connected to a laptop.

The current transducers were placed on Legs A and C of each rooftop unit. The temperature logger locations can be seen the figures 6 and 7 on the next page.

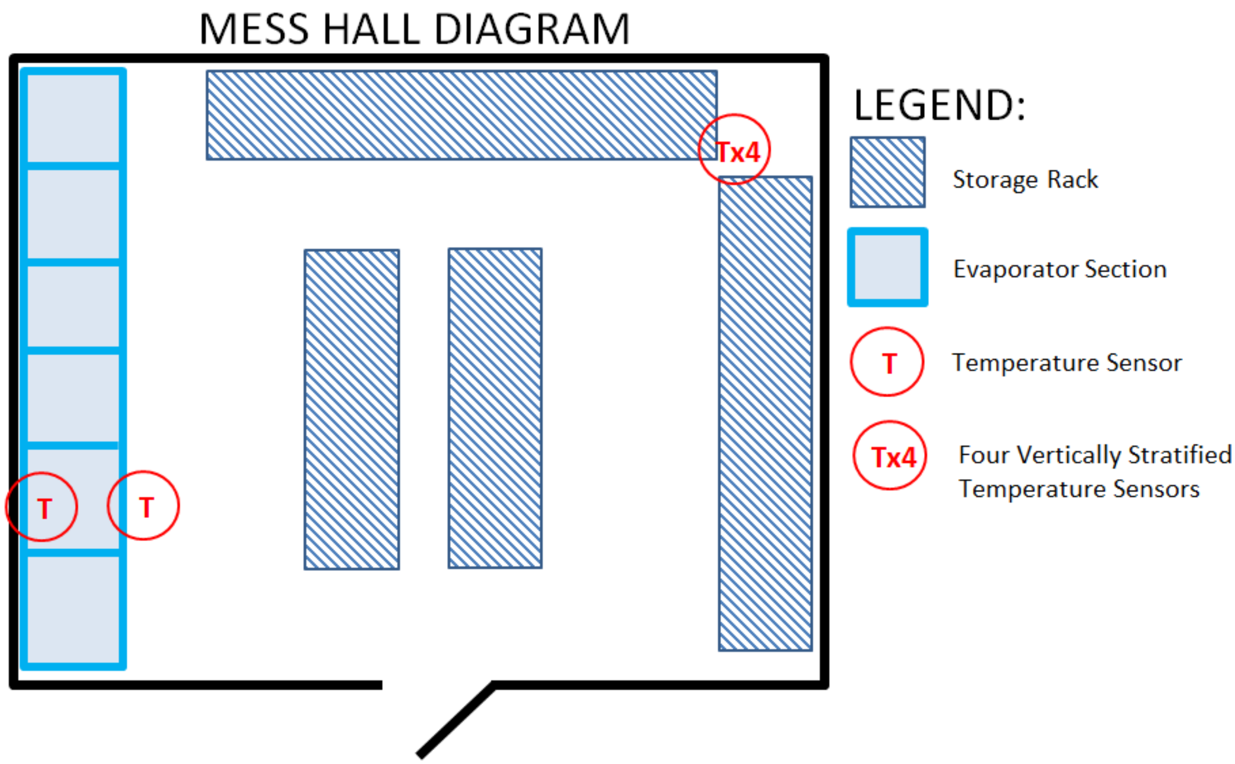


FIGURE 6. - MESS HALL DIAGRAM

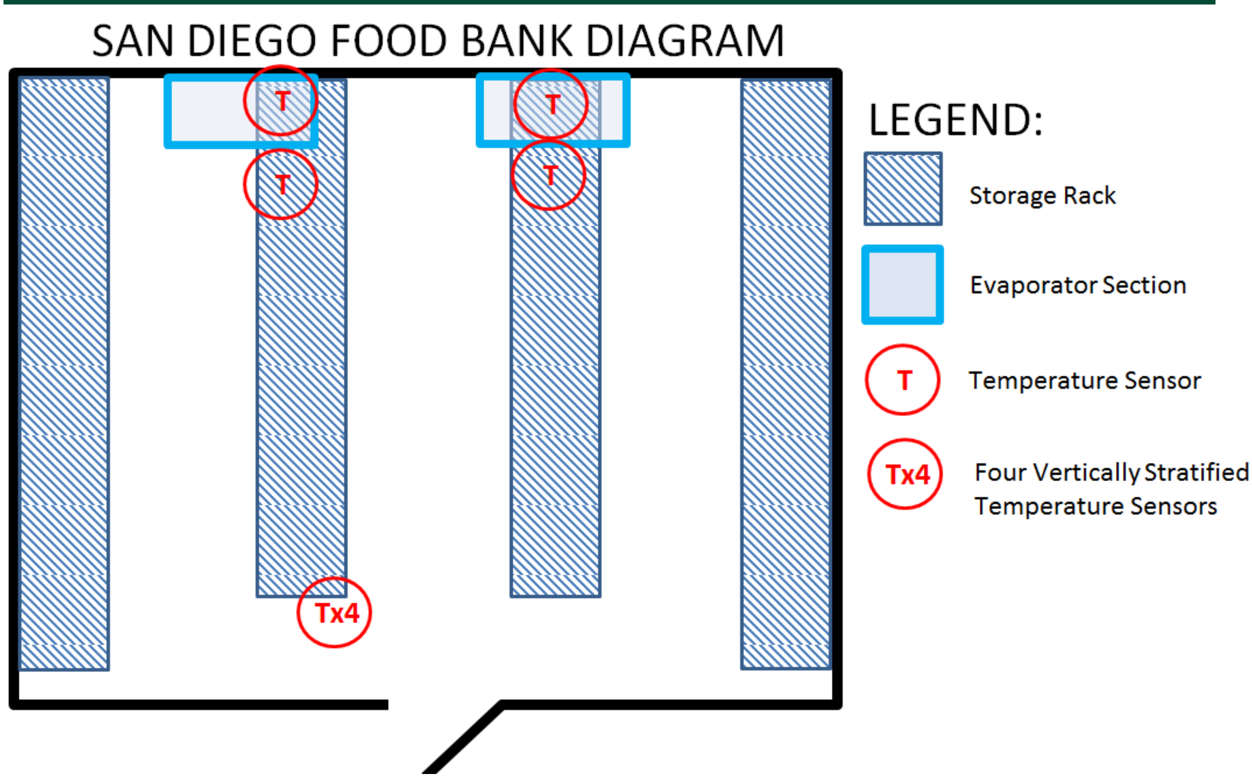


FIGURE 7. – SAN DIEGO FOOD BANK DIAGRAM

Table 6 below shows locations of each logger that was deployed between the two facilities, as well as what type of data each logger was monitoring.

TABLE 6. DATA LOGGER INSTALLATION SHEET

LOGGER NUMBER	LOGGER LOCATION	MEASUREMENT TYPE	NUMBER OF CHANNELS
5	Mess Hall – Leg A	Current	1
3	Mess Hall – Leg C	Current	1
8	Mess Hall – Fan and Defrost	Current	1
20	Mess Hall - Evaporator	Temperature	2
1	Mess Hall – Lower Temp	Temperature	2
10	Mess Hall – Upper Temp	Temperature	2
6	SDFB – Unit 1 Leg C	Current	1
9	SDFB – Unit 1 Leg A	Current	1
12	SDFB – Unit 2 Leg C	Current	1
18	SDFB – Unit 1 Leg A	Current	1
2	SDFB – Lower Temp	Temperature	2
4	SDFB – Upper Temp	Temperature	2
7	SDFB – Left Evaporator	Temperature	2
14	SDFB – Right Evaporator	Temperature	2

Current Data Calibration

In order to calculate accurate power consumption for the refrigeration units, amp loggers were installed on two of the legs for each unit and were programmed to record their amperage every minute. The amp readings these loggers recorded were correlated in order to represent accurate values to be used within any future calculation. The correlation was achieved by establishing the measured power and the average current for each AC unit. During the initial site visit, the information in Tables 7, 8, and 9 for each AC unit was measured using a Summit Technology PowerSight PS3000 Energy Analyzer.

Table 7. Mess Hall Refrigeration Unit Calibration

Leg	PowerSight [AMP]	CTV-B Logger [AMP]	Voltage Label	Voltage [V]
A	23.5	18.9	V_{ab}	203.2
B	24.3	No Logger	V_{bc}	205.5
C	16.2	16.4	V_{ca}	204.7
			Total Power Factor = 0.75	True RMS Power = 5.65 kW

Table 8. San Diego Food Bank Refrigeration Unit 1 Calibration

Leg	PowerSight [AMP]	CTV-B Logger [AMP]	Voltage Label	Voltage [V]
A	28.5	30.427	V_{ab}	464
B	29.3	No Logger	V_{bc}	470
C	31.0	32.173	V_{ca}	467
			Total Power Factor = 0.71	True RMS Power = 16.54 kW

Table 9. San Diego Food Bank Refrigeration Unit 2 Calibration

Leg	PowerSight [AMP]	CTV-B Logger [AMP]	Voltage Label	Voltage [V]
A	38.5	40.098	V_{ab}	468
B	34.5	No Logger	V_{bc}	463
C	38.0	39.524	V_{ca}	470
			Total Power Factor = 0.79	True RMS Power = 22.58 kW

Using the average amp readings from the logger and the measured power from the energy analyzer, it is possible to determine a conversion factor that can be applied to any future amp readings. This correlation factor will, therefore, convert logger amp readings into “correlated amps”, which are then used to calculate the correlated kW. The method used to achieve the correlated kW value is widely accepted within the HVAC industry and will be the method applied to all Amp/Power calculations.

RESULTS

MESS HALL RESULTS

DATA PROCESSING

The dataset obtained from the data loggers deployed at the mess hall was compiled into a master Excel spreadsheet containing all of the temperature points and current values that were monitored. The ampere (current) data, which was recorded at 1 minute intervals, was then averaged out into 5 minute intervals allow the data to align with the recorded freezer box temperature time stamps. Weather data was obtained from Weatherunderground.com, using Camp Pendleton Marine Corps Air Station as the reference weather station. This hourly weather data was processed and split into 5 minute timestamps to correspond with the recorded onsite temperature and ampere data.

The data was then designated to be either "Pre", "Post", "Downtime", or "DR Testing Period". The data designated "Pre" corresponds with the data obtained during the initial monitoring period prior to the installation. "Post" corresponds to the data obtained during the monitoring phase following immediately after the installation and calibration/adjustment phase. "Downtime" refers to any data collected that fell outside of the designated Pre and Post monitoring periods. The mess hall had an additional monitoring period, "DR Testing Period", which followed immediately after the Post period. This time frame was used to test the demand response capabilities of the PCM and control system. Differentiating the Pre data from the Post data allowed for comparisons to be drawn in overall energy consumption, daily load and temperature profiles.

