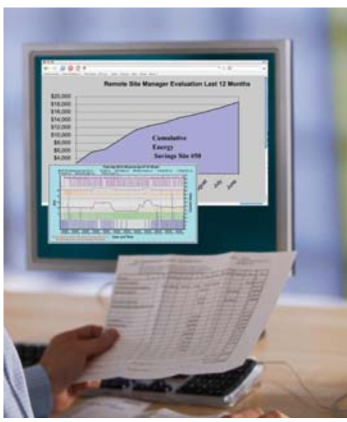
Evaluation of an Internet-Based Refrigeration Monitoring and Control System

ET 08.10 Report



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Acknowledgements

Southern California Edison's Design & Engineering Services (D&ES) group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technology program under internal project number ET 08.10. D&ES project managers John Lutton and Scott Mitchell conducted this technology evaluation with overall guidance and management from Paul Delaney. For more information on this project, contact *Paul.Delaney*@sce.com.

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ABBREVIATIONS AND ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
CoV	Change of Value
CO_2	Carbon Dioxide
CPU	Central Processing Unit
DAT	Discharge Air Temperature
DB	Dry-bulb temperature
DX	Direct Expansion
ECM	Electronically Commutated Motor
EE	Energy Efficiency
EMS	Energy Management System
FDA	Food and Drug Administration
HACCP	Hazard Analysis and Critical Control Points
HP	Horse Power
IBRMCS	Internet Based Refrigeration Monitoring and Control System
IP	Internet Protocol
mA	Milli-Ampere
NIST	National Institute of Standards and Technology
PSI	Pounds per Square Inch (gauge)
PSIA	Pounds per Square Inch (Absolute)
RH	Relative Humidity, %Rh
RMS	Root Mean Square
RSM	Remote Site Manager™
RTD	Resistive Thermal Device
RTTC	Refrigeration and Thermal Test Center

SCE	Southern California Edison
SCFM	Standard Cubic Feet per Minute
SH	Superheat
SP	Shaded Pole
TM	Thermistor
TXV	Thermostatic Expansion Valve
TTC	Technology Test Centers
VSD	Variable Speed Drive
WB	Wet-bulb temperature

FIGURES

TABLES

CONTENTS

EXECUTIVE SUMMARY

The goal of this project is to evaluate the energy savings potential of an Internet-Based Refrigeration Monitoring and Control System (IBRMCS) in a typical refrigerated warehouse application within Southern California Edison (SCE) service territory. The potential for energy savings comes from the benefit of visibility and control of compressors, evaporator fans and other equipment operation where there previously was none.

Any energy savings claims must be based on measured and documented savings. The measured savings achieved as a result of this evaluation can ultimately be used as a basis to provide utility incentives that encourage other customers to implement this technology.

An SCE customer's refrigerated warehouse in Southern California was chosen as a demonstration site to locally showcase this technology. The project was conducted in three phases to capture: 1) 'as-is' performance, 2) post-maintenance performance, and 3) energy efficiency (EE) measure impact performance. The EE technology has a bypass feature that allows any pre-existing refrigeration controls to serve as a default or backup system to the IBRMCS. This monitor-only feature proves very helpful in identifying the equipment that requires maintenance without interfering with normal operations.

After the baseline refrigeration performance was recorded, maintenance issues were identified and repairs were conducted. During this period, supplemental monitoring equipment including refrigerant pressure sensors and an SCE totalizing meter were installed with the outputs integrated into the IBRMCS. Following repairs, a post-maintenance baseline was recorded to document the ideal (maintained) performance of the equipment as it would normally operate with existing controls.

Following the post-maintenance baseline, the IBRMCS technology was activated to override control of the compressors, evaporator fans, defrost periods, setpoint temperatures, and other parameters. The software of the IBRMCS technology was used to raise or lower setpoint temperatures, delay or prolong evaporator fan and/or compressor operation, regulate anti-sweat heater on/off time and increase or decrease defrost periods as appropriate for optimizing EE and cooling performance. With the IBRMCS technology controlling the equipment, the performance of the refrigeration systems was recorded and found to save energy (see Figure 1) compared to the post-maintenance baseline operation.

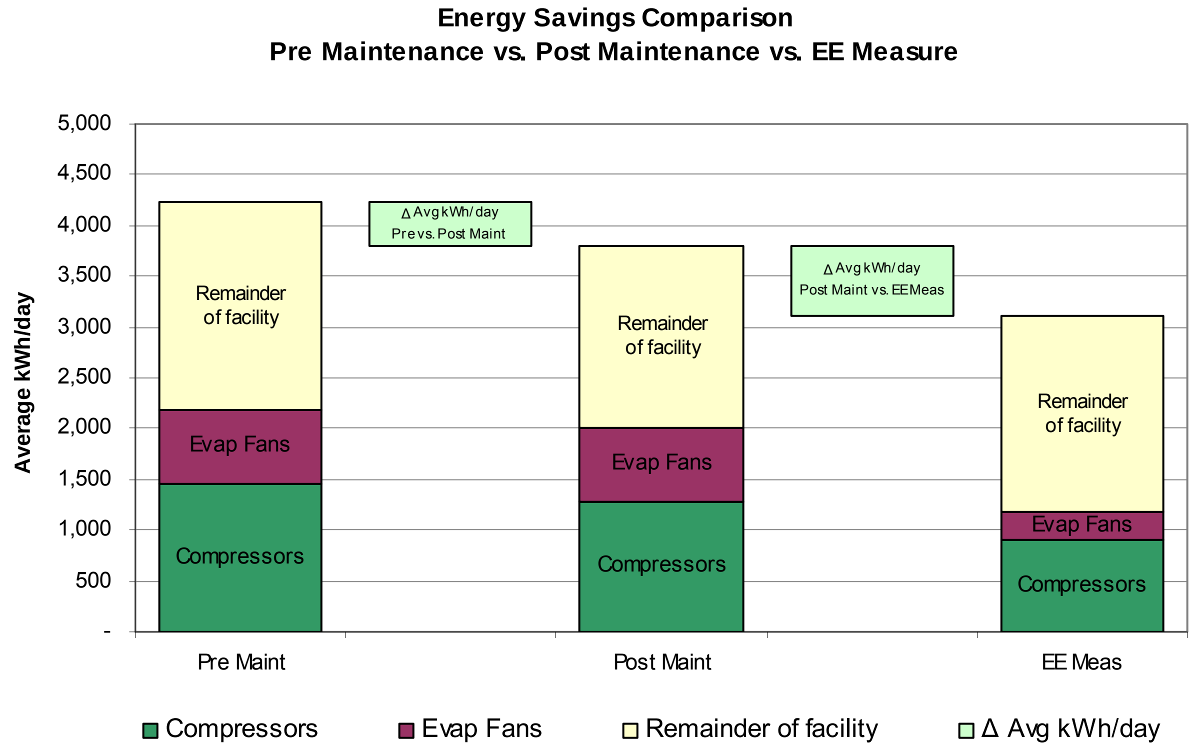


FIGURE 1. PRE MAINTENANCE VS. POST MAINTENANCE VS. EE MEASURE ENERGY SAVINGS COMPARISON

The level of energy savings achieved through implementation of this tool is compelling. Results of this evaluation show that substantial energy savings can be achieved through intelligent control strategies using this technology. The SCE site meter installed for this project confirmed an average 18% reduction in daily energy usage and an 8% average demand reduction between the post maintenance and EE measure operating conditions as measured during the September to October monitoring period.

The ability to monitor and control individual pieces of equipment within an entire refrigeration system through an easy to understand web-based interface is key to managing performance and optimizing EE. For example, compressor run times were reduced an average of 26.7% while evaporator fan run times were reduced an average of 57.4% while the product temperatures were more consistent throughout the coolers and averaged closer to the desired setpoint.

An additional benefit of this technology is the ability to conduct continuous commissioning of the equipment. This means maintenance issues will less likely go unnoticed before reaching the failure point. Also, early detection means critical maintenance tasks can be proactively scheduled rather than repaired only after failure. Real-time and historical visibility into equipment performance is presented in a straight-forward format that is easy to read and understand. Performance graphs, demand interval charts, and statistical results are displayed as web pages based on recorded data. To provide early notice of maintenance needs, system alarms can be user set to monitor maintenance critical points. Text messages or emails can then be sent directly to key personnel when an alarm has been triggered.

This technology is an example of the level of EE and maintenance benefits that can be obtained with detailed visibility into the operation of the refrigeration equipment. It is a sophisticated and powerful tool that is simple to use while it provides control and visibility into present and historical equipment performance where there previously was none. This technology has a promising future that will enable customers and technicians to precisely control their refrigeration equipment for optimum EE and performance.

Based on the energy savings results of this evaluation, it is highly recommended that this technology be considered for inclusion in SCE's EE incentive programs. It is a useful tool that will benefit refrigerated warehouse owners, operators, and technicians while saving them energy and money.

The complexity of refrigeration technology leaves refrigerated warehouses in an underserved market sector where this EE technology can save energy. Broad implementation of this technology will further enhance the key performance objectives of SCE while providing a valuable asset to the SCE portfolio of offerings. The benefit of energy savings extends to all stakeholders of EE including those of SCE.

It is also recommended to provide education and training about this technology to end users, contractors and refrigeration technicians. The training encourages use of the technology rather than turning it off or defeating its operation simply because it is not understood. After users understand the technology, they quickly realize how it can help them in their own tasks and the energy savings benefits are realized by all.

INTRODUCTION

There is significant opportunity for energy savings in the operation of refrigerated warehouses. Owners and operators of refrigerated warehouses typically do not have visibility into the operation of the refrigeration equipment and do not know problems exist until there is a failure. This Internet-Based Refrigeration Monitoring and Control System (IBRMCS) technology is a tool that allows users to analyze and make strategic decisions about the performance and efficient operation of their equipment based on historical and real-time performance data.

This project was a planned collaboration with a Southern California Edison (SCE) customer who manufactures and distributes Mexican-style cheeses in addition to other related food products. They are also the manufacturer and supplier of the IBRMCS technology. This site was primarily chosen for the energy savings potential inherent in the large refrigerated portion of the warehouse. This City of Industry site was chosen because it represents a typical refrigerated warehouse in a Southern California climate zone within SCE service territory.

It is common that refrigeration equipment of large refrigerated warehouses is either in need of maintenance and/or operating below peak performance potential. It is also common that true energy savings of new technology investigations are masked in the results of performing maintenance during an evaluation. For this reason, the sequence of this project was developed to conduct a pre- and post-maintenance baseline step before investigating the energy savings of the IBRMCS technology.

Southern California's high population density indicates that there are a large number of facilities with similar energy savings potential to the one that was evaluated for this project. The IBRMCS technology that was installed has been successfully used in the northeastern United States and results there were a compelling reason to perform a local test under local weather conditions. This document describes the performance evaluation results of this technology.

PROBLEM STATEMENT

Refrigerated warehouses and coolers are typically designed and constructed by contractors with little or no refrigeration engineering involvement or great concern for energy efficiency (EE). Pre-fabricated walk-in cooler panels, doors, fan coils and condensing units are readily available from suppliers and the coolers are often constructed ad-hoc at the installation site. Refrigeration equipment may be new, out-dated, re-manufactured, or even previously used (as was discovered to be the case at this project site).

Also, refrigeration systems are typically over-sized for the worst case scenario of the hottest time of day on the hottest day of the year. This results in frequent compressor cycling and greater energy consumption than necessary during the rest of the year when temperatures are either mild or cold.

Additionally, it is typical of coolers and refrigerated warehouses to operate long periods with equipment running at degraded levels of performance because there is no visibility into how they operate. Control systems are often minimal or non-existent (also, as was discovered to be the case at this project site). This problem is compounded by having redundancy such that two or more systems need to fail before a problem is even noticed. It is typical that a problem is not even identified until the space temperature is not maintained.

It is also typical that service to the refrigeration equipment is contracted out to third party maintenance companies. Thus, when a trouble call is placed, the service technician has only the immediate priority of fixing the problem and rarely a long-term commitment to the efficient operation of any particular facility. Service contractors typically tend to set or configure equipment operation for worst case conditions to minimize nuisance service calls.

Finally, EE strategies are rarely implemented as there is a lack of knowledge of refrigeration technology outside of those who specialize in the industry.

OBJECTIVES

The primary objective of this technology evaluation is to investigate the energy savings potential of the benefits offered by this IBRMCS technology. This is done by retrofitting and monitoring the refrigeration control system of a typical small to medium size cold storage facility. Any actual (measured) energy savings must be weighed against the cooling performance to the refrigerated space.

Significant energy savings results have been claimed at several similar refrigerated warehouse sites where this technology was implemented. However, the data lacked sufficient instrumentation necessary to monitor operating variables in enough scientific detail to verify the claimed results. Also lacking in prior data was clear and distinct information regarding savings from pre-maintenance versus post-maintenance operating conditions.

A secondary objective of this project therefore, was to identify the typical operating conditions of a refrigerated warehouse in terms of maintenance. Then, capture the energy savings related to performing the needed maintenance independent of the energy savings related to implementing the technology.

BACKGROUND

SCE has a large number of refrigerated warehouses throughout its service territory. The population in California is a good indication of how much refrigeration is required to support feeding so many people. Other refrigeration applications include floral, ice production, produce, bakeries, biotech, meat packaging and process cooling for small manufacturing facilities. Some facts about this market segment are:

- Operators have little or no visibility or information on how their equipment is performing.
- Poor maintenance standards, or lack thereof, are also very common with this market segment.
- The owner or operator usually has no on-site maintenance personnel and is totally dependent on outside service contractors who have no vested interest in energy use of the equipment or its performance as it relates to energy.
- One of the goals of this project is to identify and measure the energy savings attributable to correcting maintenance issues and possibly use that as a justification for recommending or creating training programs for service personnel.
- Refrigeration systems for many or most small to medium cold storage facilities are typically designed by contractors instead of engineers.
- Refrigeration systems are sized for the warmest day of the year, i.e., the worst case scenario
- Refrigeration operates year round 24 hours per day thus making savings projections predictable.
- The value of product stored in refrigerated space is significant so every large cooler and freezer has two or more refrigeration units for redundancy to cool the space
- Since they have redundancy, each system can typically handle the entire refrigeration load. In many cases one of the systems still operates but provides little or no cooling while consuming a significant amount of energy.
- Service contractors typically set or configure equipment operation for worst case conditions so they do not receive nuisance service calls.
- The oversized refrigeration equipment and redundant systems tend to consume significant energy as evaporator fans are always on and continually introduce motor heat into the cooled space. This is extra energy consumption that can be turned off much of the time.