Note:

In the baseline "Pre" period, it was discovered that the freezer's defrost cycle was operating erratically for the first portion of monitoring (02/29/16 to 3/10/16). This behavior can be seen in Figure 8 on the next page. Because of this unusual behavior, this period was removed from the baseline, and only 3/11/16 to 3/30/16 was evaluated. This remaining baseline sample was still deemed statistically accurate as a representation of the refrigeration system pre-PCM install. The resulting shorter analysis window for the baseline was pro-rated to be comparable to the longer post installation analysis window. The change in defrost behavior coincides with a site visit from the controls contractor, who likely returned the defrost controls to normal operation.

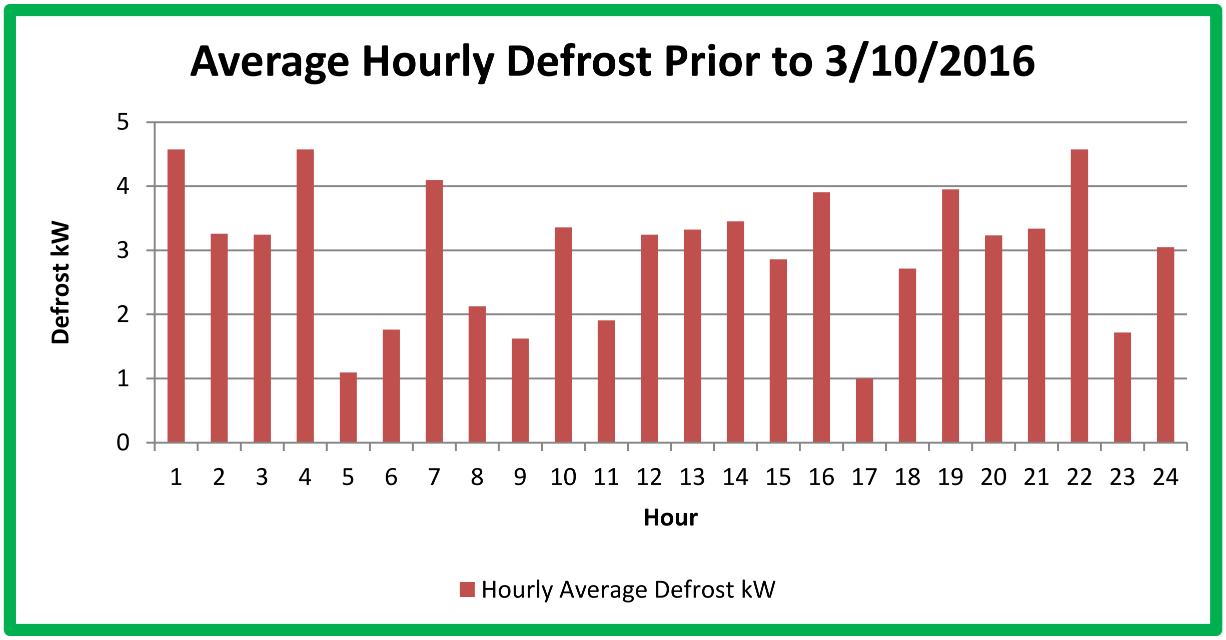


FIGURE 8. – MESS HALL DEFROST ISSUE

REFRIGERATION POWER AND FREEZER TEMPERATURE TRENDS PRE AND POST

The refrigeration power and freezer temperature profiles associated with the mess hall's walk-in (when compared) indicate a marked change in behavior. An average of the hourly Pre and Post kW and temperature profiles can be seen in the following Figures 9 and 10. In the Pre data, there are four observable periods of increased demand that occur every 6 hours. The increase in demand occurs as the compressor runs longer in order to remove the heat added to the freezer during the evaporator defrost cycles, which are initiated by the timeclock's defrost settings. These trends in the Pre data can be identified in both the power and the temperature graphs displayed below. The post data shows a marked change in the defrost behavior, in that there is only one significant demand "spike" in the graph. This event represents a significant part of the PCM technology vendor's daily control strategy. This strategy ensures that the phase change material is completely frozen; this is accomplished by reducing the space temperature to well below the (0°F) PCM freezing point (occurring at approximately 3-5 AM, when outside air temperature is near coldest).

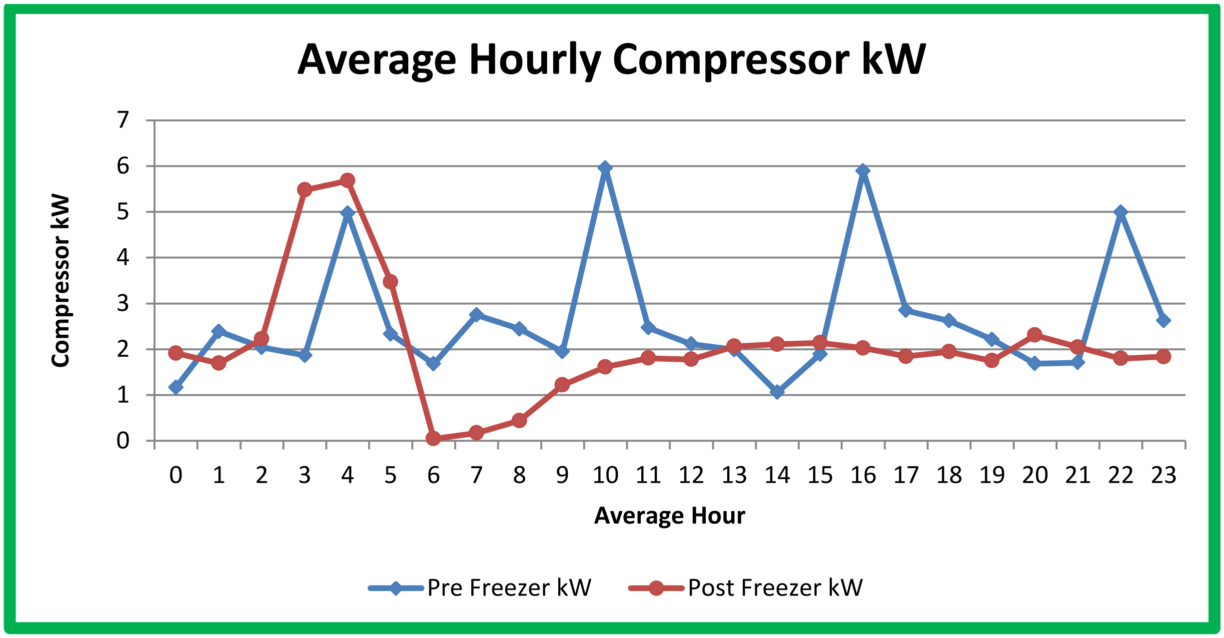


FIGURE 9. – MESS HALL AVERAGE HOURLY COMPRESSOR KW

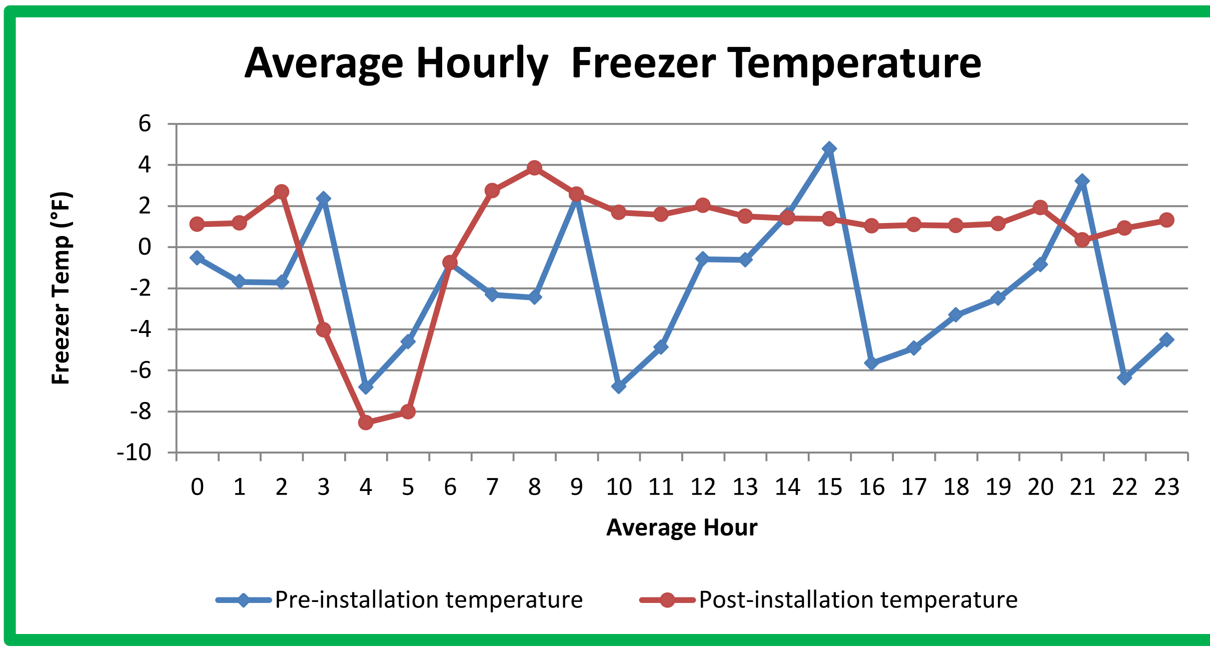


FIGURE 10. – MESS HALL AVERAGE HOURLY FREEZER TEMPERATURE

It is also worth noting that the average overall freezer temperature is slightly elevated in the Post period when compared to the Pre period. The system was able to maintain this slightly elevated temperature average without apparent impact to the frozen product. The rise in average temperature contributes to the energy savings, as the evaporator now operates at a slightly higher average suction pressure, which (at these temperatures) increases system efficiency at more than 2% per degree Fahrenheit (Refer to Appendix A).

A much smaller factor contributing to the overall savings is that the increase in average freezer box temperature results in less heat transfer through the freezer envelope. This results in less total heat to be removed from the space by the refrigeration system.

The conductive heat transfer through the freezer walls, floor and ceiling is affected by the change in the average temperature in the freezer, assuming the exterior temperature remains constant.

The average temperature in the freezer during the baseline ("pre") case was measured to be -2.0°F, while the post-PCM installation average temperature was measured to be 0.46°F. The freezer itself is located in conditioned space, so we can estimate the exterior temperature to be constant at 72.0° F.

The equation governing the amount of conductive heat transfer can be simplified to U (the reciprocal of the insulation's R-value) multiplied by A (the surface area of the freezer) all multiplied by ΔT ("delta" T, the difference between the interior freezer temperature and the exterior temperature.)

As neither the R-value of the insulation nor the surface area of the freezer change from the pre to the post timeframes, the heat transfer is governed strictly by the ΔT. The pre case ΔT is estimated to be 72.0-(-2.0) = 74.0°F, while the post-installation case is 72.0-0.46 = 71.54°F. The percent change in conductive heat transfer from pre to post is calculated by 1-(74.0/71.54) which indicates that there is a decrease in conductive heat transfer through the freezer's envelope of 3.3%.

Change in Defrost Operations

As mentioned earlier in the mess hall freezer results, the new control system changes the defrost process considerably. In the Pre monitoring period, the defrost operations were controlled by a timeclock which initiated a defrost cycle 4 times per day. Each defrost cycle lasts for approximately one hour (although the graphic shows a two-hour duration. This is due to a timestamp differential associated with daylight savings which occurred in the middle of the Pre time period). In the Post monitoring period, the data shows that significantly less defrost time was needed to maintain a frost-free evaporator. This can be seen in figure 11 below.

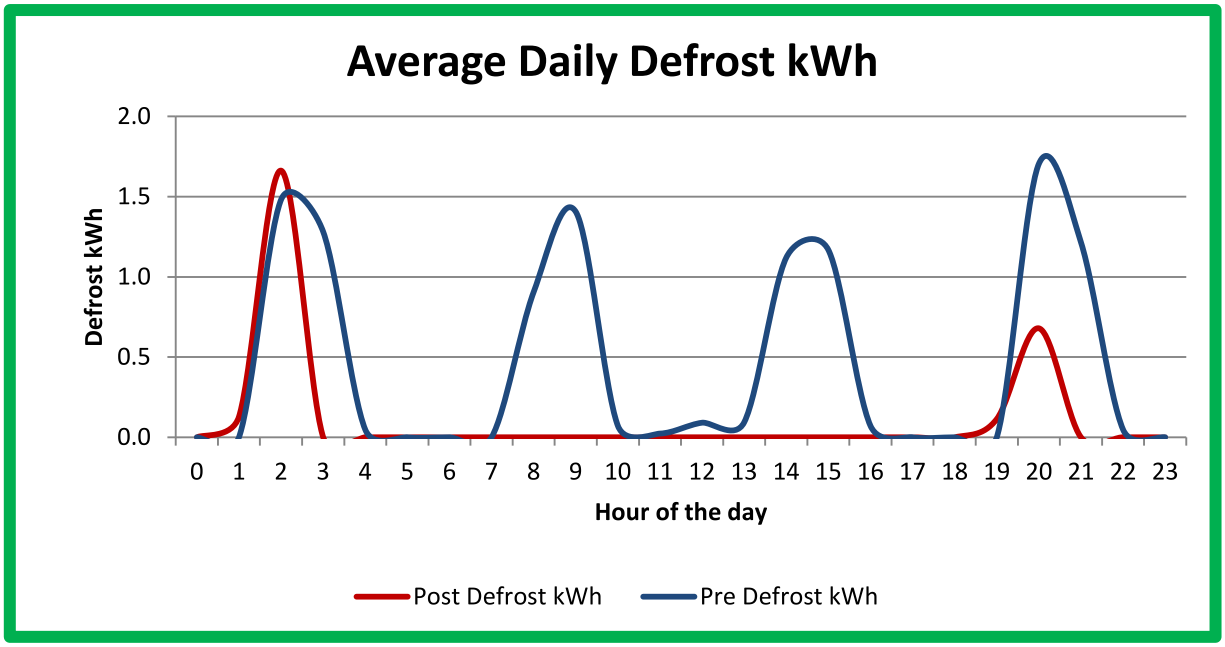


Figure 11. – Mess Hall Average Daily Defrost kWh

Less defrost operation was required in the Post period, likely because the refrigeration system operated in shorter cycles (but more frequently) than it did in the Pre period. These shorter cycles allow the room temperature to remain closer to the freezing point of the PCM without overcooling, which creates excessive frost on the evaporator coils. This behavior can be seen in the temperature trend of figure 9 on the previous page.

There is a considerable reduction in energy usage by the system due to the change in defrost behavior. The average daily energy savings due to the reduction in defrost cycles are estimated to be approximately 8 kWh, or 2,920 kWh annually.

COMPRESSOR RUN TIME

The length of the average compressor runtime was shown to be greatly reduced by the new control system associated with the installation of the PCM. These shorter run-times are an important factor in the energy savings identified with this project. A longer system run results in a colder evaporator temperature (all else being held constant). The energy savings due to the increased system suction pressure (as discussed above) which increases system efficiency at more than 2% per degree Fahrenheit at these temperatures.

The control strategy appears to focus on having the compressor do most of its work while the PCM is undergoing the phase change process. This can be demonstrated in figures 12 and 13 following:

Figure 12 plots the freezer box temperature against the length of compressor runs. The flatter section of the post plot (circled) indicates the box temperature range at which the PCM melts and freezes. As can be seen by inspecting the graph, this plateau is associated with compressor run durations of approximately 10-20 minutes in length.

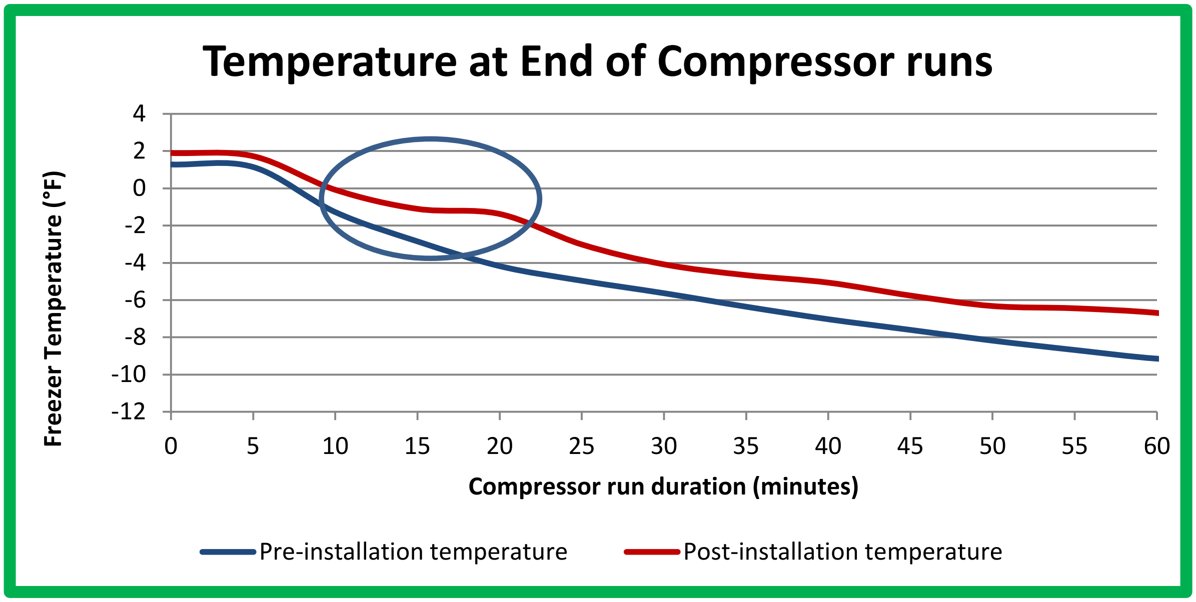


FIGURE 12. – MESS HALL TEMPERATURE AT END OF COMPRESSOR RUNS

Figure 13 plots the number of times per day that the compressor operates for various run-time durations. The left-hand circle of Figure 13 identifies that the refrigeration system runtimes now last from between 5 and 20 minutes long, and that trend, when combined with the information from Figure 12 on the previous page, suggests that the refrigeration system operates mainly within the latent phase change process associated with the PCM. The oval area on the right illustrates the longer run durations in the pre-installation period. These longer runs resulted in more need for defrost and also more time spent operating at lower freezer temperatures, thus using more energy to provide the same benefit.

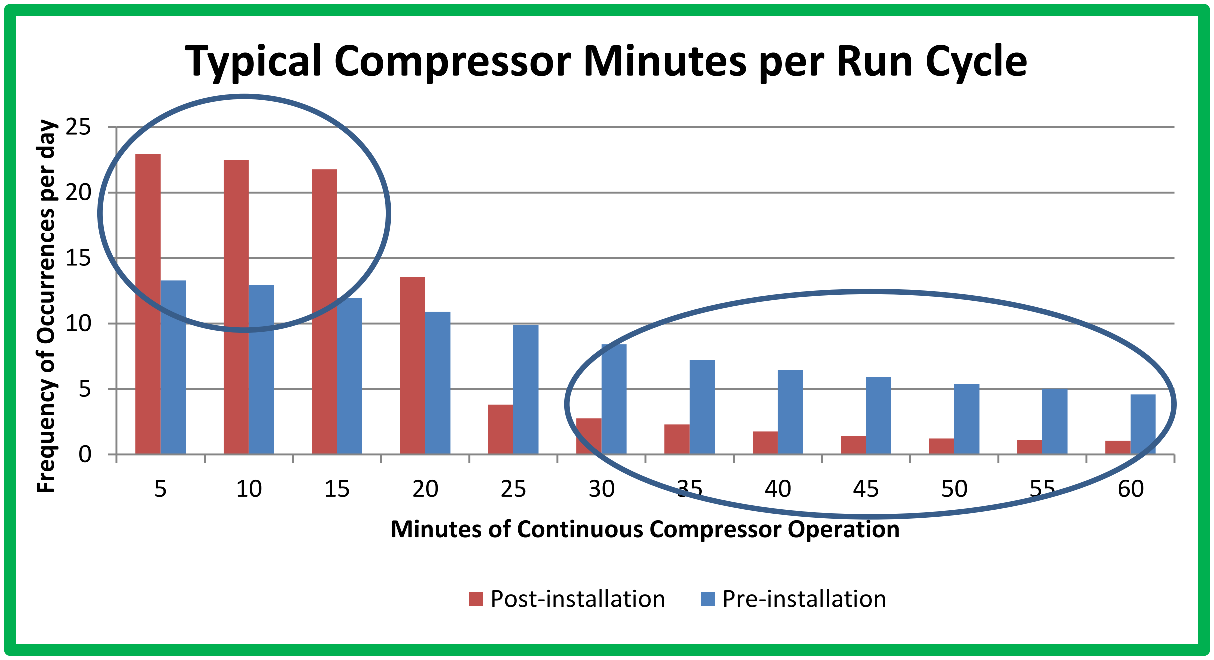


FIGURE 13. – MESS HALL TYPICAL COMPRESSOR MINUTES PER RUN CYCLE

DAILY AVERAGE ENERGY SAVINGS

In the pre installation monitoring period, the average daily kWh usage including defrost energy was approximately 74 kWh. In the post installation monitoring period, the daily average kWh dropped to approximately 52 kWh, which indicates a 30% reduction in energy use. This energy reduction can be attributed to the following:

- Reduced compressor run time
- Operating at slightly warmer average evaporator temperatures (made possible by the effect of the PCM), the effect of which is to increase the capacity of the refrigeration system as well as reducing heat conduction through the freezer's exterior envelope.
- Much lower thermal resistance (R-Value) of the PCM compared to stored food product, allowing for faster heat transfer
- Significantly less time spent in defrost mode, resulting in less heat being added to the freezer by the defrost heaters, and consequently less refrigeration required to recover from those defrost periods.