TECHNOLOGY DESCRIPTION

This internet-enabled technology is a modern tool that provides visibility into the operation and historical performance of refrigeration and other related equipment where little or no visibility existed previously. It provides information and control capability to allow EE and cost-saving solutions and operating strategies to be implemented in walk-in coolers, freezers and related equipment.

GENERAL DESCRIPTION

This technology-based tool consists of measurement, control and data transfer hardware to detect, capture, and record physical performance parameters of the mechanical refrigeration equipment. This information is collected, stored, managed and presented over the internet with software that allows the user to review real-time or historical data. The user can also perform statistical analysis and energy consumption studies to determine how to best manage future equipment performance.

The web pages load quickly and the user interface is straight-forward and requires minimal training. According to the manufacturer, user training is mandatory and is recommended for consistent performance and energy savings. The three primary elements of this technology are, therefore, hardware, software, and training.

HARDWARE

GATEWAY

The gateway is the main communication hub between equipment controllers, data and web servers. The gateway communicates with controllers using an RS485 protocol serial network and with the data server using a standard Ethernet port connected to the internet via the customer's internet access. The server can be located on site or remotely where it can be accessed via the internet. The gateway can be accessed via the server to adjust control parameters but only with proper user authentication. In the event of a loss of internet connection, the gateway can journal up to 8 hours of time-stamped data. When the internet connection is restored, the stored data messages are sent to the server with associated time stamps. Figure 2 below illustrates the architecture of this technology.

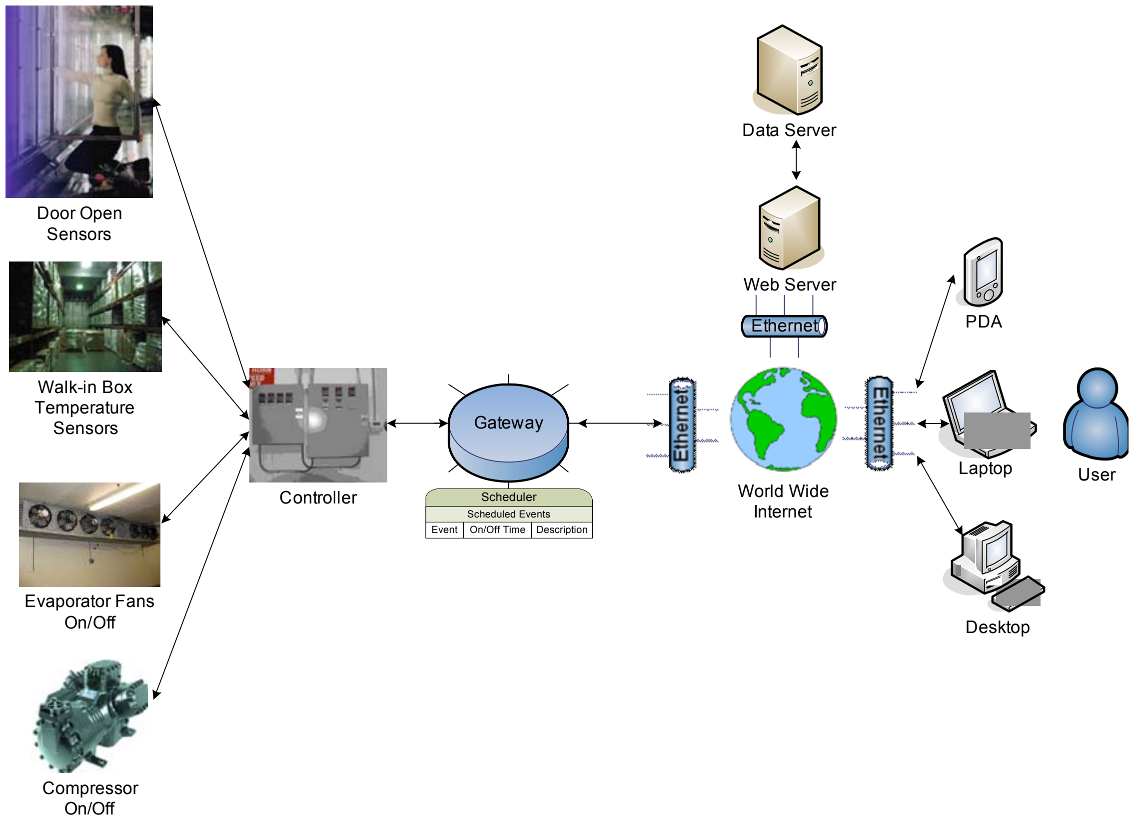


FIGURE 2. HARDWARE ARCHITECTURE

Locally, when the gateway is powered up it evaluates the type and number of controllers to which it is connected and then self-configures the data it collects. The gateway does not require a static IP address as only the gateway itself can make the initial connection with the server (this is an added security feature as it can only initiate communications; it ignores requests for communications). When the gateway connects, data transfer to the server begins and the server then self-configures based on the data it receives.

The gateway continually polls each controller and each new variable value is compared with the previous reading. Only when a variable such as a temperature or controller state changes, is the new value sent to the server to be recorded. This polling occurs about every 7-20 seconds. Since the gateway only sends data based on Change of Value (CoV), the resolution is much greater than typical interval data while the data packet is smaller. When analyzed, the data has greater significance than interval data as the reports generated show true weighted averages and events longer than 7-20 seconds are never lost.

Installation of the gateway is as simple as connecting the power and communication lines. There are no buttons to set and it does not require programming by installers, thus making it relatively easy for non-IT technicians to install.

Each gateway unit has:

- 11 Analog Inputs that are typically used to monitor current transformers, pressure transducers, photocells, CO_2 and other 4-20 mA signals.
- 10 Digital Inputs that are typically used to monitor door(s) status (Open/Closed), pulses from power meters (where each pulse is equal to a certain kWh), or any other dry contact from a relay or mechanical device.

- 10 Digital Outputs that are typically used to switch relay outputs for loads such as lighting and motors, or to enable/disable equipment at scheduled times.
- Two additional serial ports are available for communication using other control protocols.

The software within the gateway also includes a powerful scheduler that can be used to schedule any of the outputs to turn ON or OFF (i.e., lighting or motors). It can also be used to schedule parameter settings such as temperature, differential temperature, bypass mode, or fan operation within any of the controllers with which it is communicating. In this project the digital outputs of the gateway were not used as there were no external loads that required controlling. All controls were implemented in the refrigeration controllers.

REFRIGERATION CONTROLLER

In addition to controlling the refrigeration unit, the controller provides the hardware connection between the refrigeration equipment and the gateway. The controller has a remote keypad that is used to view temperature and control status, and for access to control parameters. Each refrigeration circuit or zone is retrofitted with a new electronic communicating controller with the following features and capabilities:

- Ability to communicate with the gateway over an RS485 network using Modbus® RTU serial protocol.
- Three thermistor probe inputs used to measure the following temperatures:
  - Probe 1 -Space temperature sensor located in the return air path behind the evaporator. This sensor is the reference used to control space temperature and is the basis for space temperature alarms.
  - Probe 2 - Evaporator coil temperature located in the fins of the evaporator near the point where refrigerant enters the coil. Evaporator coil temperature is an important diagnostic point and is also used for terminating and controlling of defrost strategy. Alarms may also be configured based on coil temperature.
  - Probe 3 – This is an optional temperature sensor that can be used to monitor temperature where product is stored. It can also be used to monitor outside temperatures or create a virtual device within the system for any other desired point.
- Five digital outputs that are used as follows:
  - The **main control relay** is used such that when the device/controller is turned ON, this relay is energized to take control of the refrigeration system. In the OFF position, the relay is off and control is handed back to the pre-existing control system. (Note, in the OFF mode, the controller still reports values of each temperature sensor). This control mode is labeled with reverse logic as the 'bypass' output on the system charts and has the following useful purposes:
    - It is used to perform comparison testing of the operation and performance of the refrigeration system while in Run mode compared to while in Bypass mode. This can be useful for measuring EE differences with and without the operation of the IBRMCS technology.

- It can be a diagnostic tool for the user or technician and can help prevent misdiagnosis. The user or technician can readily place the unit in Bypass mode if operational problems with the system are suspected.
- It can be used as an easy way to isolate problems between refrigeration equipment and the controls to determine if a problem is with a controller or with other equipment.

- The **solenoid/compressor relay** is energized by the controller when a call for cooling is received. Refrigeration operates on a relatively small 2°F-4°F temperature differential so it cycles ON upon a rise above the thermostatic setpoint temperature plus the differential. It cycles OFF when the temperature drops to the setpoint. The solenoid/compressor relay is OFF during the defrost cycle.

- The **evaporator fan relay** is energized when cooling is on and can be controlled using a variety of methods. During air defrost it is ON and with electric or hot gas defrost it is OFF. At temperatures above the coil temperature setting, it is programmed to be OFF to avoid adding heat to the refrigerated space.

- The **defrost relay** is not normally used in medium temperature coolers with off-cycle defrost. It is primarily used in freezers or coolers where the temperature setpoint is below 34°F and electric heating elements or hot gas are used to perform the defrost. In this case, the defrost relay controls the on and off periods of the electric heating elements or the hot gas solenoid.

- The **alarm relay** can be used locally to indicate an alarm condition by signaling the user via a flashing light locally on the controller keypad. Alarm types and conditions can be set by the user for temperatures or conditions as desired and appropriate.

SOFTWARE

CONTINUOUS PERFORMANCE MONITORING

This web-based technology continually collects data from all the monitored points and stores it in a database server for remote viewing by engineers, end users and technicians. Since it is web-based, no special or proprietary software needs to be installed or downloaded onto the user's computer. Access to authorized users is available anywhere via a web browser and an internet connection. The IBRMCS technology provides users the ability to view real-time data over a selectable time period in tabular and graphical form. Statistics for the last 24 hours and 7 days displayed next to real-time data provide a simple way to observe changes in performance as well as equipment health issues.

Statistical and trend data can also be viewed graphically for user selectable historic periods and the results can be used to diagnose equipment problems or to configure controls. Each user associated with a site must log in on the server. Based on their authorization level, each user can access different levels of privileges such as view only, change setpoints or configure controller parameters. The following is a description (with examples) of how data can be displayed and configured by a user.

Directory Page

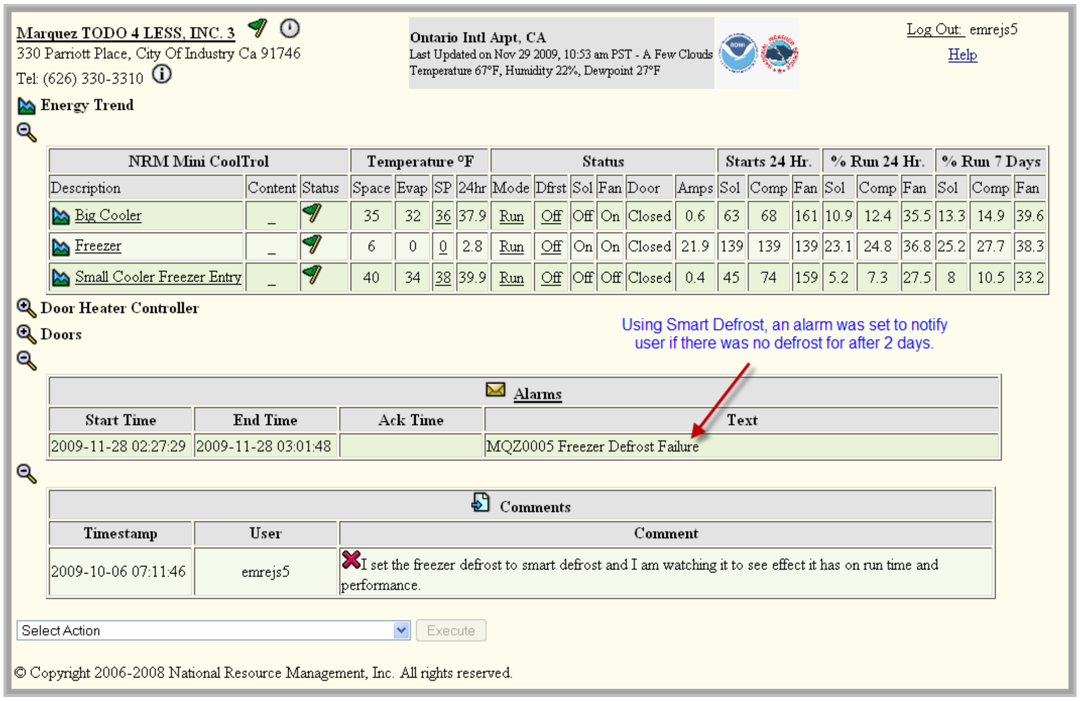
The first screen after successful login is the directory page. If a user has access to multiple facilities, the directory page lists their accessible sites and shows all current alarms for those sites. By selecting a site the user is directed to a new web page or tab where the relevant Summary Page is displayed.

Summary Page

The main page for any gateway reporting to the server is the Summary Page, see Figure 3. The Summary Page screen displays information about the site including:

- Site name, address, telephone number, contact information, weather conditions local to the site, and location of weather information source.
- A table listing the coolers and/or zones of the site with the following information:
  - Trend icons, cooler names, setpoint temperatures, current space temperatures, current evaporator temperatures and the average space temperature over the previous 24-hour period.
  - Controller Mode Status (Run or Bypass), Defrost Status, Liquid Line Solenoid Status, and Evaporator Fans Status (ON or OFF). In Bypass mode, the solenoid, fan, and defrost control status is unknown and thus left blank.
  - When monitored, the compressor amperage can be viewed in both Run and Bypass mode.
- Statistical information from historical data enhances the performance monitoring and empowers the user to optimize the operation. The tables in Figure 3 and Figure 4 show statistical data on the Solenoid, Compressor and Evaporator Fans including:
  - Number of starts during previous 24 hours
  - The percent (%) Run Time during the previous 24 hours
  - The percent (%) Run Time during the seven days prior to the previous 24 hours
- The Alarm Table shows alarms event information including:
  - Start, End and Acknowledged Time
  - Text of Alarm Message that was sent to recipients
  - Alarm types include:
    - High and Low temperatures
    - Compressor safety – if coil is iced up or if defrost contactor was stuck in ON position
    - Bypass – if unit is bypassed it prompts user to find out why
    - Probe failure
    - Defrost alarm – if defrost has not occurred after a set period of time
  - The Comments Table is used to inform other users by leaving messages about an action, alarm or any other message that other users should know. The table displays message time stamp, user's name and the message sent to selected users.

Figure 3 below is an example of the Summary Page for the retail store at this project site. Note the two coolers and freezer summary data, the weather data at the top, and the comments box near the bottom. In this example, a Smart Defrost alarm (Smart Defrost is discussed later) is set to notify the user if defrost has not occurred after two days (the annotated text in blue was added later).



Marquez TODO 4 LESS, INC. 3
330 Parriott Place, City Of Industry Ca 91746
Tel: (626) 330-3310

Ontario Intl Arpt, CA
Last Updated on Nov 29 2009, 10:53 am PST - A Few Clouds
Temperature 67°F, Humidity 22%, Dewpoint 27°F

Log Out: emrejs5
Help

Energy Trend

NRM Mini CoolTrol			Temperature °F				Status						Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	SP	24hr	Mode	Dfrst	Sol	Fan	Door	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Big Cooler	_		35	32	36	37.9	Run	Off	Off	On	Closed	0.6	63	68	161	10.9	12.4	35.5	13.3	14.9	39.6
Freezer	_		6	0	0	2.8	Run	Off	On	On	Closed	21.9	139	139	139	23.1	24.8	36.8	25.2	27.7	38.3
Small Cooler Freezer Entry	_		40	34	38	39.9	Run	Off	Off	Off	Closed	0.4	45	74	159	5.2	7.3	27.5	8	10.5	33.2

Door Heater Controller
Doors

Using Smart Defrost, an alarm was set to notify user if there was no defrost for after 2 days.

Alarms			
Start Time	End Time	Ack Time	Text
2009-11-28 02:27:29	2009-11-28 03:01:48		MQZ0005 Freezer Defrost Failure

Comments		
Timestamp	User	Comment
2009-10-06 07:11:46	emrejs5	I set the freezer defrost to smart defrost and I am watching it to see effect it has on run time and performance.

Select Action
Execute

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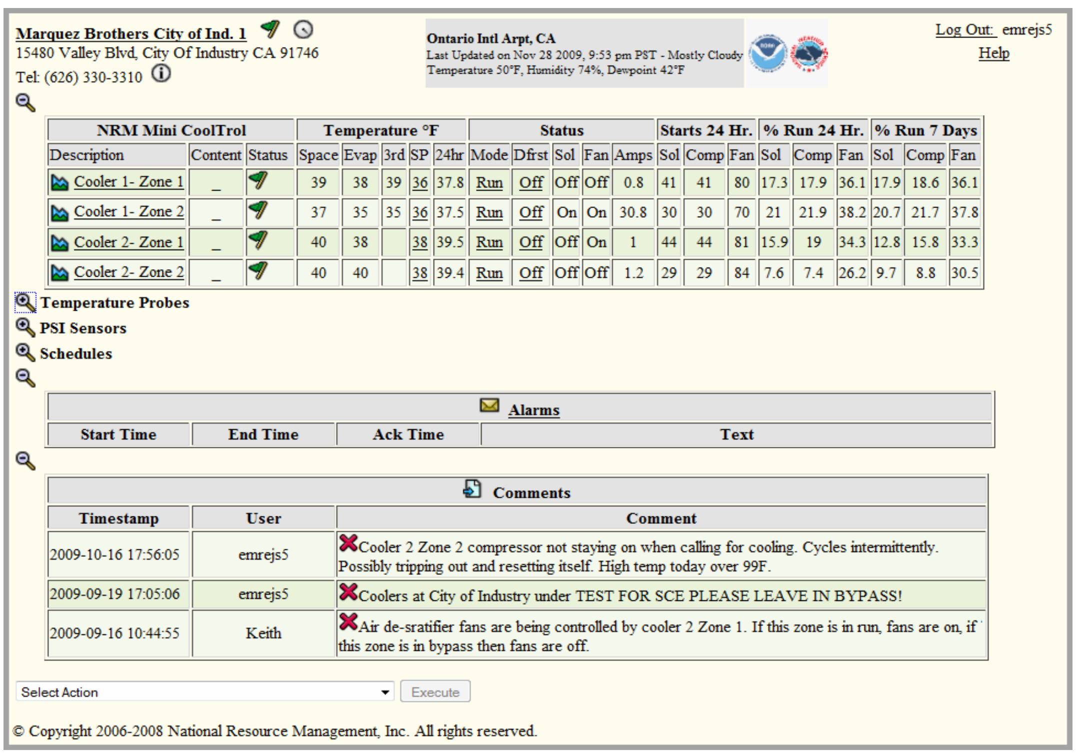
FIGURE 3. RETAIL STORE SUMMARY PAGE AFTER IBRMCS IMPLEMENTATION

Figure 4 is an example of the Summary Page for two of the large cold storage coolers monitored in this project (note the low fan run times implemented with this technology).



Marquez Brothers City of Ind. 1
15480 Valley Blvd, City Of Industry CA 91746
Tel: (626) 330-3310

Ontario Intl Arpt, CA
Last Updated on Nov 28 2009, 9:53 pm PST - Mostly Cloudy
Temperature 50°F, Humidity 74%, Dewpoint 42°F

Log Out: emrejs5
Help

NRM Mini CoolTrol			Temperature °F					Status					Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	3rd	SP	24hr	Mode	Dfrst	Sol	Fan	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Cooler 1- Zone 1	_		39	38	39	36	37.8	Run	Off	Off	Off	0.8	41	41	80	17.3	17.9	36.1	17.9	18.6	36.1
Cooler 1- Zone 2	_		37	35	35	36	37.5	Run	Off	On	On	30.8	30	30	70	21	21.9	38.2	20.7	21.7	37.8
Cooler 2- Zone 1	_		40	38		38	39.5	Run	Off	Off	On	1	44	44	81	15.9	19	34.3	12.8	15.8	33.3
Cooler 2- Zone 2	_		40	40		38	39.4	Run	Off	Off	Off	1.2	29	29	84	7.6	7.4	26.2	9.7	8.8	30.5

Temperature Probes
PSI Sensors
Schedules

Alarms			
Start Time	End Time	Ack Time	Text

Comments		
Timestamp	User	Comment
2009-10-16 17:56:05	emrejs5	Cooler 2 Zone 2 compressor not staying on when calling for cooling. Cycles intermittently. Possibly tripping out and resetting itself. High temp today over 99F.
2009-09-19 17:05:06	emrejs5	Coolers at City of Industry under TEST FOR SCE PLEASE LEAVE IN BYPASS!
2009-09-16 10:44:55	Keith	Air de-sratifier fans are being controlled by cooler 2 Zone 1. If this zone is in run, fans are on, if this zone is in bypass then fans are off.

Select Action
Execute

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FIGURE 4. COOLER 1 AND COOLER 2 SUMMARY PAGE AFTER IBRMCS IMPLEMENTATION

From the Summary Page it is possible to view trends of historical data by selecting the trend icon for any particular cooler. This is done by selecting the trend icon to the left of the cooler name in the Descriptions column, see Figure 4. Selecting this icon displays a real-time or historical trend for that cooler directly below the summary table. A time window can then be selected from ½ hour to 7 days (the default is 4 hours), see the example in Figure 5 below.

The format of this example trend graph is the same for all trends in this report and is presented here as they are displayed by the IBRMCS system. From top to bottom, the temperature chart, current chart, and controller status chart make up the typical trend graph for any of the coolers of this project site. As shown in the example in Figure 5, the color-coded legend at the top of the temperature chart in this trend graph identifies which temperatures are displayed. Dark blue is the space temperature for the cooler, light blue is the evaporator temperature, and red is the fixed setpoint temperature.

The current chart in this trend graph shows the combined compressor and evaporator fan current in black. Finally, the status chart at the bottom of this trend graph displays the state of each output of the controller as color-coded in the legend at the top of the status chart. Red is the liquid line solenoid, light green is the evaporator fan(s), blue is defrost, orange is energy saving mode (if used), green is shut down, brown is bypass, and pink is open/closed door(s) status (if monitored).

The example in Figure 5 shows the beginning of a defrost cycle (status is ON) in the large cooler of the retail store monitored at this project site. Note the compressor current is at zero during the defrost period and that the corresponding evaporator and space temperatures increase with respect to time until the end of defrost (status is OFF).

The ON status of the evaporator fans during the defrost period is controlled by the IBRMCS technology to help clear any frost from the evaporator. At the end of defrost, the current reading increases when the controller calls for cooling and the compressor turns on again. This is coincident with the temperatures beginning to drop again. Finally, the cooler door openings are indicated by the pink line at the bottom of the status chart.

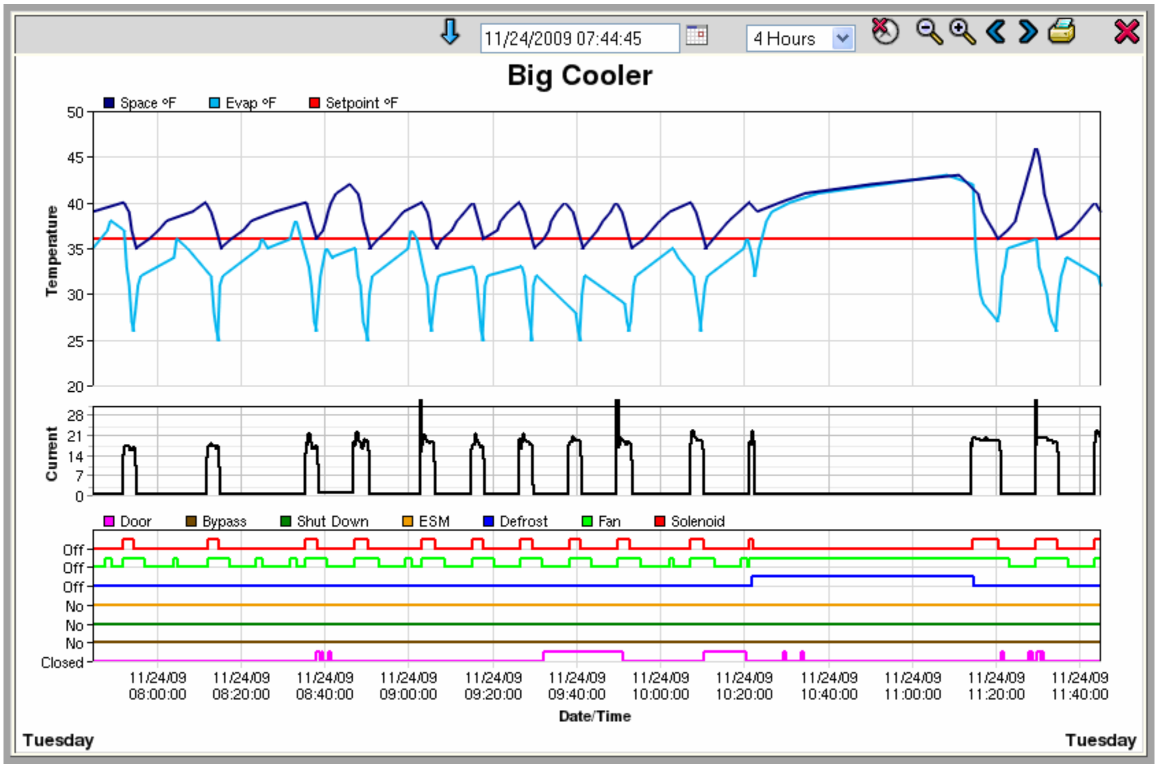


FIGURE 5. LARGE COOLER IN RETAIL STORE AFTER IBRMCS IMPLEMENTATION

As an example of another type of trend information available with this technology, Figure 6 shows a 30-day performance trend of one of the main coolers monitored at this project site. The highlighted values represent the percent run time averages over the period displayed.