TABLE 10. MESS HALL DAILY AVERAGE ENERGY SAVINGS

Location	Avg Daily Pre	Avg Daily Post	Avg Daily Savings	Average Daily % Savings	Annualized Savings	Demand Savings
Mess Hall	74 kWh	52 kWh	22 kWh	30%	8,167 kWh	0.2 kW

ANNUALIZATION METHODOLOGY

In order to calculate annual energy savings from a monitoring period of less than one year, it is necessary to determine if there is a correlation between the energy consumption of the refrigeration system and a related factor with a year's worth of data. Historic outside air temperatures were compared against refrigeration system electric load for the pre and post monitoring periods. The linear correlation can be seen in Figure 14 below.

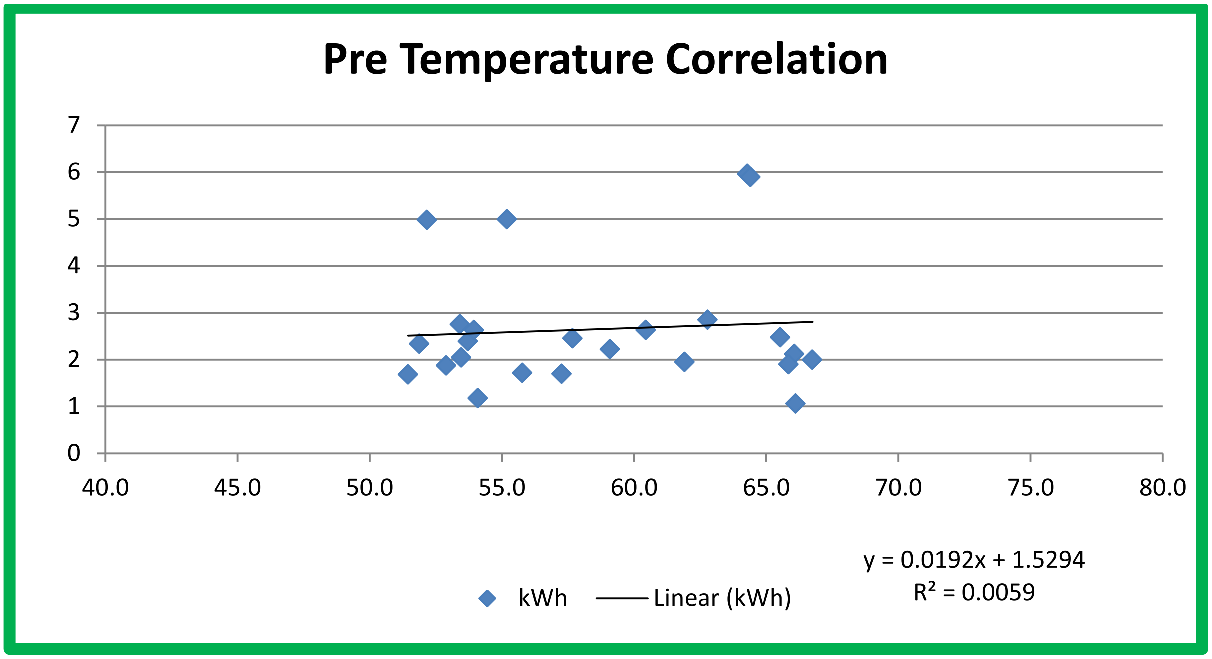


FIGURE 14. –MESS HALL WEATHER CORRELATION ATTEMPT

The mess hall R^2 value determined was 0.0059 for the pre period, and was found to be unusable for the post period due to the strong compressor run in the early morning hours. Because of the mild weather at this coastal location, the poor R^2 correlation of outside air temperature (OSAT) to kWh combined with the lack of facility meter data, annualization of the results is reduced to simply scaling the average daily savings to an annual estimate with a factor of 365. This results in an annual estimated savings of 8,167 kWh.

DEMAND RESPONSE SIMULATION

In addition to reducing overall energy usage, the PCM and associated control system provide the mess hall walk-in freezer with the capability to curtail the operation of the refrigeration system in response to (in this case) simulated demand response testing. In the three simulated demand response tests, the refrigeration system was programmed to shut down for periods of variable length (lasting 2, 4, and 7 hours respectively). The tests were scheduled with a day-ahead notice so that the refrigeration system could pre-cool in advance of the test if desired. Test day performance was compared against the 30 day post-implementation average kW profile to calculate load shed instead of the typical 10-in-10 baseline used for DR calculations, as there was no direct weather correlation found between OSAT and refrigeration kW usage. The average load curtailments for each demand response simulation were 1.89 kW, 1.72 kW, and 0.54 kW respectively. Day-of load profiles for each DR test can be seen in Figures 15 through 17.

DR Simulation 1: The first DR simulation took place on 7/8/16 from 12 PM to 2 PM. Figure 15 below shows that test-day compressor kW, the 30 day average hourly load profile taken from the post-installation period for comparison, and a plot of the freezer temp throughout the event. The data points in the demand response graphs are "Hour Beginning", meaning the point at 12 PM reflect the average of the values between 12 PM and 1 PM. This first demand response simulation was 2 hours in duration, and the load shed was calculated by subtracting the test day load from the DR baseline for the 2 hours in question, and then taking the average. This calculates out to 1.89 kW of load curtailment for the 2 hour period.

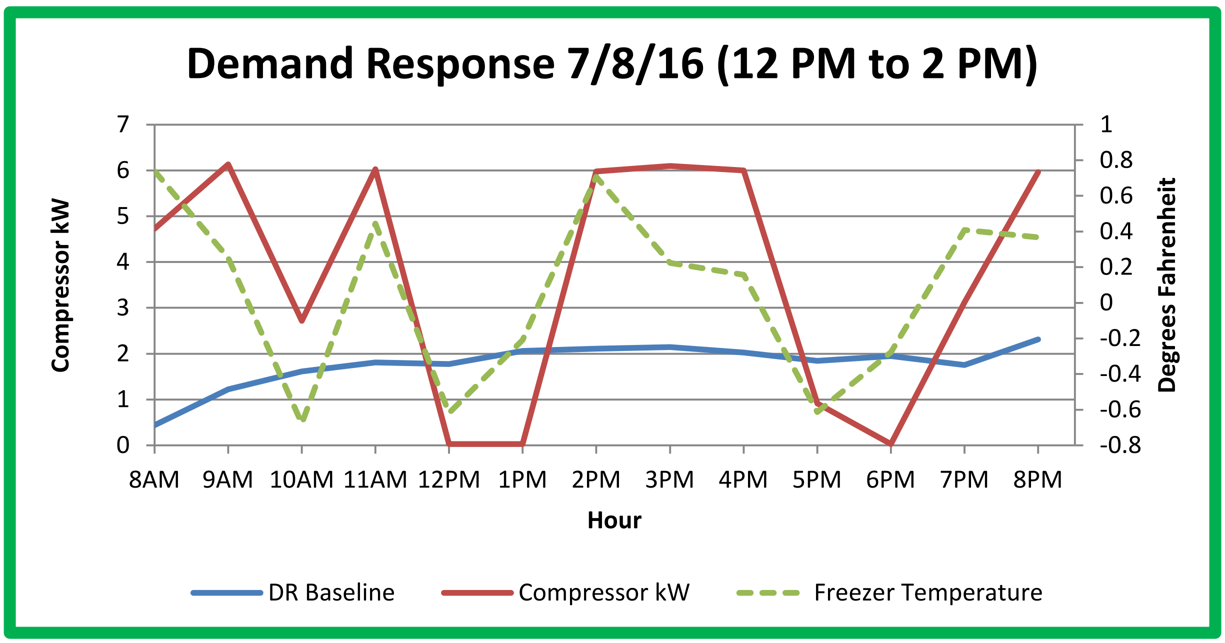


FIGURE 15. – MESS HALL DEMAND RESPONSE SIMULATION 1

DR Simulation 2: The second DR simulation took place on 7/12/16 from 12 PM to 4 PM. This test scheduled a 4 hour shut down of the refrigeration system. As can be seen in Figure 16 below, the refrigeration system actually did turn on briefly during the event, which slightly impacts the average load curtailment. When applying the same calculation strategy used in DR simulation 1, the average load curtailment was 1.72 kW. The temperature profile remained fairly constant during the 4 hours of refrigeration downtime.

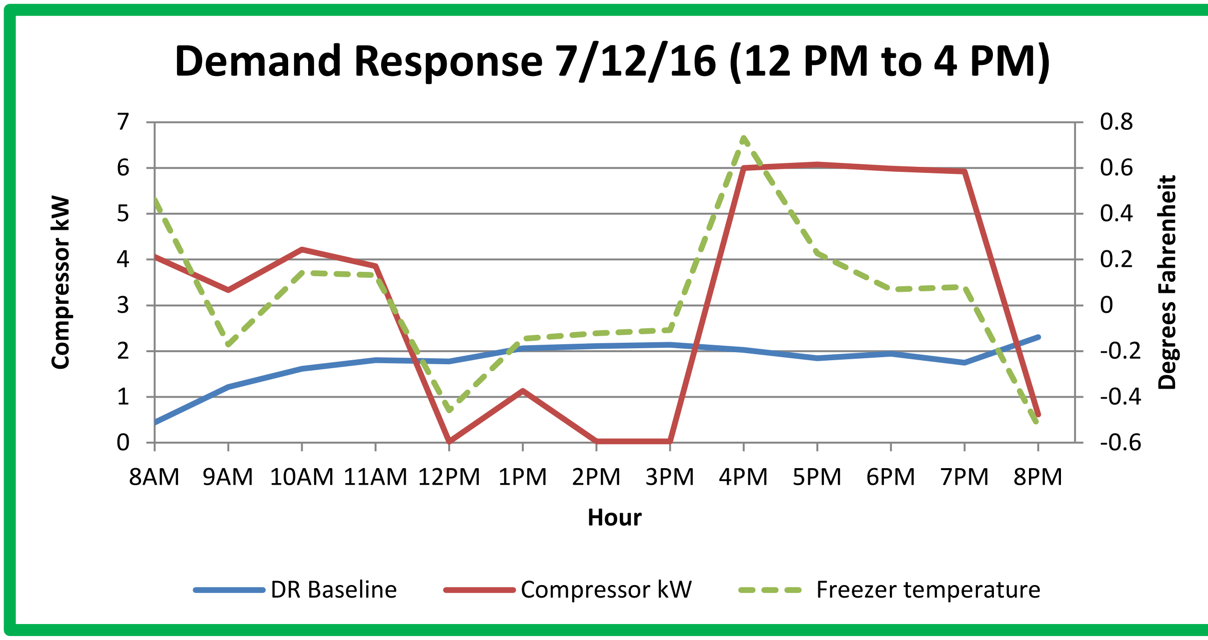


FIGURE 16. - MESS HALL DEMAND RESPONSE SIMULATION 2

DR Simulation 3: The third DR simulation took place on 7/19/16 from 11 AM to 6 PM, and is represented by Figure 17 on the following page. The test was schedule for 7 hours; however it was necessary for the system to turn on after a few hours as the freezer temperature started to increase beyond acceptable limits. Because the refrigeration system turned on midway through the test, the average load curtailment was reduced significantly, to 0.54 kW. Had the event gone from 11 AM to 4 PM, the load curtailment would have been 1.8 kW for each hour of that 5-hour period. While additional PCM could be implemented in the freezer to slightly improve the duration of system downtime, it would not be recommended due to space, cost, and efficiency factors. The PCM technology vendor calculated the required quantity of PCM with energy efficiency as the priority more so than demand response.