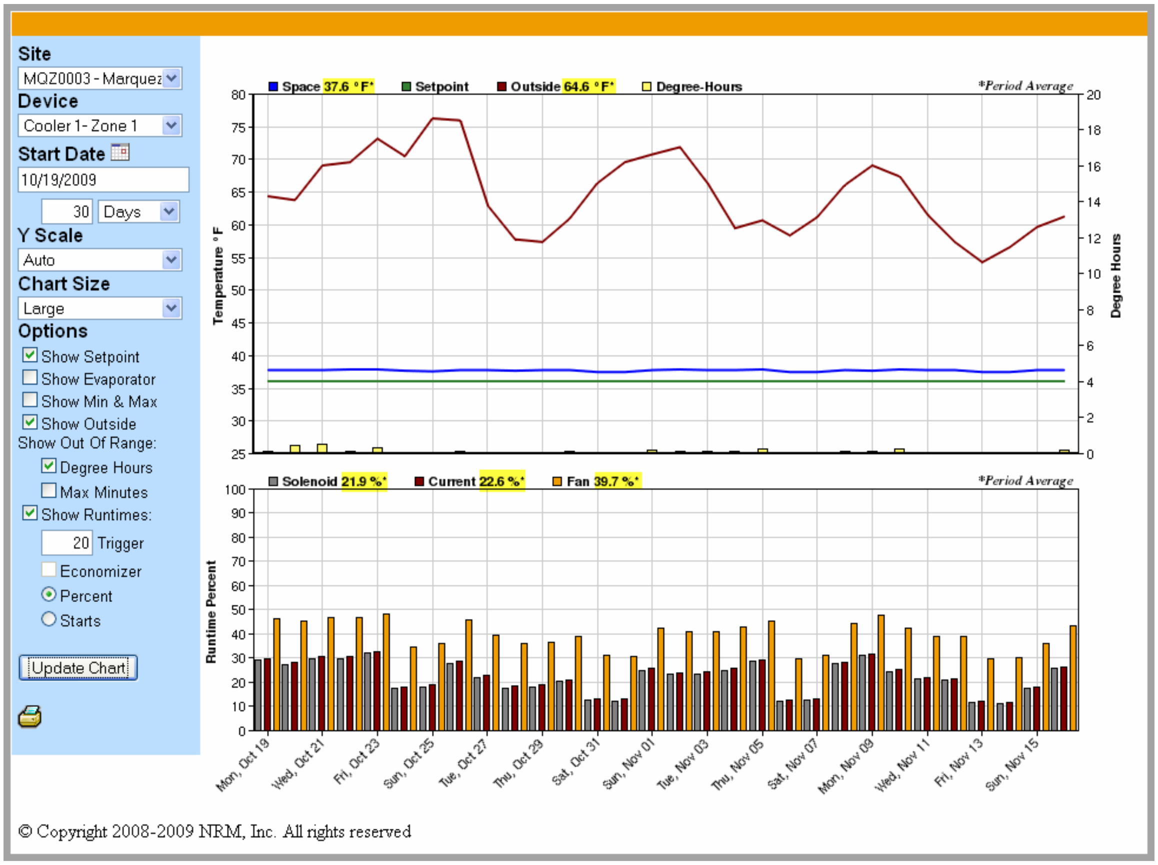


FIGURE 6. COOLER 1 ZONE 1 PERFORMANCE TREND AFTER IBRMCS IMPLEMENTATION

ENERGY EFFICIENCY STRATEGIES

The IBRMCS is a tool that allows users to implement energy saving strategies while continually monitoring the performance of the refrigeration and related equipment. Some of these energy saving strategies are listed below:

- Electronic Temperature Control provides greater accuracy in control of temperature. The differential between the space temperature and the evaporator temperature can be used as a tool for fine-tuning the timing of the rise in space temperature as well as controlling how often cooling is turned ON and OFF during a given period. Tighter differentials tend to reduce infiltration and ex-filtration due to the expansion and contraction of the air volume in the refrigerated space. This is a naturally occurring phenomenon where a rise in temperature expands air volume resulting in cooled air leaving the refrigerated space. Likewise, as temperatures drop when cooling is on, the air volume contracts and warm outside air is drawn into the refrigerated space. Maintaining a tight differential temperature results in saved energy.
- Evaporator fan cycling can save significant fan energy, as in most unintelligent systems, the fans are on 100% of the time. The fan relay can be programmed with customizable algorithms that cycle the fans sufficiently to mix the air and measure accurate average temperatures without running the fans unnecessarily. This can result in significant energy savings as the equipment of cold storage facilities is typically oversized for worst-case conditions.

Evaporator fan ON/OFF cycling is recommended over continually variable fan speed control for the following reasons:

- Slowing the fan speed can result in 'short circuiting' of the air flow whereby the exiting air returns to the inlet of the evaporator rather than travelling the full distance away from the evaporator that would provide for good mixing throughout the space. In long coolers, the air can potentially not reach the opposite side of the cooler and the product integrity may be put at risk.
- From a service perspective, it is much easier for technicians to service a relay than to diagnose or configure variable speed fan control systems.

- A defrost control strategy can be set based on a time of day schedule, an off-cycle duration, or a smart defrost methodology. In medium temperature coolers, it is standard practice to use the off-cycle defrost method. This is fairly straight-forward as the fans operate with the liquid line solenoid OFF until the coil temperature reaches termination temperature or the maximum defrost time has expired, whichever occurs first. When the space setpoint is below 32°F or 34°F, the defrost method is usually electric or hot gas bypass – depending on the installed equipment. This project had only one freezer that was equipped with an electric defrost feature. Below are two additional strategies that can be employed for either air or electric defrost:
  - **Thermostatic defrost** terminates based on time instead of terminating defrost based on temperature. The defrost termination temperature of the coil is lowered such that when the defrost heaters make the coil reach the setpoint, they are turned OFF. As the coil temperature drops 4°F below termination temperature, the heaters are re-energized and heat is again applied until the coil temperature reaches the setpoint. This ON/OFF cycling of the heaters continues until the defrost time setting expires. This method greatly improves the defrost efficiency as less heat is required, less heat is introduced into the space, and the coil is given enough time to fully defrost. A properly defrosted coil performs much better and the timed defrost ensures complete defrost without needlessly overheating the coil or the space.
  - The **Smart Defrost** algorithm within the refrigeration controller calculates when defrost is actually needed based on the coil temperature and the amount of time that temperature is below the Smart Defrost setpoint. This strategy can save a considerable amount of energy when compared to a traditional defrost clock. Defrost clocks typically perform defrosts several times per day whether they are needed or not. Each defrost requires that sufficient heat be applied to the evaporator to melt any accumulated frost or ice. This heat is typically applied for up to 40 minutes to ensure complete defrost. The added heat must then be removed by the refrigeration system to maintain the space temperature. This entire process requires a significant amount of energy that can be minimized by setting and tuning the best defrost method for an application. In this project, Smart Defrost was configured for the freezer that reduced the number of defrosts from 3 to 4 per day to 1 or 2 every 2 days.

- The use of low-power destratification fans in large coolers can save energy over the use of the higher power evaporator fans. Air stratification can occur in large coolers without sufficient mixing, especially in coolers with high ceilings. Evaporator fans are typically shaded-pole type motors that are not low power, and they may not be positioned for optimally de-stratifying the space. It is more energy efficient to install low-power de-stratifying fans to provide good mixing and use the evaporator fans only to deliver cooling.

TRAINING

Consistent with implementing the energy efficient strategies available through the use of this technology is the requirement of performance management through training. While this technology is simple and straight-forward to use, training is recommended for consistent performance and savings. One of the primary goals of the IBRMCS system is to ensure that everyone who interfaces with the system realizes a benefit from it in the way it serves their needs. This ensures that there is great motivation for all to use and maintain the system. Understanding the purpose and functionality of this tool are keys to the continued use and benefit of the technology.

Training the end user and their refrigeration contractor empowers them to take full advantage of the new system and teaches them the key indicators that should be reviewed on a regular basis. The primary goal of the training is to ensure each party understands how the energy savings are derived. The training also teaches how to recognize poor operating conditions that indicate losses in EE and what to do about it. As an added benefit, the service contractor learns that the ability to remotely diagnose problems enables them to better serve their customers and arms them with information that can make their job easier.

SITE INFORMATION

The SCE customer site chosen for this demonstration and evaluation project was a large dry goods distribution warehouse with a large multi-zoned medium temperature cooler inside the warehouse. The site also operated a small retail store with a walk-in cooler and freezer that was located apart from and operated independently of the large warehouse cooler.

DRY GOODS WAREHOUSE

The 210,000 ft^2 dry goods distribution warehouse provides protection from solar radiation to the cooler and retail store within, see Figure 7.

FIGURE 7. DISTRIBUTION WAREHOUSE

COOLER WITHIN THE WAREHOUSE

The 5,820 ft^2 medium temperature cooler within the warehouse serves as distribution storage for cheese and other dairy products that need to be refrigerated but cannot be frozen, see Figure 8.

FIGURE 8. INSIDE MEDIUM TEMPERATURE COOLER

This large medium temperature cooler is made up of four separate rooms interconnected by doors for forklift travel. These four coolers are served by 9 compressors and 17 evaporators. For simplicity of the evaluation, the cooling zones are broken down into areas within each cooler according to the compressors serving those zones. For example, cooler 1, zone 1 is served by one compressor. See Figure 9, below, and Table 4 of Appendix A.

Cooler 2 is primarily used as a sorting room to minimize the time delivery trucks remain at the dock. Products are taken off the trucks and dropped off here for a short time, then gradually moved into the racks of the other coolers. Trucks are also quickly loaded from this 'staging' area. Use of this temporary storage area minimizes the amount of time cold product is exposed to warm loading dock temperatures.

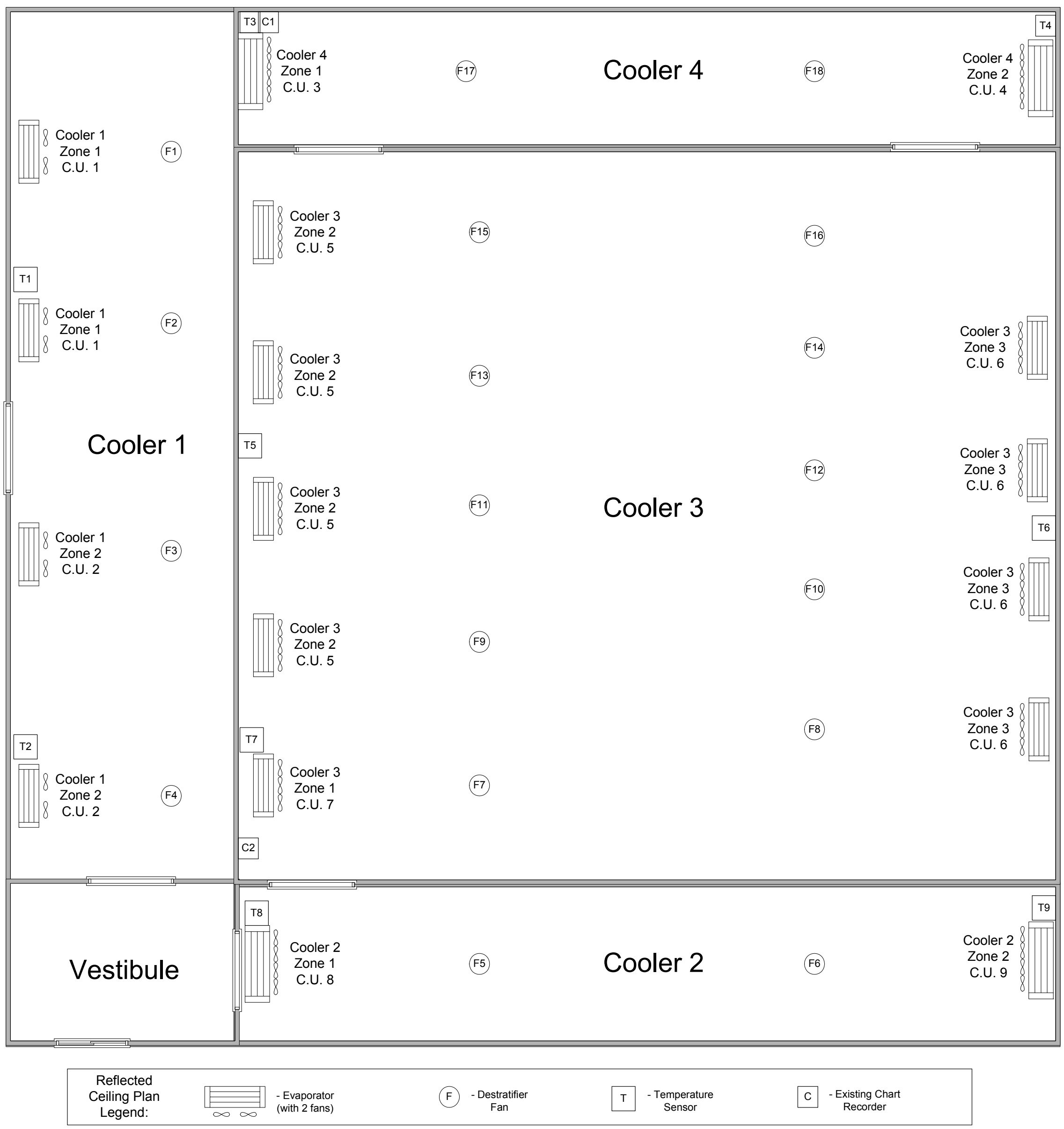


FIGURE 9. COOLER-REFLECTED CEILING PLAN

It is known that some of the compressor systems were not installed as new systems when the coolers were installed in the warehouse. Some of the compressor systems were moved from a previous refrigerated warehouse and were 1980's vintage. As of this writing, two of the older compressor/condenser units were replaced with new, more efficient units.

RETAIL STORE

There is a small cash and carry store at the back of the warehouse. It includes a walk-in freezer sandwiched between two walk-in coolers, all with glass reach-in doors opening to the main store area.

The retail store contains a 204 ft^2 walk-in freezer served by one evaporator and one compressor. The freezer is located between two medium temperature supermarket type walk-in coolers (see Figure 10 and Figure 11).

FIGURE 10. RETAIL COOLERS AND FREEZER

The smaller 96 ft^2 retail cooler A is served by one evaporator and one compressor. The larger 300 ft^2 retail cooler B is served by two evaporators and one compressor (see Figure 11 below and Table 4 of Appendix A).