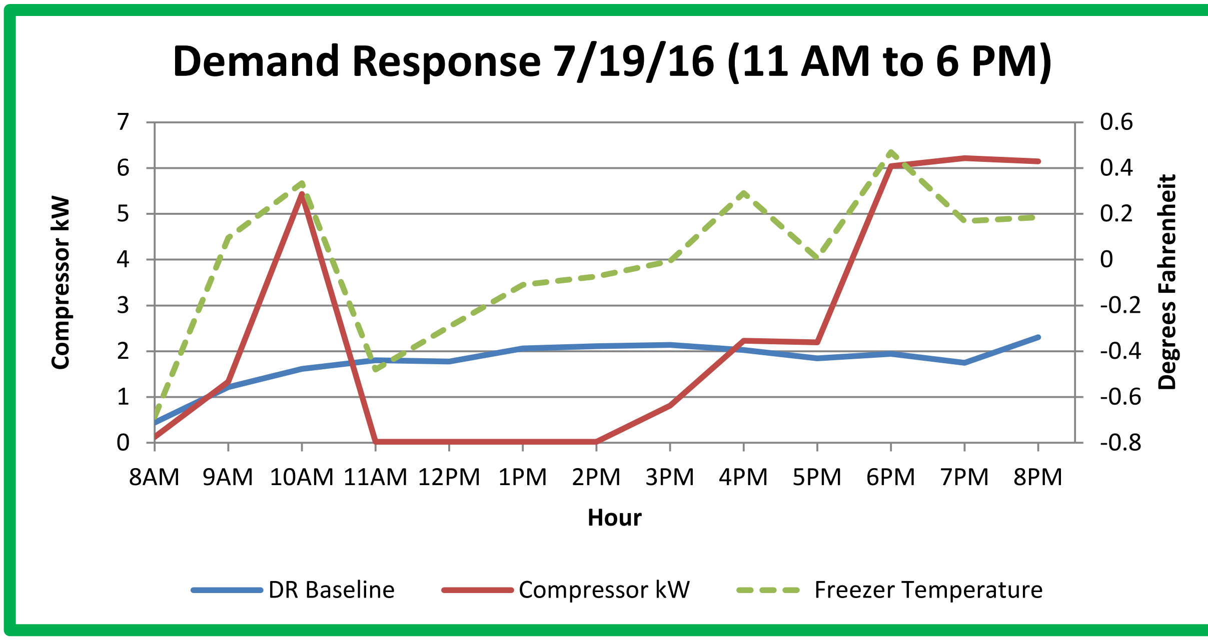


FIGURE 17. - MESS HALL DEMAND RESPONSE SIMULATION 3

Demand Response Simulation Comments:

As can be seen on inspection of these DR performance graphs, the energy use during those times outside of the DR period appears to be excessive. This is not typically "best practice" operation for DR. The operator was advised of the upcoming tests and chose to operate the freezer in this manner to prepare for the simulated event. While recognizing that some preparation for a DR event is necessary to ensure that the PCM is fully frozen, the strategy implemented was not ideal. Although demand was reduced during the DR periods, the overall energy use for these days was excessive when compared to the daily average of the post-implementation period.

Based on the results of these tests, ASWB does not recommend attempting 7 hour demand response events. However, it should be noted that the control system correctly identified the temperature increase and overrode the DR strategy in order to keep the refrigerated product safe, which is the ultimate priority.

This particular installation would likely be enrolled in CPP-D, or Critical Peak Pricing – Default Event Day NOT Activated. Under this time of use tariff, the customer submits a capacity reservation of how much kW they would like to protect from the higher CPP-D event day prices, and instead pay a capacity reservation charge. If this refrigeration unit were the only load on the facility, the capacity reservation would be set at 0 kW. However, since this refrigeration unit is a small portion of a larger facility where data is not available, the capacity reservation cannot be determined in this example.

If the technology provider became a DR aggregator, the Capacity Bidding Program (CBP) program would be most beneficial. The CBP program is a voluntary demand response program that allows aggregators to bid in for how much demand they are able to shed. The flexible nature of this program would allow the mess hall to participate in DR events only when they are positive the freezer is able to shed load without the risk of high energy cost penalties of the CPP-D program.

FINANCIAL ANALYSIS

Using the prices provided on the Viking Cold Solutions proposals and invoices, along with the projected annual energy savings, a financial analysis was conducted to determine the cost effectiveness of the PCM and controls system. A life expectancy of 20 years was assumed for this analysis, which was taken directly from Viking Cold Solutions product literature. An energy cost of $0.10/kWh was assumed. As there is no incumbent technology, the incremental cost is equal to the installed cost of the product.

The implementation cost was determined from actual project invoices totaling $19,723.00, and included:

- 150 tubular PCM cells - $4,006.00
- PCM cell installation - $4,590.00
- Power Monitoring and Refrigeration Controls - $5,304.00
- Monitoring and Control Installation - $5,400.00
- Shipping - $423.00

If the PCM and controller technology were included under the Energy Efficiency Business Incentives (EEBI) Program and Technology Incentives (TI) Program, the project would have received an incentive based on the energy efficiency, peak demand savings realized, and kW shed for DR events. This project would NOT qualify for On-Bill Financing (OBF). Refer to the SDG&E Customer Programs section in Appendix C for further detail. The incentive calculation assumes TI incentives of $300 per kW reduced, and EEBI incentives of $0.15 per kWh saved and $150 per peak demand kW reduced.

Additionally, it should be mentioned that Viking Cold Solutions has significantly reduced technology and implementation costs since the time of this installation. It has been reported that the mess hall installation could be installed for approximately $10,000 under current pricing, with the reduction in cost being attributed to improved design. The cost is projected to drop even lower in 2017, as low as $6,000 for a similar installation. This reduction in cost would drastically improve the financial analysis and cost effectiveness of the technology, even for smaller freezer applications. The manufacturer has claimed that the same energy savings would be achievable with the new manufacturing method. The results of the financial analysis can be seen in table 11 below.

TABLE 11. MESS HALL FINANCIAL ANALYSIS

SCENARIO	IMPLEMENTATION COST	INCENTIVE	TOTAL COST	ANNUAL COST SAVINGS	SIMPLE PAYBACK
Current Installation, no incentive	$19,723.00	$0.00	$19,723.00	$816.70	24.1 Years
Current Installation, with incentive	$19,723.00	$1,822.05	$17,900.95	$816.70	21.9 Years
Forecasted 2017 Installation, with incentive	$6,000.00	$1,822.05	$4,177.95	$816.70	5.1 Years

The relatively small size of the mess hall freezer causes the monitoring controls costs to comprise a higher percentage of the total project cost. As freezer space and system size increase, the energy savings should also increase, as the cost of the controls and installation either remains fixed or increases minimally.

Although the simple payback period of 24.1 in Table 9 may not be considered to be economically attractive in this instance, the PCM and associated control system provide more benefits than simply a reduced electricity bill, such as increased monitoring capability, load flexibility, and improved product survivability in the event of a power outage. These additional benefits may persuade a small facility operator to implement this technology despite the less than optimal simple payback for small freezer applications.

SAN DIEGO FOOD BANK RESULTS

DATA PROCESSING

As with the mess hall, the dataset obtained from the data loggers deployed at the San Diego Food Bank was compiled into a master Excel spreadsheet containing all of the temperature points and current values that were monitored. The ampere (current) data, which was recorded in 1 minute intervals, was averaged out into 5 minute intervals to allow the data to align with the recorded freezer temperature time stamps. Weather data was then obtained from Weatherunderground.com using Miramar Marine Corps Air Station-Mitscher as the San Diego Food Bank reference. This hourly weather data was processed and split into 5 minute timestamps to correspond with the recorded onsite temperature and ampere values.

The data was then designated as either "Pre", "Post" and "Downtime". The data designated "Pre" corresponding with the data obtained during the initial monitoring period prior to the installation. "Post" corresponds to the data obtained during the monitoring phase following immediately after the installation and calibration/adjustment phase. "Downtime" refers to any data collected that fell outside of the designated Pre and Post monitoring periods. Differentiating the pre data from the post data allowed for comparisons to be drawn in overall energy usage, daily load and temperature profiles.

OPERATIONAL SHIFT

The San Diego Food Bank utilizes the PCM and associated controls in a much different manner than does the mess hall. The San Diego Food Bank is a much larger freezer located in a facility that includes a photovoltaic system that generates large amounts of energy in the daytime hours. The solar generation often exceeds the demand of the entire facility during the peak solar hours. By shifting more of the refrigeration load to these daytime "over-generation" periods and reducing nighttime operation, the facility is now able to accomplish two goals. The food bank now utilizes more of the photovoltaic energy available, while also saving energy at night when the solar is not available. This helps move the San Diego Food Bank closer to achieving Zero Net Energy (ZNE).

The San Diego Food Bank was able to utilize the PCM and control system to shift almost all of their mechanical refrigeration to the day-time solar generation hours, allowing them to completely shut down overnight by "coasting" on the passive cooling delivered by the PCM as the material melts. It is worth noting that the refrigeration system made up approximately 25% of the overnight facility load prior to the change in control strategy.

Figure 18 on the next page shows the hourly average refrigeration system kW both before and after the PCM and controls installation. The pre installation period, represented by the blue line, operates consistently throughout the 24 hour period. The post installation period, represented by the red line, clearly shows no overnight operation, while running at much higher power levels in the daytime hours.