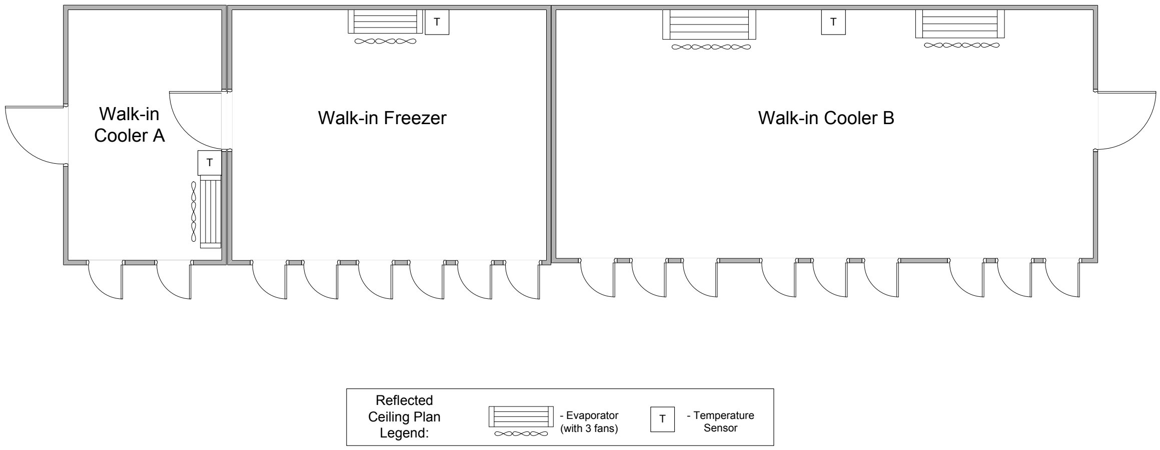


FIGURE 11. RETAIL STORE COOLER & FREEZER REFLECTED CEILING PLAN

TEST PLAN

This section describes the test plan sequence. Many times, in existing buildings, the refrigeration systems are not operating normally as they are in need of maintenance. This can complicate the technology evaluation process, especially if there are issues related to repaired or non-repaired equipment at the time data is recorded for the measure technology. This project was structured to eliminate these complicating issues by incorporating a step in the data acquisition process to account for maintenance. A minimum of 2 weeks of data was collected at each step of the sequence described below.

PRE-MAINTENANCE BASELINE

The purpose of this step of the test plan was to capture the operating conditions of the refrigeration system as the customer was operating it, i.e., before any changes to operating schedules or unplanned equipment maintenance. This step effectively captures the daily operating conditions that correspond to the customer's current billing. This pre-maintenance baseline is presumed to be representative of other, similar refrigeration systems in the field.

The monitoring plan (described in a subsequent section) was implemented for this step as well as for the other data collection steps of this project. The instrumentation used is referenced in Table 2 and the results of the four largest refrigeration units are tabulated in Table 5 of Appendix A.

PERFORM MAINTENANCE

Following the pre-maintenance baseline data collection, the IBRMCS was used in Bypass mode to help identify improper equipment operation of the refrigeration systems. This feature proved valuable in helping to identify the units and elements in need of maintenance. The problems that were discovered are discussed in detail in the Results section of this report. The following subsections describe the additional hardware and features installed during the maintenance period of this project.

INSTALL DESTRATIFICATION FANS

Figure 12 below shows the destratification fans installed in the coolers. The fans were strategically located so they would not interfere with forklift access to the top racks of the storage shelves. Fan locations are shown on the reflected ceiling plan of the coolers as depicted in Figure 9.

FIGURE 12. DESTRATIFICATION FANS INSTALLED IN COOLER

A total of 18 fans were installed throughout the coolers to run continuously. The fans can be de-activated with the IBRMCS for maintenance, if necessary. Table 1 below shows input and output ratings of the fans.

TABLE 1. DESTRATIFICATION FANS

EQUIPMENT	MANUFACTURER	MODEL	RATED INPUT	RATED OUTPUT
Destratification Fans	Airius, LLC	Model 25-120	120 Vac 30-35 watts	460-550 cfm @ 48dBA

Each fan draws only 30-35 watts for a total of approximately 540 watts across all coolers. The benefit of continuous operation is the circulation and de-stratification of air in the space especially when the evaporator fans are off. This is a more energy efficient approach to maintaining even floor-to-ceiling space temperatures than running the evaporator fans. The existing evaporator fans consume significantly more power and it is therefore not desirable to operate them other than when needed to provide cooling to the space. Secondly, their location in front of the coil is less than optimal for circulating air throughout the cooler. Additionally, continually operating high velocity evaporator fans creates a great deal of unnecessary turbulence and introduces a significant amount of heat into the space that then has to be removed by refrigeration.

Retail Store Evaporator Fan Motors Replaced with ECM

The evaporator fan motors in the freezer and coolers of the retail store were replaced with electronically commutated motor (ECM) fans. These motors consume 65% less energy than the standard shaded-pole type motors. Based on the significant decrease in energy consumption, it is desirable to replace all evaporator fan motors with ECMs. However, at the time this project started, ECMs were not available for the larger coolers in either ½ hp, 230 Vac or 460 Vac, 3Φ versions and were thus not included in the scope of this project. As of this writing, the 230 Vac ECMs are now available up to ¾ horsepower.

Anti-Sweat Door Heater Controls in the Store

A door heat controller was installed in the retail store to control the anti-sweat heaters in the glass doors of the two coolers and freezer. The controller is equipped with a temperature and humidity sensor that is used to calculate the dew point in the store. The controller cycles the door heaters using dew point-based algorithms, keeping the door and frame temperatures above the dew point of the store to prevent condensation from forming on them. Temperature values and status from the controller are collected by the gateway and the information is sent to the IBRMCS system. Prior to implementation of the IBRMCS, the anti-sweat heaters operated at 100% power. The new controls continually adjust heater power according to the changing environmental conditions in the store.

Post-Maintenance Baseline

The purpose of the post-maintenance baseline data collection is to re-establish a baseline of the operation of all the refrigeration systems after any needed maintenance is performed. This prevents attributing EE gains related to maintenance improvements with gains attained from the IBRMCS technology. The result is a clear 'before and after' correlation of EE gains that are solely related to the technology under investigation.

The results of the post-maintenance baseline data for the four largest refrigeration systems are tabulated in Table 6 of Appendix A. The post-maintenance baseline data for all compressors and evaporator fans of the entire site are shown in Table 7 of Appendix A.

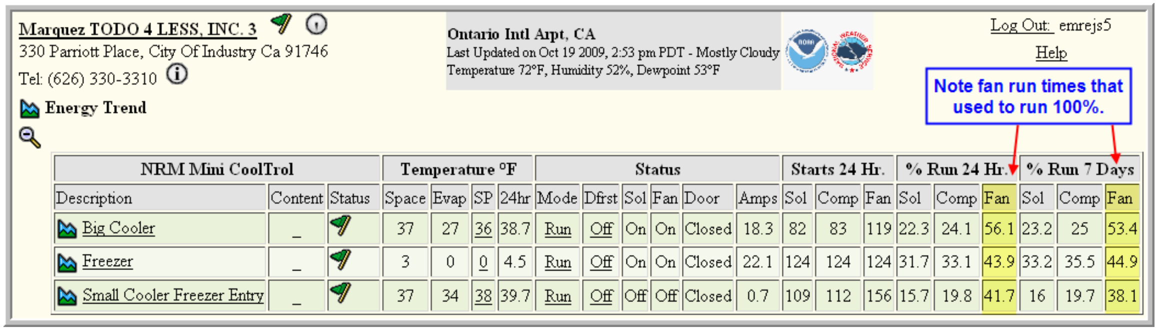
Finally, it should be noted that although the destratification fans were installed before the post-maintenance baseline data was collected, they were not set to operate during this period.

Energy Efficiency Measure Controls Activated

Upon completion of the two-week post-maintenance baseline period, the IBRMCS was taken out of Bypass mode and placed in Control (Run) mode. The switch to control mode occurred on 10/15/09 at 2:23 pm.

Evaporator Fan Run Times

One of the first steps implemented with the IBRMCS in Control mode was to directly control operation of the evaporator fans for all cooler zones. The summary table shown in Figure 13 below shows the new fan run times for the freezer and coolers in the retail store. The energy savings results for all coolers are shown in the Results section of this report.



NRM Mini CoolTrol			Temperature °F				Status						Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	SP	24hr	Mode	Dfrst	Sol	Fan	Door	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Big Cooler	_		37	27	36	38.7	Run	Off	On	On	Closed	18.3	82	83	119	22.3	24.1	56.1	23.2	25	53.4
Freezer	_		3	0	0	4.5	Run	Off	On	On	Closed	22.1	124	124	124	31.7	33.1	43.9	33.2	35.5	44.9
Small Cooler Freezer Entry	_		37	34	38	39.7	Run	Off	Off	Off	Closed	0.7	109	112	156	15.7	19.8	41.7	16	19.7	38.1

FIGURE 13 QUICK REFERENCE SUMMARY SCREENS

A secondary energy saving step was later implemented on the evaporator fan run times to optimize the cooling delivered to the space. This is explained in more detail in the Results section of this report.

ALL COOLER ZONES SET TO 36°F

Another one of the first adjustments made with the IBRMCS control was to set the thermostatic setpoint of all coolers to 36°F. This was done to bring all cooler temperatures to the same operating level with the destratification fans ensuring even temperature mixing with the continued circulation of the air.

ALARMS CREATED

Alarms were then created that were sent to the responsible refrigeration maintenance technician for the site. These can be sent by email or a text message. The alarms were set to alert if a temperature zone drifted out of range for a selected time period (too warm or too cold for the cheese and dairy products).

ANTI-SWEAT HEATERS

The anti-sweat heaters of the retail coolers were then controlled through the IBRMCS using a dedicated door heater controller based on the dew point in the store. This required a periodic visual inspection of the doors to ensure a balance between clarity and moisture condensation versus energy consumption. After this calibration step was performed, the operation was reliable.

MONITORING PLAN

Table 2 lists the instrumentation equipment used in monitoring the refrigeration units and cooler zones at this site as described in the sub-headings immediately below. Cut sheets for this non-SCE equipment can be found in Appendix B. The equipment was not independently calibrated because they were purchased new (except for the existing SCE meter), from their respective manufacturers.

TABLE 2 INSTRUMENTATION

Equipment	Manufacturer	Model	Rating	Output	Accuracy
True RSM AC watt-hour Meter	Watt-Node, Inc.	WNB-3D-480-P	480Vac 3Φ, 3 wire	Opto-isolated Bidirectional 4 Hz Pulsed	± 0.5% of reading
Discharge Pressure Sensor	Measurement Specialties, Inc.	MSP300-500-P-4-N-1	0-500 psi	1-5Vdc fixed	± 1.0% of span
Suction Pressure Sensor	Measurement Specialties, Inc.	MSP300-250-P-4-N-1	0-250 psi	1-5Vdc fixed	± 1.0% of span
Split Core Current Transformers	Continental Control Systems, LLC	CTS-0750-100	100 Amp	0.333 VAC at rated current	± 1% from 10% to 130% of rated current
Split Core Current Transformers	Continental Control Systems, LLC	CTS-0750-200	200 Amp	0.333 VAC at rated current	± 1% from 10% to 130% of rated current
SCE Utility Meter	Landis & Gyr	V349N-004936	20 Amp	KYZ Pulse	±0.5% by Mfr. ±1% Field Test

STANDARD ELEMENTS MONITORED

This project required a total of three gateways. The number of devices in the main coolers required a total of two gateways. The retail store with two coolers and a freezer was distant from the main coolers and thus warranted a separate, third gateway that was also used to monitor the SCE utility meter.

Each gateway unit is equipped with:

- 11 Analog Inputs that are typically used to monitor current transformers, pressure transducers, photocells, CO_2 and other 4-20 mA signals. In this project these inputs were used to measure the amperage on one phase of each compressor and the high- and low-side pressures of two refrigeration systems.

- 10 Digital Inputs that are typically used to monitor door(s) status (Open/Closed), pulses from power meters (where each pulse is equal to a certain number of kWh), or any other dry contact from a relay or mechanical device. In this project these were used to monitor cooler and freezer loading doors and pulses from power meters.
- 10 Digital Outputs that are typically used to switch relay outputs for loads like lighting and motors, or to enable/disable equipment at scheduled times.

TEMPERATURE SENSORS

It should be noted that the setpoint temperature is not a measured temperature but a setting on the IBRMCS that the space temperature is driven toward by controlling the operating periods of the refrigeration system. Typically, when refrigeration is ON, the supply air discharged from the evaporator is 5-10°F below the return air temperature, where warmer air is drawn into the evaporator.

The temperature sensors used throughout this project site were type 'NTC' thermistors. The application of these is described below:

EVAPORATOR TEMPERATURE

The evaporator temperatures were measured using a thermistor inserted into the fins of the coil near the point where the refrigerant line enters the coil. This is downstream of the expansion device but before the refrigerant has absorbed any heat from the coil.

SPACE TEMPERATURE

The space temperatures were measured at the air inlet to the evaporator for each respective zone in the coolers. The locations of these sensors can be identified as T1 through T9 on Figure 9 in the

Site Information section of this report.

3RD TEMPERATURE PROBE

In this project one of these probes was used to monitor outdoor roof temperature and three others (from other controllers) were placed next to existing chart recorders. These temperature probes were intended to track the data from the customer's chart recorders used to monitor food safety as part of their Hazard Analysis and Critical Control Points (HACCP) plan. The intent here is that the client will no longer have to use the chart recorders but instead use the charts from the web-based monitoring.

ALL ZONES COMPRESSOR KW

Analog inputs were used to monitor current on one phase of each compressor. The kW power demand was calculated from the current measured and the known voltage for each respective compressor as listed in Table 4 of Appendix A.

All Zones Evaporator Fan kW

As is typical, the evaporator fan power was fed from the same electrical supply lines as the compressor power. As a result, when the evaporator fans are operated without the compressor, the fan power is measured as a smaller power demand on the same current chart as the compressor.

Anti-sweat Heaters kW

The power of the anti-sweat heaters for the doors of the coolers and freezer in the retail store were also monitored. Each of the twenty doors had two anti-sweat heaters – one around the perimeter of the door frame and one around the perimeter of the mating mullion.

Humidity Sensor

The anti-sweat heaters in the freezer and cooler doors of the retail store are controlled based on the input from a humidity sensor in the IBRMCS controller unit located in the store area. This sensor provides temperature and humidity information that is converted to dew point temperature within the controller. The heaters can then be modulated according to the amount of heat required to keep the doors clear as humidity changes.

Door Open Sensors

The main loading doors of the coolers and freezer of the retail store are monitored with sensors that detect when a door is opened and the duration of opening. This is useful in understanding causes for high temperature alarms that are frequently linked to an open door. Each of the retail coolers and freezer have 30-minute wind-up timers installed that are used to shut down the refrigeration as needed for activities such as loading, inventory or stocking. This reduces unnecessary refrigeration operation while the doors are open.

Supplemental Sensors

Additional sensors were required for this evaluation project to better capture the details of the performance. The additional sensors exceeded the total number of input channels on the gateway so an additional gateway was installed to accommodate the number of inputs.

While all refrigeration units were monitored by the standard configuration of the IBRMCS, supplemental instrumentation was installed on the four largest of the nine total condensing units serving the 5,820 ft^2 cooler of this site. These were C3Z2, C3Z3, C1Z1, and C1Z2.

Two of the four condensing units chosen were the two largest refrigeration systems of the site - C3Z2 and C3Z3. The other two units chosen were C1Z1 and C1Z2. These additional two condensing units were chosen because their location in the facility provided for a good balance to the distribution of all the condensing units serving the entire cooler space, see Figure 9 discussed previously.

SCE Total Building Meter

As part of this evaluation project, the pulse output from the SCE whole building utility meter at this customer site was used to collect totalizing information. The KYZ pulse output of this totalizing meter was sent to the IBRMCS as an input to continually record the total kWh and power demand of the facility. This was done to be able to compare the operation and energy savings of the refrigeration systems to the total consumption of the facility.

Discharge and Suction Pressure Sensors

High and low side pressure sensors were installed on each of the four largest refrigeration units of this site. These pressure sensors were supplemental to the standard sensors of the IBRMCS and required that additional software be written to provide the ability to display the pressure data. Figure 14 shows the discharge and suction pressures of the C3Z2 refrigeration unit. The graphs show the correlation between compressor operation, refrigerant pressures, and evaporator temperature with respect to time. The graph shows a delay in the space temperature reading following the evaporator temperature reading. This shows the amount of time required for the cold air leaving the evaporator to mix with the warm air and circulate back to the location of the space temperature sensor. Detailed performance information such as this can prove invaluable for maintenance and energy efficient operation.

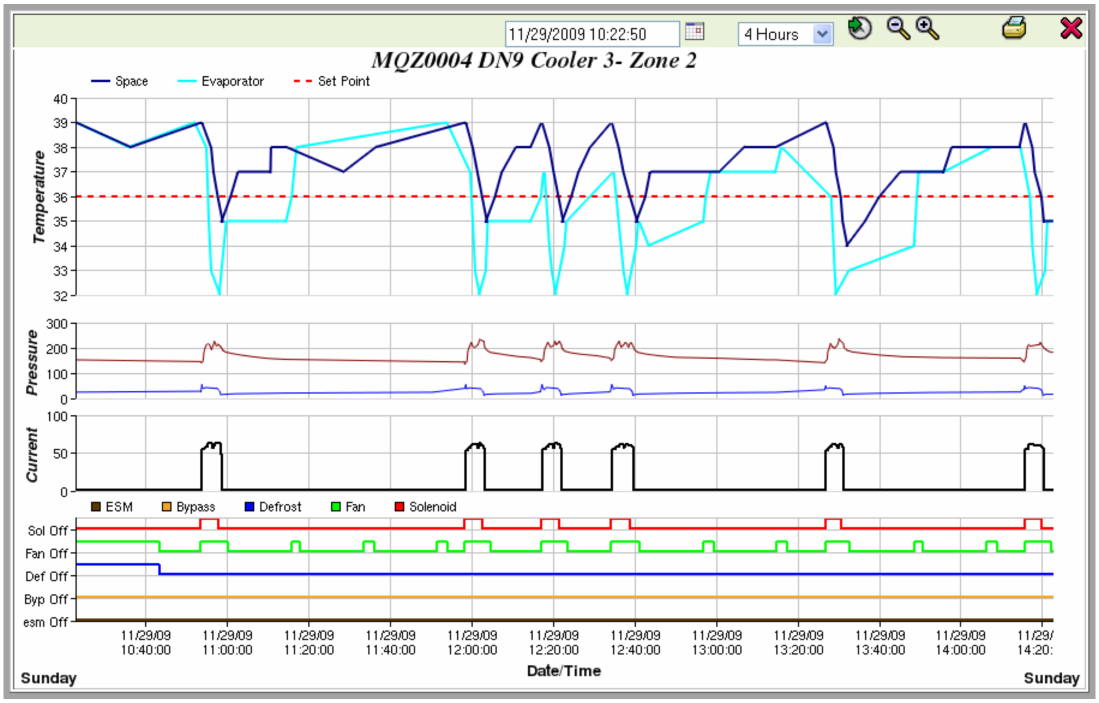


Figure 14 IBRMCS Graph Showing C3Z2 Discharge And Suction Pressures

POWER METERS

Additional power meters were installed on each of the four largest compressor and fan coil units of the nine at the site. These supplemental meters are referenced in Table 2 and Appendix B. The IBRMCS software was supplemented to provide display capability for these additional power meters. This was done to monitor and provide insight into the actual kilowatt-hour consumption and kilowatt demand readings of these large units as compared to the IBRMCS data. Figure 15 below shows, by example, the power usage trends for the C3Z2 refrigeration unit. Note this graph shows both the instantaneous and the 15-minute average demand reading updated every 5 minutes. In general, this type of information may be beneficial to a customer if they choose a demand interval basis for billing and may be useful with demand response programs.

Also, note the correlation of demand in Figure 15 to cooler performance and compressor operation in Figure 14 as they both display the same time period on the horizontal axis.

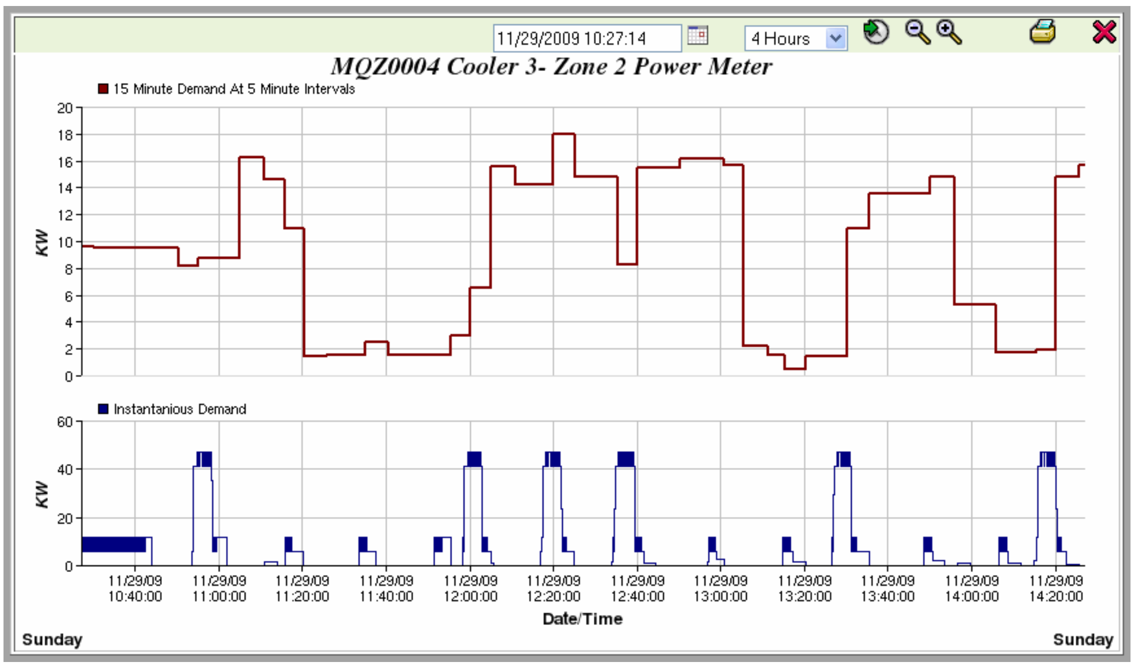


FIGURE 15 IBRMCS GRAPH SHOWING C3Z2 POWER DEMAND

SUPPLEMENTAL TEMPERATURE SENSORS

OUTDOOR AMBIENT AIR TEMPERATURE

The outdoor ambient air temperature was monitored on the roof of the facility near the condensing unit of C3Z2. This location was monitored with a sun-shielded thermistor to minimize false readings due to radiant heating. Only one outdoor ambient air temperature sensor was required.

PRODUCT TEMPERATURES

Several sensors were used throughout the coolers to monitor product temperatures via air temperature at the product locations within the coolers. Each zone of each cooler has the potential of supporting the instrumentation of an extra temperature sensor (3rd temp) to be used as needed. These were used to monitor product temperature and are indicated as the '3rd temperature' on the graphs and trends where they were applied. In zones where they were not needed, the '3rd temperature' shows no reading.

TEMPERATURE AT CHART RECORDERS (HACCP)

In the locations where an existing chart recorder was installed, a temperature sensor reporting back to the IBRMCS was also installed as a way to correlate data between the chart recorder and the IBRMCS. In these instances, the '3rd temperature' sensor of that respective zone was used to monitor the temperature next to the chart recorder. Figure 16 shows a fan coil above a door with strip curtains and an existing chart recorder in the cooler, that is an integral part of the customer's required HACCP plan.

FIGURE 16. HACCP CHART RECORDER

RESULTS

As discussed previously, this project was structured to collect baseline performance data before and after performing maintenance. This was done to eliminate confusion of energy savings due to maintenance versus energy savings due to the IBRMCS technology. To accomplish this, the evaluation sequence steps were conducted as follows:

1. Perform a pre-maintenance baseline,
2. Perform a post-maintenance baseline, and
3. Collect EE measure impact data.

The IBRMCS was therefore, installed and set to Monitor Only or Bypass mode to collect 'as-is' performance data for the pre-maintenance baseline step. This Monitor Only capability of the IBRMCS technology proved indispensable to discovering the elements in need of maintenance as described below.

PRE-MAINTENANCE BASELINE

Several problems were discovered in normal operation mode. Some of the evaporator coils were completely covered in ice as none of the existing refrigeration systems at this site employed defrost clocks. At the time the coolers were built it was thought that off-cycle defrost with the fans running 100% of the time was sufficient to clear the coils. At the penalty of tremendous energy usage, this incorrect assumption allowed ice buildup on several evaporators. These coils could not defrost completely before the compressors cycled on in response to the call for cooling and the problem simply compounded over time. Consequently, this was the basis of some of the first maintenance problems that were discovered.

Fortunately, the bypass feature of the IBRMCS technology allows one, all, or any combination of the refrigeration units to operate in Bypass mode where the refrigeration unit defaults to its original control system. Thus, any operational problem(s) can be isolated to the refrigeration unit without concern of the EE control strategy in the IBRMCS. In Bypass or Monitor Only mode, the operation of the refrigeration units was passively observed and the following problems were discovered.

SHORT-CYCLING COMPRESSORS

A visual walk-through inspection of the site revealed extreme ice buildup on some of the evaporator coils, particularly the evaporators in cooler 1 located above a seldom used service door to the non-refrigerated portion of the warehouse. Door infiltration combined with low evaporator suction temperatures ultimately created a buildup of ice on the coils. Figure 17 shows one of the condensing units of cooler 1 and the corresponding evaporator. Note the remaining ice (outlined in red) after four manual defrosts in attempt to clear the coil.

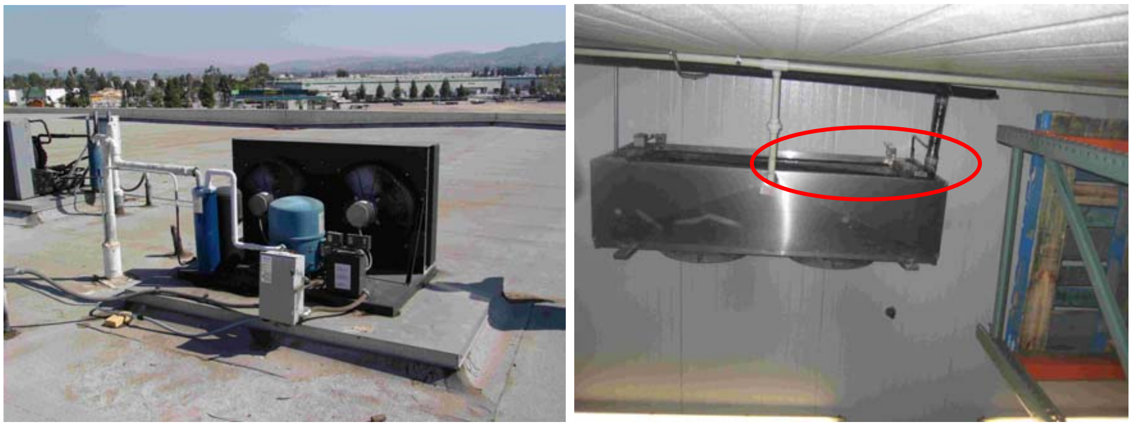


FIGURE 17 CONDENSING UNIT AND ICE ON EVAPORATOR COIL

As expected from the visual confirmation of ice on the coils, Pre-Maintenance Baseline monitoring showed the compressors of C1Z1 and C1Z2 cycling without defrosting. Figure 18 below shows the evaporator temperature of C1Z2 to be below freezing and the current to the compressor cycling continually from the point at which monitoring began when the IBRMCS was first connected. An extremely cold evaporator temperature is an indication of low refrigerant charge. A low charge condition was later confirmed and corrected during maintenance.

Though it was desirable to collect two weeks of data before conducting any maintenance, the IBRMCS controls were switched to control (Run) mode to take this refrigeration unit out of Bypass mode on 9/21/09. This was done as a responsible act to defrost the coil and avoid destroying the compressor as it was at risk of being 'slugged' with liquid refrigerant.

Defrosting the coil required more than 24 hours and several defrost cycles. Note the IBRMCS control signal alternating from bypass to non-bypass and the corresponding evaporator temperatures during those periods (again, Figure 18). After the coil was defrosted, this unit still did not reach the desired cooler setpoint; apparently because the thermostat was set too low.