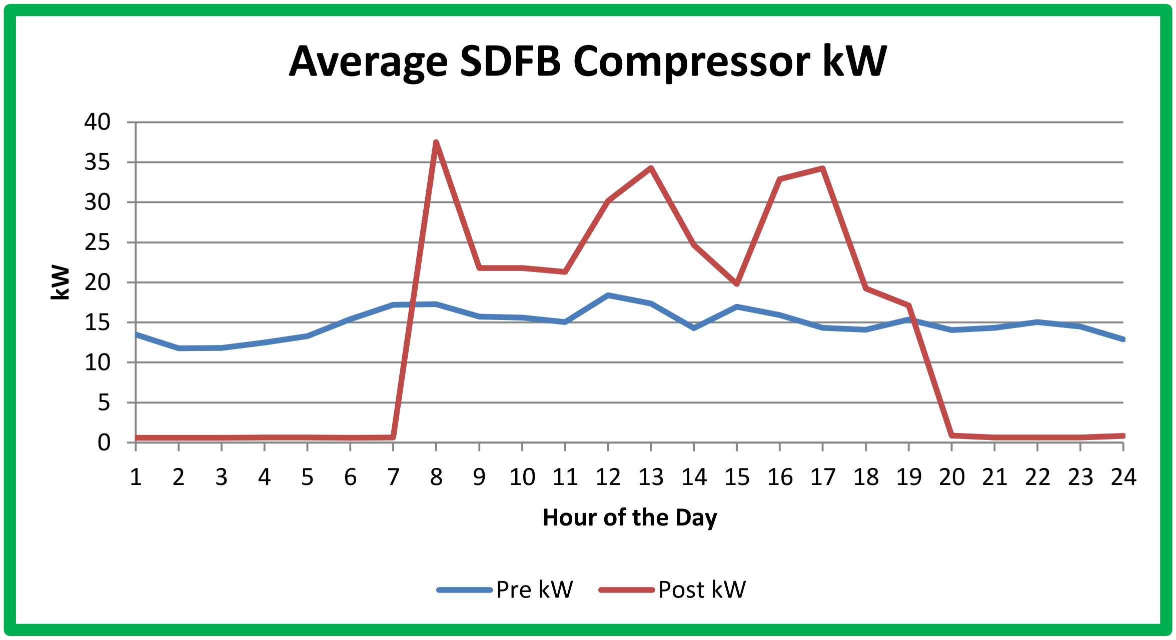


FIGURE 18. – FOOD BANK AVERAGE COMPRESSOR KW

Figure 19 is the same data from Figure 18 above, but the areas inside the graph have been shaded to illustrate how energy (kWh) is being shifted and utilized. The highlighted blue area represents the energy that is saved by not operating at night. The highlighted red area represents the increased energy in the afternoon hours, where the excess photovoltaic generated energy can be utilized where it previously wasn't. As can be observed, the blue shaded areas (two areas totaling approximately 158 kWh) are greater than the red shaded area (approximately 124 kWh) in this figure. This indicates that the overall energy use of the refrigeration system has decreased by roughly 34 kWh per day between the pre and post implementation periods.

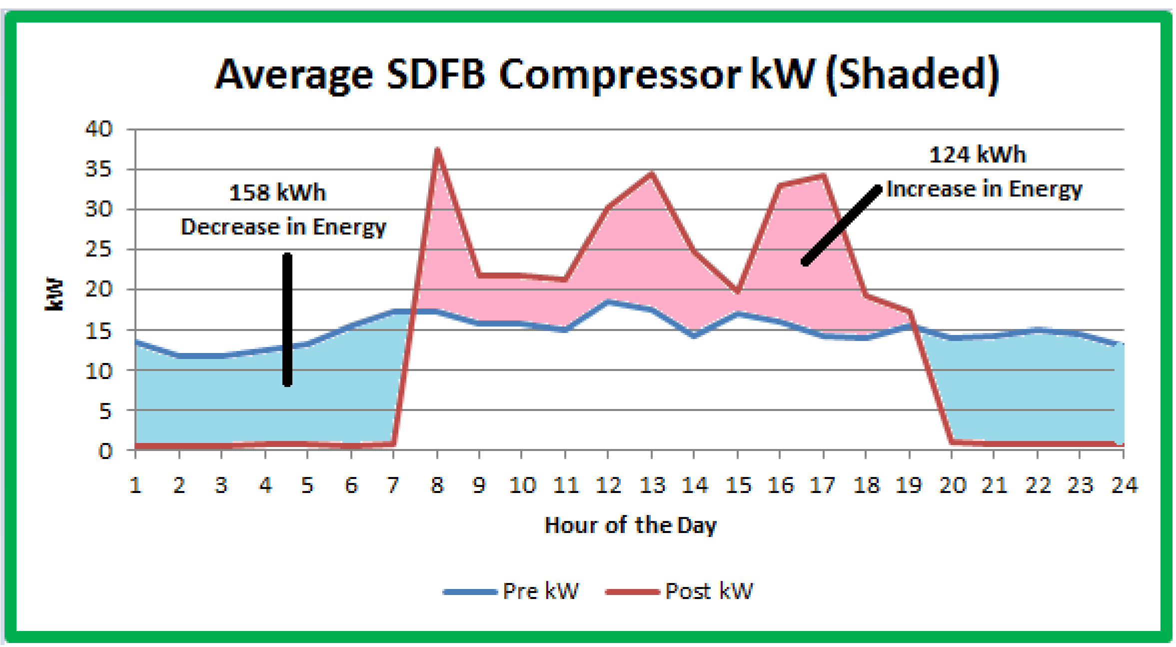


FIGURE 19. – FOOD BANK AVERAGE COMPRESSOR KW (SHADED)

INCREASED AFTERNOON OPERATION AND RELATION TO SOLAR

In order to claim that the post installation increase of energy occurring in the afternoon hours is being supplied from the photovoltaic system on the roof, average hourly facility meter data was compared for the pre and post installation periods. The facility meter data was supplied by SDG&E with the customer's permission. The facility meter data does not record negative values, meaning that when the photovoltaic energy output exceeds the facility's total energy usage, the meter records that data as a zero. Because of this, the average hourly kW data for the facility will always read as 0 kW or greater in the afternoon periods, even if the majority of the time the facility generates more energy than it can use. Figure 20 below plots the average hourly facility demand for the pre and post installations. As can be seen, the Post operation uses less energy during the nighttime hours. While the difference can be seen in after-hours operation, the operation during the on-peak daytime hours is very similar, suggesting the photovoltaic system is able to accommodate the increase in daytime load resulting from the updated control strategy without increasing the net load seen at the meter by any significant amount.

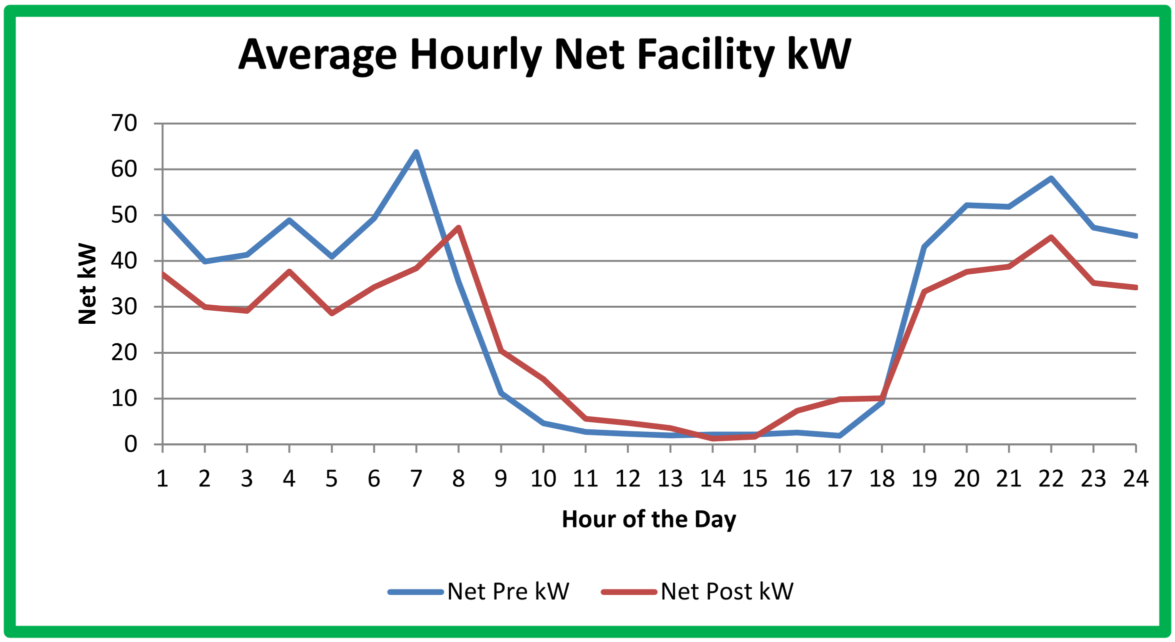


FIGURE 20. – FOOD BANK AVERAGE HOURLY NET FACILITY

FREEZER TEMPERATURE AND ENERGY EFFICIENCY

Figure 21 below shows the average hourly temperature profiles for the San Diego Food Bank freezer for both the pre and post installation periods. As can be seen, the temperature in the pre installation period is tightly controlled between -2°F and -4°F. In the post installation period, the temperature range was much larger, allowing the temperature in the freezer to reach upwards of 3°F on average before reactivating the refrigeration system. The enhanced control system combined with the PCM provide the facility operators with the peace of mind, security, and backup overrides necessary to operate in this fashion, as this strategy could not be deployed previously without risking the stored product.

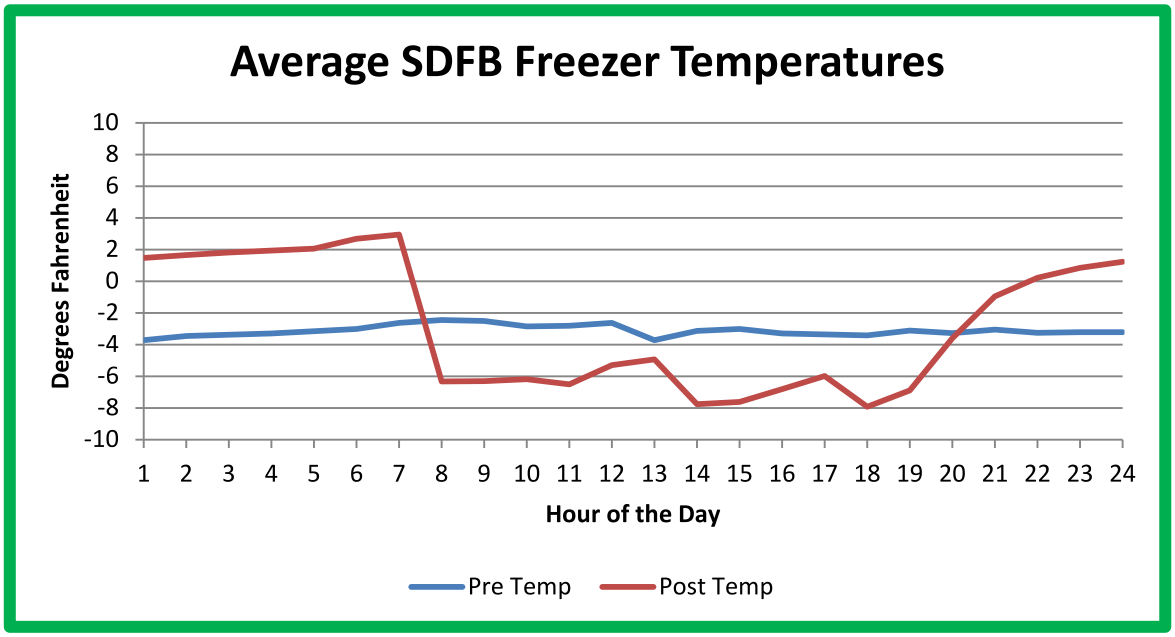


FIGURE 21. – FOOD BANK AVERAGE FREEZER TEMPERATURES

PEAK FACILITY DEMAND

Peak facility demand was also compared for both the pre and post installation periods. Figure 22 plots the hourly kW values for the respective peak demand days of each monitoring period. The peak demand in the pre installation period occurred on 3/30/16 at 6:00 AM, and was 108 kW. The peak demand in the post installation period occurred on 5/12/16 at 7:00 AM, and was 96 kW. This is a reduction of 12 kW. The peak typically occurs in the early morning, as facility operations have begun but the photovoltaic system has not begun to generate energy. It may be possible to reduce this peak further (roughly 45 to 50 kW compared to the current 12 kW) by starting the refrigeration process later in the day.