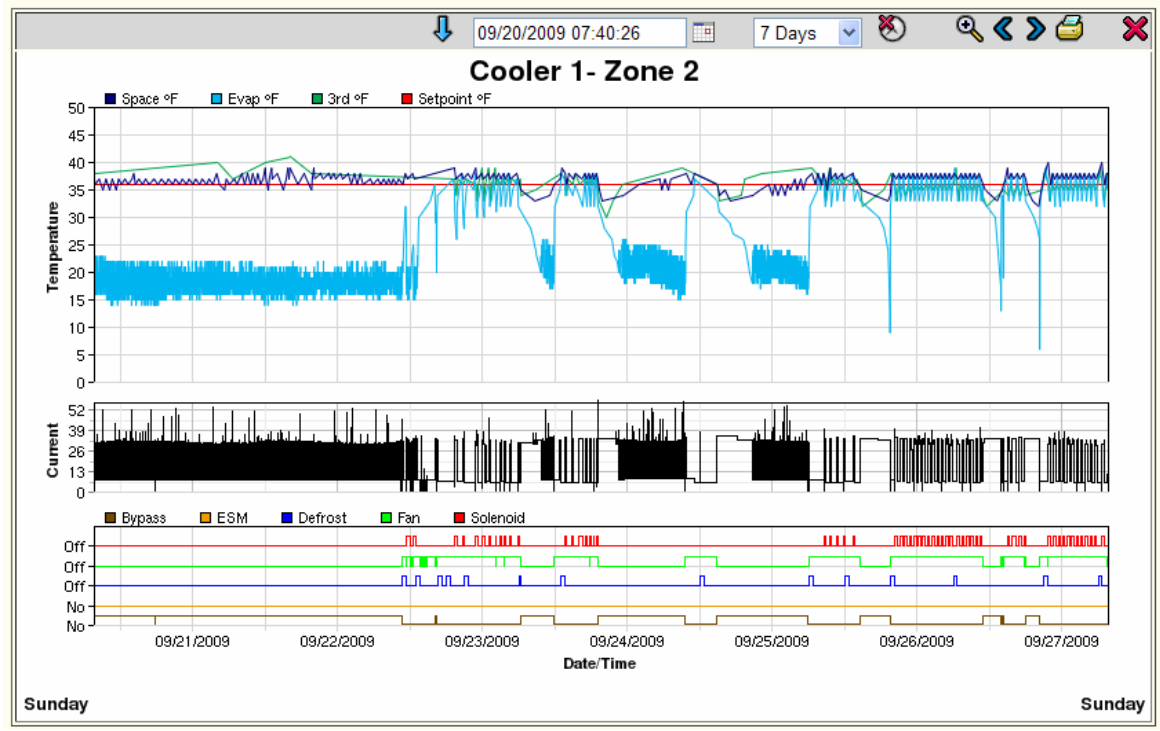
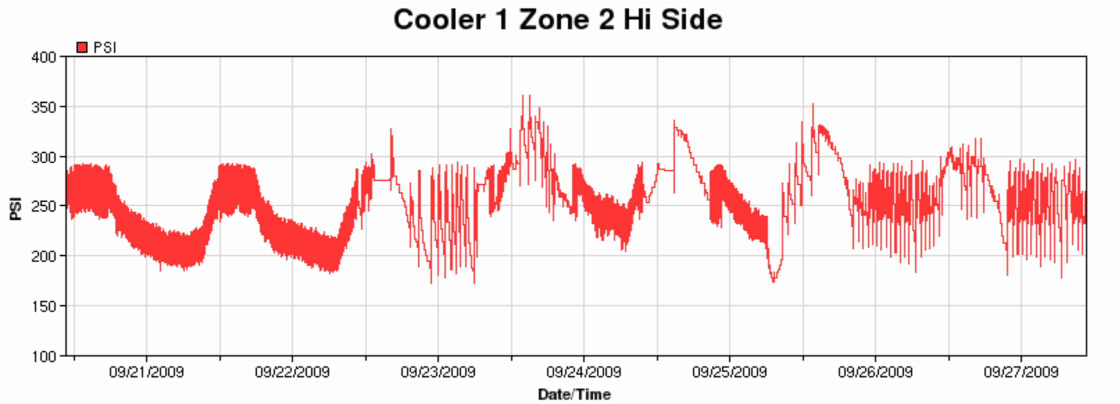
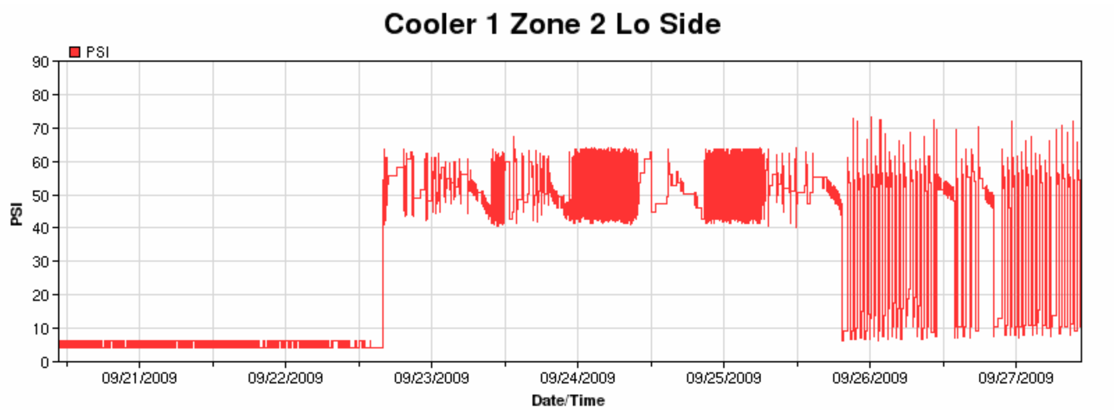


FIGURE 18 C1Z2 PRE-MAINTENANCE & MANUAL DEFROSTS

Figure 19 shows the corresponding refrigerant discharge and suction pressures correlated to the events of Figure 18 above. Note the very low suction pressures when the coil was covered with ice. Also note that after the four defrosts, each time the compressor achieved pump down pressure it would cycle off. Perhaps the pressure controls were used as secondary means to maintain space temperature.



Sunday Sunday



Sunday Sunday

FIGURE 19 C1Z2 PRE-MAINTENANCE DISCHARGE & SUCTION PRESSURES

The power meter readings for C1Z1 and C1Z2 revealed that these two refrigeration units consumed more power after the ice-covered evaporators were defrosted than when they were covered with ice. This makes sense in that the units were not providing significant cooling to the space until air flow across the coils was re-established. While these refrigeration units were ineffectively cycling and consuming energy, the majority of the cooling to the space was no doubt coming from the second refrigeration unit of that cooler and from the other coolers through the interconnected doorways.

This highlights the EE problems that can be encountered with redundant systems in refrigerated warehouses. The space temperature was maintained but significant energy was wasted by the systems that were not providing useful cooling.

Similar to the refrigeration units of cooler 1, cooler 2 also had short cycling compressors with ice buildup on the evaporators. In cooler 2 however, this was due to the traffic through the forklift doors as cooler 2 is the sorting room used to quickly off-load delivery trucks.

Located directly above the vestibule door (refer back to Figure 16), the C2Z1 evaporator is subjected to outside air. This is the only evaporator served by condensing unit number 8 and the short cycling compressor was never able to reach the setpoint even though, as Figure 20 shows, the evaporator temperature was mostly below the setpoint.

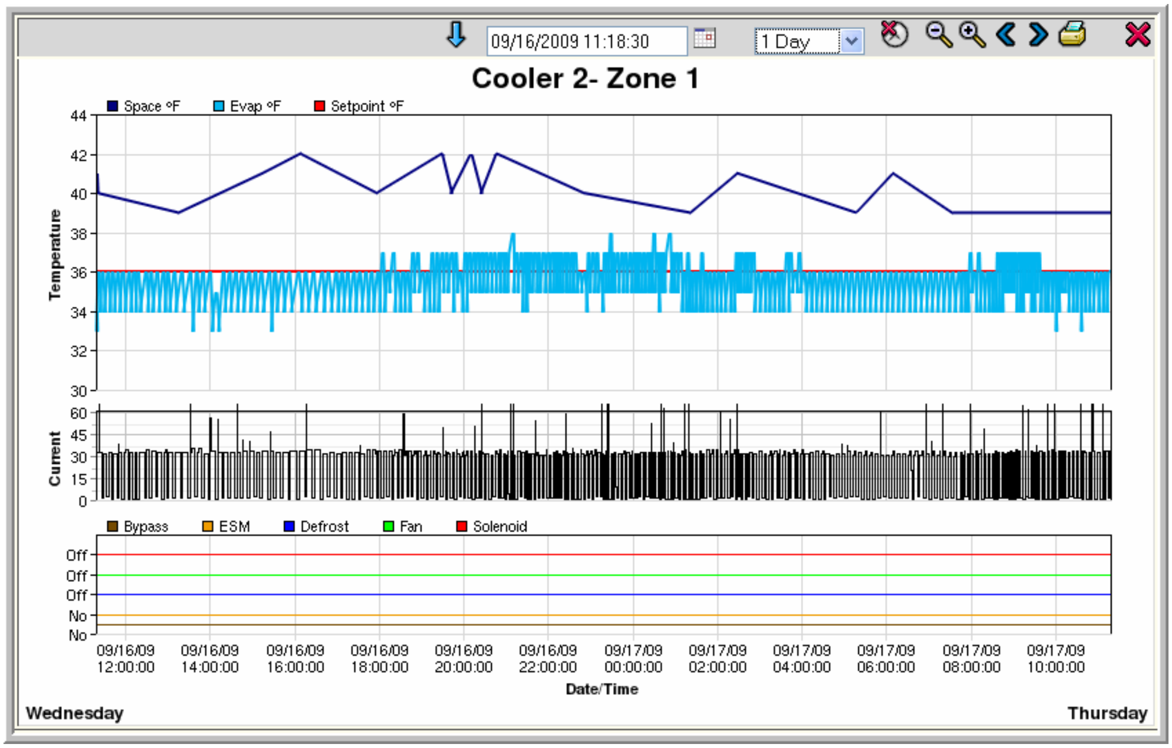


FIGURE 20 C2Z1 EVAPORATOR TEMPERATURE & CYCLING COMPRESSOR

At the opposite end of the sorting room (cooler 2), the compressor for the C2Z2 evaporator was also discovered to be severely short cycling. Figure 21 shows over 2,000 compressor starts per day and the unit was not able to maintain the setpoint temperature of 36°F as shown by the red horizontal line. In this case, the short cycling is suspected to be due to low refrigerant charge. To compound this problem, the line filter was dirty and it thus restricted the flow of refrigerant. This, in turn, starved the evaporator of refrigerant and added to the short cycling problem. Note the operation after changing the liquid line filter and adding proper charge to the system.

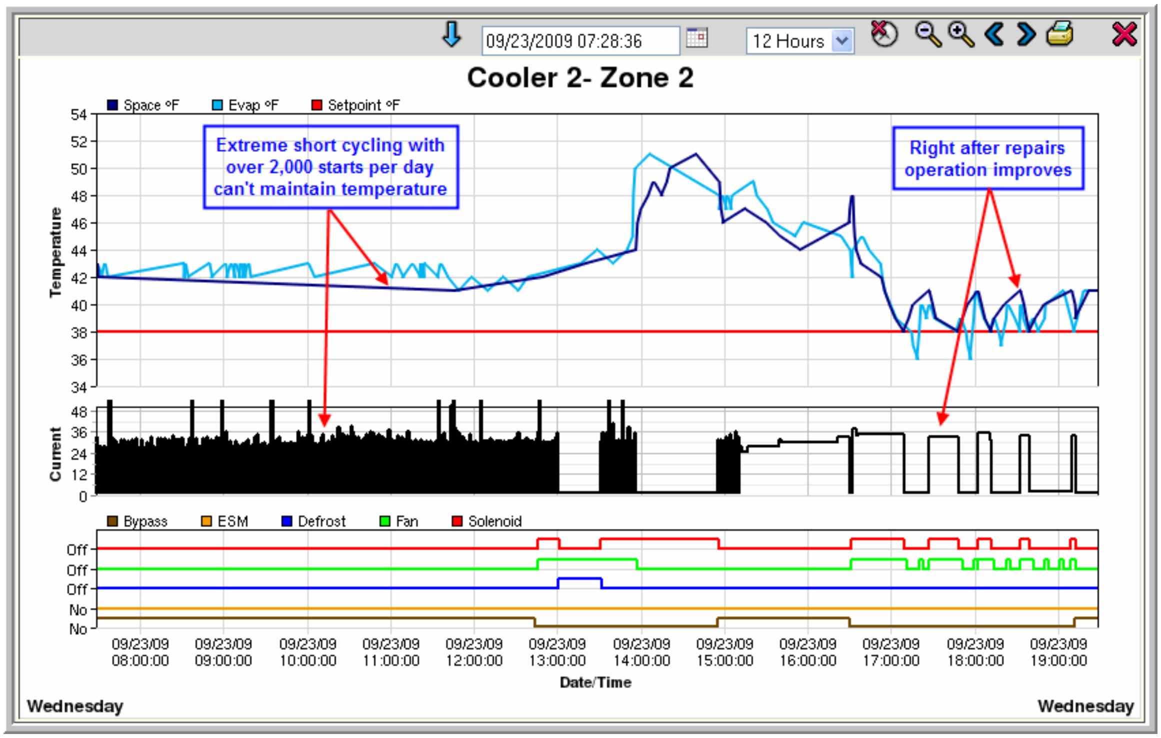


FIGURE 21 C2Z2 EVAPORATOR TEMPERATURE & CYCLING COMPRESSOR

Figure 22 shows the pre-maintenance baseline performance of the freezer in the retail store in Bypass mode (highlighted in yellow) compared to Control mode (not bypassed). The compressor for the walk-in freezer was found to be short cycling in Bypass mode as shown by the black line compressor current graph in Figure 22 below. The short cycling was due to a very tight differential temperature setting and a slightly oversized compressor for this application. Short cycling can eventually harm the compressor. Each compressor start pumps refrigerant oil into the refrigerant lines. During rapid short cycling, the compressor begins pumping oil out of the compressor faster than it can be returned through the suction line. Ultimately, lack of oil within the compressor increases the risk of friction-related damage to the compressor.