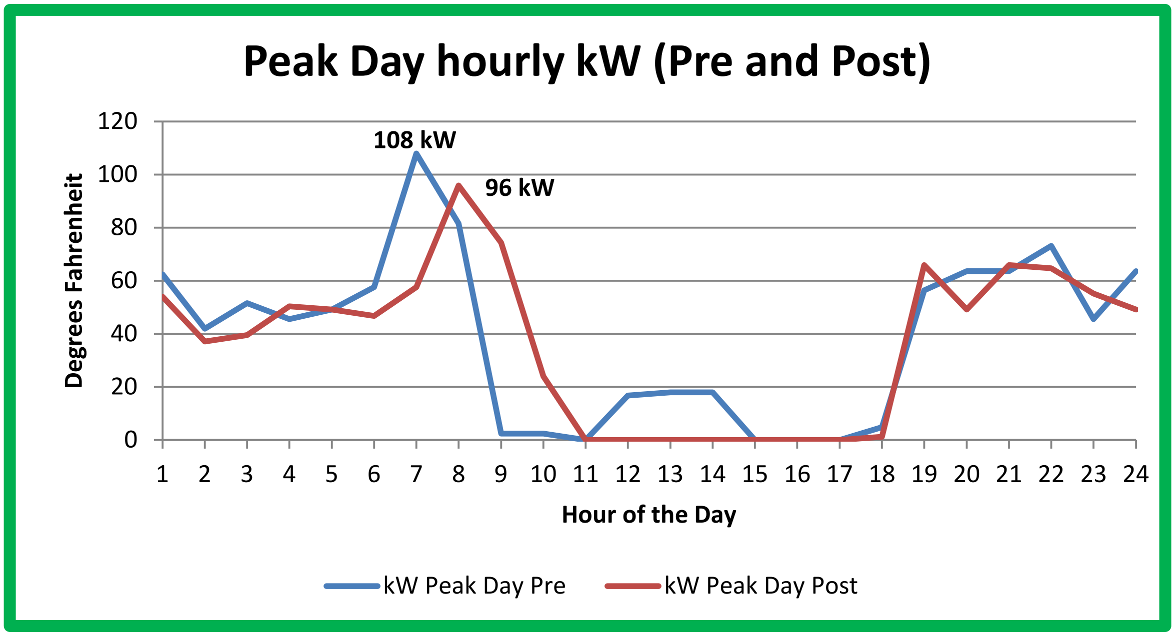


FIGURE 22. – FOOD BANK PEAK DAY HOURLY KW (PRE AND POST)

DAILY AVERAGE ENERGY SAVINGS

The average daily kWh of the refrigeration system in the pre installation period was 358.7 kWh. The average daily kWh use of the refrigeration system in the post installation period was 322.8 kWh. This is a reduction of 33.9 kWh per day, or approximately 10%. Along with the energy efficiency savings from the PCM, an additional 124 kWh is shifted over to the daytime where it is provided by the excess solar energy, resulting in an overall energy bill savings of 158.3 kWh per day, or 44% of the original average daily kWh.

TABLE 12. SDFB DAILY AVERAGE ENERGY SAVINGS

LOCATION	AVG DAILY PRE	AVG DAILY POST	AVG DAILY SAVINGS	AVERAGE DAILY % SAVINGS	ANNUALIZED SAVINGS
SDFB	356.7 kWh	198.4 kWh	158.3 kWh	44%	50,169 kWh

ANNUALIZATION METHODOLOGY

In order to calculate annual energy savings from a monitoring period of less than one year, it is necessary to determine if there is a correlation between the energy consumption of the refrigeration system and a related factor with a year's worth of data. Historic outside air temperatures were compared against refrigeration system electric load for the pre and post monitoring periods. For this project, such a correlation is not possible, as the entire refrigeration electric load was moved to the daylight hours.

It was determined that the best course of action was to annualize the savings associated with the shift to day time hours against the solar production data provided from Food Bank management. This meter shows the total net energy per day for on-peak, mid-peak, and off peak periods, as well as the daily net meter and daily generation values in kWh. If the on-peak and mid-peak values summed up to be negative and of greater magnitude that the 124 kWh savings associated with the shift, the full 124 kWh got carried through for that day. If the on-peak and mid-peak values summed up to be negative and of smaller magnitude (than the 124 kWh savings), the day was credited with the absolute value of that sum for the savings, as that is the remaining excess energy assumed to be available from the photovoltaic system. If the sum of on-peak and mid-peak values yielded a positive result, no energy savings associated with the shift to solar power were credited for that particular day. This methodology is summarized by table 13 below. The energy savings for 365 days were then summed to determine the annual kWh savings associated with the shift in load to the solar production hours.

TABLE 13. SDFB DAILY SHIFTED SAVINGS METHODOLOGY

SUM OF ON-PEAK AND MID-PEAK CONDITION	ENERGY SAVINGS CREDITED TO DAY FOR TIME SHIFT
If X ≤ -124 kWh	124 kWh
If -124 kWh < X ≤ 0 kWh	X kWh
If 0 kWh < X	0 kWh

The 10% energy efficiency savings associated with more efficient operation were annualized by multiplying by a factor of 365, as there was no direct correlation with weather OSAT data possible due to the shifting of the timeframe of energy use. The annual energy efficiency savings were added to the annual energy savings associated with the load shift for a total of 50,169 kWh projected annual savings.

While the average daily energy savings for a day with ideal solar generation was 44%, this factor does not take into consideration the results of the annualization for days with insufficient solar energy to offset the operation shift. The post-annualization annual savings are 39%.

FINANCIAL ANALYSIS

Using the prices provided on the Viking Cold Solutions proposals and invoices, along with the projected annual energy savings, a financial analysis was conducted to determine the cost effectiveness of the PCM and controls system. A life expectancy of 20 years was assumed for this analysis, which was taken directly from Viking Cold Solutions product literature. A cost of $0.13/kWh and $11.34 per kW of demand reduction per month was assumed. As there is no incumbent technology, the incremental cost is equal to the installed cost of the product.

The implementation cost was determined from actual project invoices totaling $47,039.43, and included:

- 164 PCM Cell Packs - $24,640.00
- PCM Cell Pack installation - $5,507.00
- Power and Temperature/Monitoring and Control Installation - $14,929.43
- Shipping - $1,963.00

If the PCM and controller technology were included under the Energy Efficiency Business Incentives Program (EEBI), the project would have received an incentive based on the energy efficiency and peak demand savings realized. This project would also qualify for On-Bill Financing (OBF). Refer to the SDG&E Customer Programs section in Appendix C for further detail. The incentive calculation assumes $0.15 per kWh saved and $150 per peak demand kW reduced. While the food bank did experience a reduction in demand, there was no demand reduction during the peak window of 12 PM to 6 PM due to the solar generation.

As with the mess hall facility, Viking Cold Solutions has provided updated implementation costs that have improved due to technology design. It is estimated that under current conditions, a similar sized install could be completed for approximately $30,000. The 2017 forecasted implementation cost for the same installation would be approximately $24,000. These updated costs drastically improve simple payback. The manufacturer has claimed that the same energy savings would be achievable with the new manufacturing method.

The results of the financial analysis can be seen in table 14.

TABLE 14. SDFB FINANCIAL ANALYSIS

SCENARIO	IMPLEMENTATION COST	INCENTIVE	TOTAL COST	ANNUAL COST SAVINGS	SIMPLE PAYBACK
Current Installation, no incentive	$47,039.43	$0.00	$47,039.43	$8,154.93	5.8 Years
Current Installation, with incentive	$47,039.43	$7,525.35	$39,514.08	$8,154.93	4.8 Years
Forecasted 2017 Installation, with incentive	$24,000.00	$7,525.35	$16,474.65	$8,154.93	2.0 Years

DISCUSSION

Benefits other than energy savings and demand shifting capabilities exist due to the PCM and control system. Due to the observed reduction of refrigeration system run time, the effective useful life of the refrigeration equipment may be increased. The control system also provides daily monitoring reports of product, space, and PCM temperature, along with details on power and system run time. An example report can be seen in Appendix B.

The thermal storage capabilities of the PCM also allow for increased product survivability during power emergencies that could normally result in significant product loss. The PCM material is a passive technology that does not require maintenance, and is claimed to last upwards of 20 years. Because of the passive nature of the PCM technology, it is very versatile and can be installed alongside existing refrigeration equipment without issue.

The increased monitoring and reporting ability of the controls also provide predictive tools and alarms that can provide early detection of potential problems within the system.

The control and thermal storage aspects of this technology greatly increase the load flexibility of a facility. This flexibility is ideal for Permanent Load Shifting (PLS), Demand Response, or responding to grid Over-Generation scenarios. As grid system stability becomes an increasingly pressing issue, this flexibility could allow the cold storage industry to become part of the solution to this concern.

Based on the financial analysis done for both facilities, it appears that the mess hall walk-in freezer was too small of a refrigerated space to save enough energy to pay back under the cost of the PCM and controls at the time of install within a reasonable timeframe. This is largely due to the cost of the control system and system installation, which is required for all similar installations. The mess hall system controls and monitoring equipment was 54% of the total project cost, while the similar equipment at the San Diego Food Bank amounted to only 31% of the total project cost. As square footage (and therefore the system size and required PCM) increase, so do the annual energy and cost savings. A break-even point for sufficient freezer space size where the system will become cost-effective exists, but there is not enough data available given the two locations to determine what that break-even point is, partly due to the fact that the two facilities underwent completely different PCM control applications. Viking Cold Solutions has reported a significant drop in their implementation costs, and anticipates costs going even lower, which will improve the cost effectiveness of the technology.

There are no known major potential market barriers that may prevent the adoption of this technology.

Some customers could be reluctant to try a new control strategy in cold storage applications if very expensive, temperature critical products are being stored, as was encountered in the outreach efforts to secure participants for this M&V project. Other customers may be put off by the initial cost and thus a shared savings model could be entertained by the PCM technology vendor as an accelerator to enter the market. As more examples of successful implementations are documented, it is anticipated that this reluctance may diminish.

CONCLUSIONS

The results of this study clearly show energy savings for both facilities. The mess hall freezer had a total energy savings of 8,167 kWh annually, or 30%. The San Diego Food Bank freezer had a total net facility energy savings of 50,864 kWh annually, or 39% of the refrigeration system energy.

Permanent load shifting and demand response applications were able to function as intended. In longer demand response simulations, when the space temperature became too warm, the control system overrode the demand response command and brought the refrigeration system back online to protect the product.

Based on these observations, the PCM and control system were able to perform as the manufacturer claimed. There are quantifiable benefits associated with having a PCM and control system in a walk-in freezer compared to a non-PCM walk-in freezer under the same conditions. However, despite the benefits of installing the PCM and control system, this option may not be cost effective in all scenarios, which should be taken into consideration when deciding whether or not to implement this technology in a specific freezer.

RECOMMENDATIONS

Based on the results of this study, it is recommended that the PCM and controller technology be adopted into the EE program. The assessment provides sufficient information to demonstrate the flexibility and capabilities of this technology. Further testing could be done to analyze other potential PCM applications, such as traditional permanent load shed to overnight hours, or applications similar to the mess hall but in larger freezers.

APPENDIX

APPENDIX A: COMPRESSOR SUCTION TEMPERATURE AND CAPACITY REFERENCE

R-134a

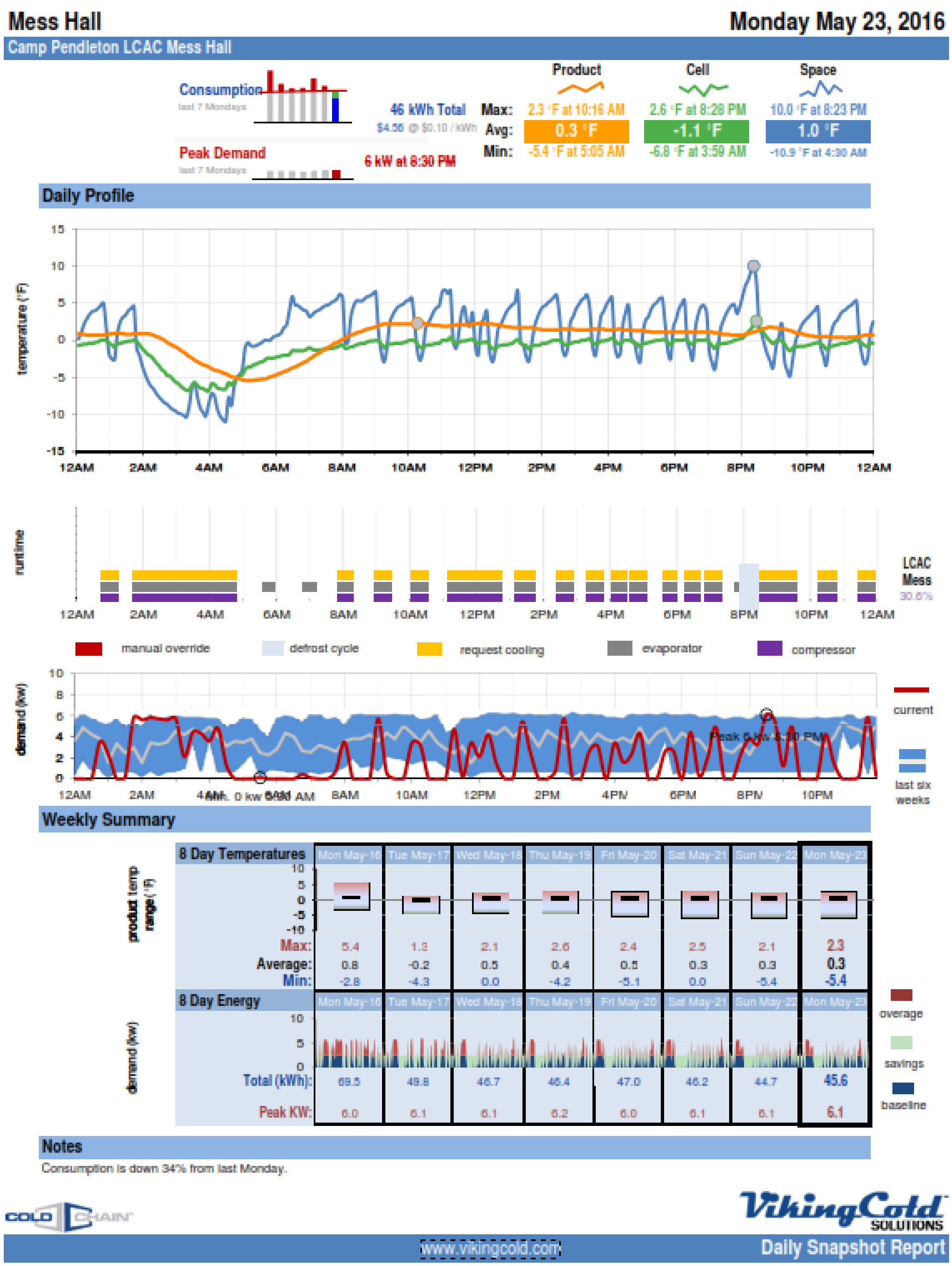
Copeland air-cooled condensing units

Unit Model	Compressor	-25	-20	-15	-10	-5	0	5	10	15	20	25	30	35	40	45
90° Ambient																
CTAH-0100	KAJA-011E						4620	5210	5840	6510	7230	7990	8790	9630	10500	11400
CTAH-0150	KAL*-01*E						6220	7050	7930	8870	9880	10940	12050	13210	14410	15650
CNAG-0200	EAV*-021E						8120	9380	10700	12000	13500	15000	16600	18300	20100	22000
CTAM-0300	LAHA-031E					11300	13300	15400	17700	20000	22500	25200				
CFDP-0300	2DF3F16KE					16600	18900	21600	24300	27200	30300	33600	37000	40700	44700	48800
CFDP-0400	2DA3F23KE					20900	23900	27200	30700	34500	38500	42700	47100	51900	56800	62100
CFDP-0500	3DA3F28KE						29700	33900	38400	43200	48200	53500	59200	65200	71500	78100
CFDP-0550	3DB3F33KE						34100	38900	44000	49300	55000	61000	67300	74000	81000	88300
CFDP-0600	3DF3F40KE	12600	18600	24500	30400	36400	42500	48800	55400	62300	69600	77400	85700	94600	104100	114300
CFDP-0700	3DS3F46KE	14800	21100	27300	33500	39800	46400	53200	60300	67800	75800	84300	93400	103100	113500	124600
100° Ambient																
CTAH-0100	KAJA-011E						4230	4780	5350	5970	6630	7330	8070	8840	9650	10500
CTAH-0150	KAL*-01*E						5690	6460	7280	8170	9100	10090	11130	12210	13340	14500
CNAG-0200	EAV*-021E						7350	8530	9730	11000	12300	13800	15300	16800	18500	20300
CTAM-0300	LAHA-031E					10200	12100	14000	16100	18300	20600	23100				
CFDP-0300	2DF3F16KE					15200	17400	19900	22500	25200	28100	31100	34400	37900	41600	45500
CFDP-0400	2DA3F23KE					19200	22000	25100	28400	31900	35600	39500	43700	48200	52800	57800
CFDP-0500	3DA3F28KE						27400	31400	35600	40100	44900	49900	55200	60800	66700	72900
CFDP-0550	3DB3F33KE						31300	35900	40800	45800	51200	56800	62700	68900	75500	82300
CFDP-0600	3DF3F40KE	10100	16000	21800	27500	33200	39100	45000	51200	57800	64700	72000	79800	88100	97100	106700
CFDP-0700	3DS3F46KE	12200	18400	24400	30400	36500	42700	49200	55900	63000	70500	78500	87000	96100	105900	116400
110° Ambient																
CTAH-0100	KAJA-011E						3840	4340	4860	5420	6030	6660	7340	8050	8790	9550
CTAH-0150	KAL*-01*E						5130	5850	6610	7430	8300	9220	10180	11190	12250	
CNAG-0200	EAV*-021E						6590	7680	8790	9970	11200	12500	13900			
CTAM-0300	LAHA-031E					9070	10800	12600	14600	16600	18700	21000				
CFDP-0300	2DF3F16KE					13800	15900	18100	20500	23100	25800	28700				
CFDP-0400	2DA3F23KE					17400	20100	23000	26000	29300	32800	36500	40400			
CFDP-0500	3DA3F28KE						24900	28800	32800	37100	41600	46300	51300	56500	62100	
CFDP-0550	3DB3F33KE						28400	32900	37500	42300	47300	52600	58100			
CFDP-0600	3DF3F40KE	7420	13300	19000	24600	30100	35700	41400	47300	53400	59900	66800	74200	82000	90500	99600
CFDP-0700	3DS3F46KE	9550	15600	21500	27400	33200	39200	45300	51600	58300	65300	72900	80900	89500	98700	108600

Capacities rated at 65°F return gas, 5°F subcooling

2011DS-4 _C (9/15) 3 Emerson Climate Technologies

Appendix B: Sample of PCM Technology Vendor Daily Reports



APPENDIX C: SDG&E CUSTOMER PROGRAMS

ENERGY EFFICIENCY BUSINESS INCENTIVES PROGRAM

The Energy Efficiency Business Incentives Program (EEBI) allows customers to benefit from cash incentives for retrofitting or installing new high-efficiency equipment to save energy. The incentive can cover up to 50% of the project cost. For a non-lighting targeted measure such as the implementation of a PCM and controller system in a cold storage walk-in freezer, the incentive rate would be $0.15 per kWh, as well as a $150 per kW in peak demand reduction. For application instructions and additional information on the EEBI Program, refer to http://www.sdge.com/rebates-finder/save-energy-earn-incentives

ON-BILL FINANCING

If the customer's SDG&E accounts is in good standing, has been active for the past two years, and has received a rebate or incentive through an SDG&E energy efficiency program, the customer is eligible for On-Bill Financing (OBF). OBF helps qualified commercial and government-funded customers pay for energy-efficiency business improvements through their SDG&E bill. Only equipment that qualifies for a rebate or incentive is eligible for OBF. Additionally, the loan must be at least $5,000 and have a simple payback of no more than 3 or 5 years depending on the installed equipment. The loan amount is the total project cost minus the rebate/incentive amount. For more information on the OBF program, refer to http://www.sdge.com/business/bill-financing

TECHNOLOGY INCENTIVES

The Technology Incentives program (TI) provides incentives to customers with verified, dispatchable, fully automated on-peak load reduction. Incentives offered are for the purchase and installation of qualified demand response measures at customer owned facilities. Eligible customers can receive up to $300 per kW of demand reduction. The total incentive is limited to the actual, reasonable cost of the installed measure. For more information on the TI program, refer to http://www.sdge.com/business/demand-response/technology-incentives