Also, notice the high coil temperature during defrosts in Bypass mode compared to the coil temperature during defrost in Control (Run) mode. The number of freezer defrosts went from 4 per day to 1 every two days with the Smart Defrost feature of the IBRMCS technology (explained in a subsequent section).

Note the pink line at the bottom of this graph indicating freezer loading door openings.

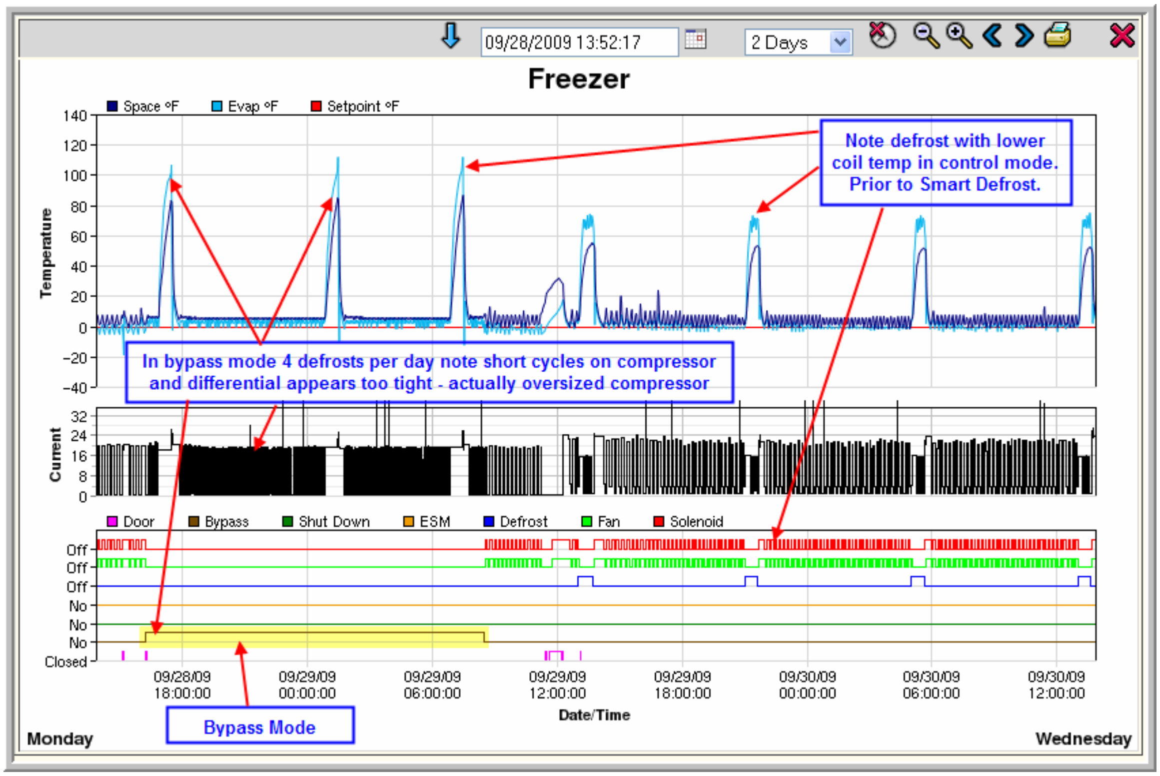


FIGURE 22 RETAIL FREEZER PERFORMANCE PRE-MAINTENANCE

NON-WORKING COMPRESSORS

After the initial maintenance of correcting the short cycling compressor problem on C2Z2, the compressor was discovered to have another problem whereby it did not consistently respond to the call for cooling. Figure 23 shows the compressor mostly OFF over a 3-day period while the average space temperature for that location was operating in an alarm condition above 41°F. While this may not be a problem for the sorting area cooler since products are quickly transferred to the other coolers, unknown space temperatures in other areas could potentially be a problem. Note that these coolers were operating this way for some time. The problematic operation had gradually developed over a period of months or possibly years, without a 'sudden event' that would prompt investigative maintenance. Continuous monitoring of key indicators will result in consistent temperatures and product integrity. Pre-alarm conditions prompt corrective action before serious alarm conditions can develop.

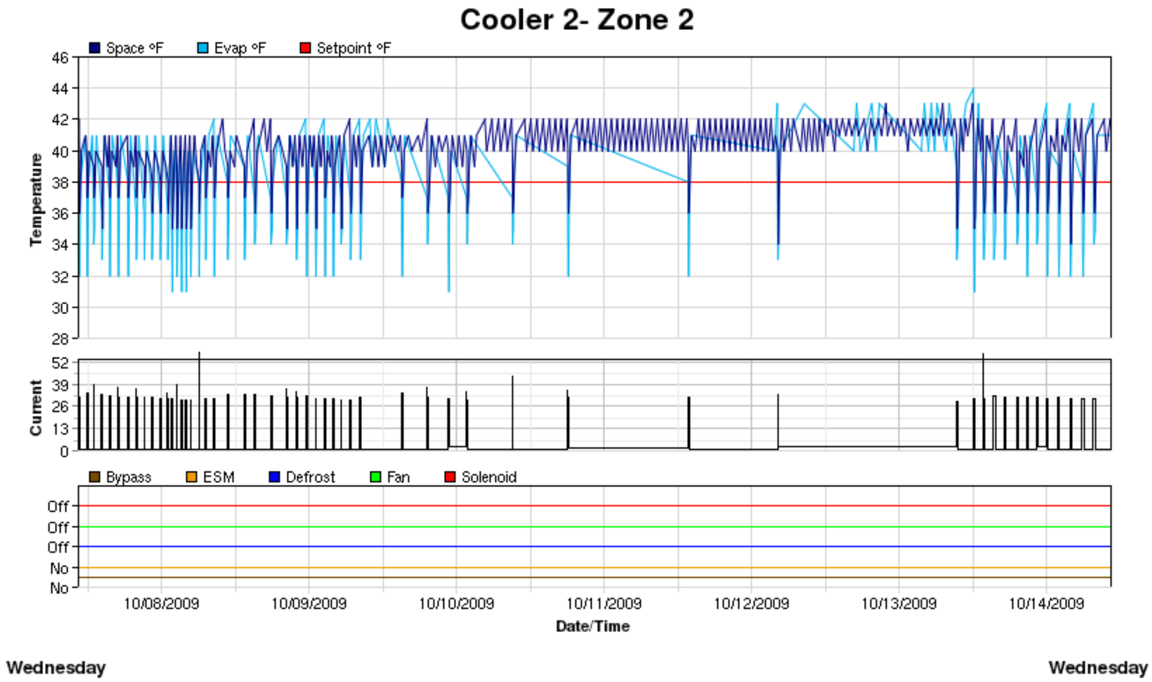


FIGURE 23 C2Z2 IRREGULAR COMPRESSOR PERFORMANCE IN BYPASS MODE

In Control (Run) mode as shown in Figure 24 below, the compressor still did not consistently respond to the call for cooling - note the occurrences where the red graph line of the solenoid activity does not correspond to the compressor current. Also note how the solenoid and compressor current better correlate after a secondary maintenance was performed on 10/19/09. At this point, the system began short cycling again and the cause was this time determined to be a combination of low refrigerant and incorrect pressure control settings. The low refrigerant level caused the compressor to turn off on low suction pressure because the cutoff setting was not set to tune out the unnecessary pump-downs and re-starts.

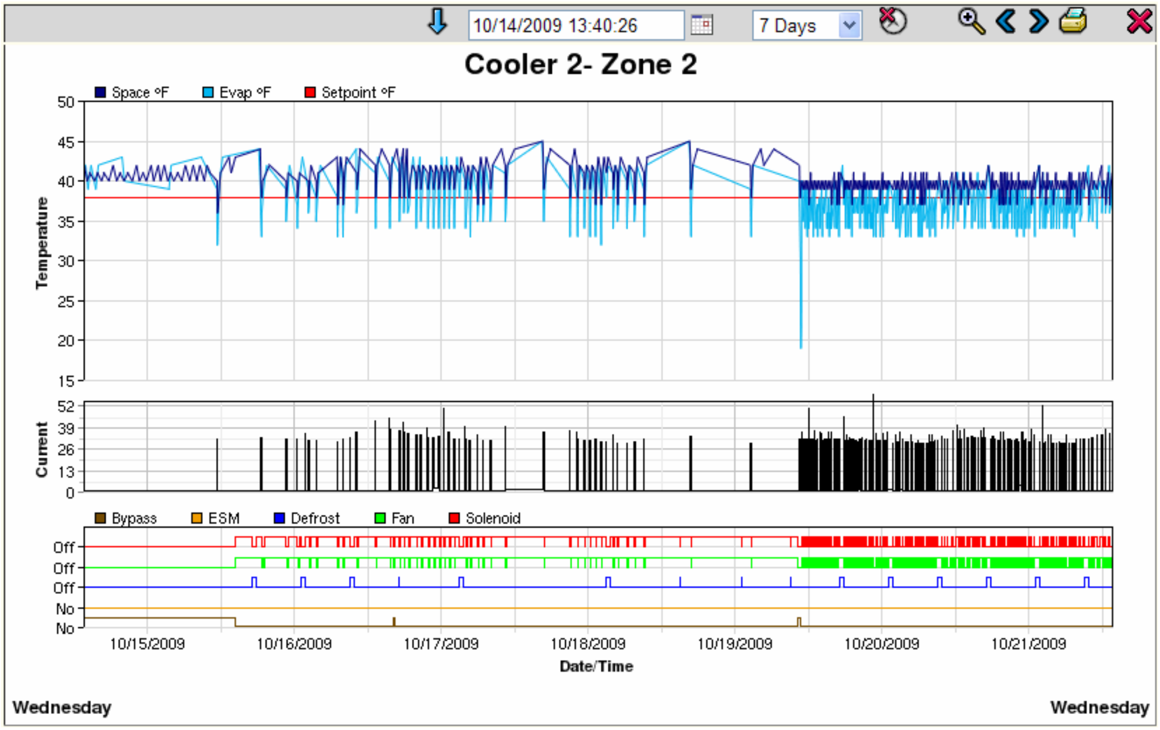


FIGURE 24 C2Z2 COMPRESSOR NOT RESPONDING TO COOLING CALL

Cooler 3 was the largest of all the coolers and was served by three zones. The C3Z1 refrigeration unit served only a single evaporator while the other two zones of cooler 3 were each served by 4 evaporators. Because of this imbalance in the method of conditioning the space along with improper setpoints, the C3Z1 unit rarely turned on as it rarely received a call for cooling (refer back to Figure 9). The two larger refrigeration units of zone 3 were able to satisfy the setpoint in the cooler leaving C3Z1 to run only 0.7% of the time, see Figure 25 below. The evaporator fans of this unit ran 100% of the time, even though the unit rarely provided cooling.

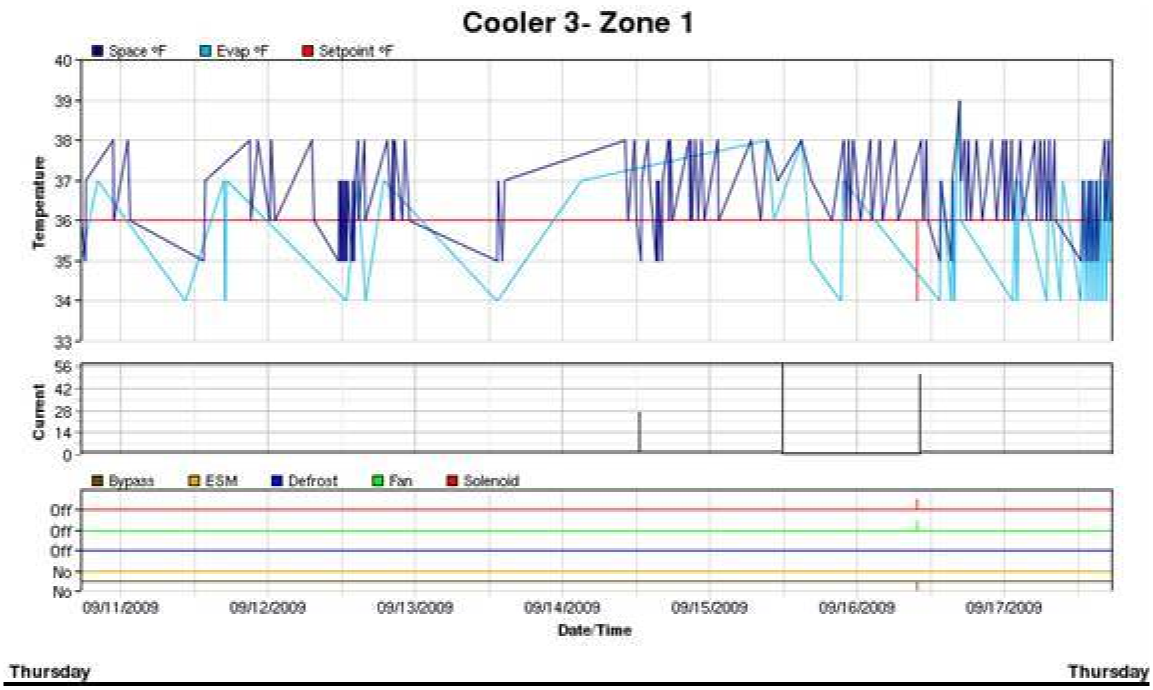


FIGURE 25 C3Z1 COMPRESSOR RARELY TURNING ON

The compressor serving C4Z1 was not running at all. Figure 26 below shows no compressor current before the manual test at around 2:00 PM on 9/23/09. The manual test can be identified where the bypass signal is temporarily removed and the compressor current can be seen to momentarily rise to 39 amps. After the manual test, the IBRMCS was returned to Bypass mode and the compressor again remained OFF until maintenance was performed between 9/28/09 and 9/29/09. After maintenance, the graph shows the compressor operating and the evaporator and space temperatures averaging near the setpoint.

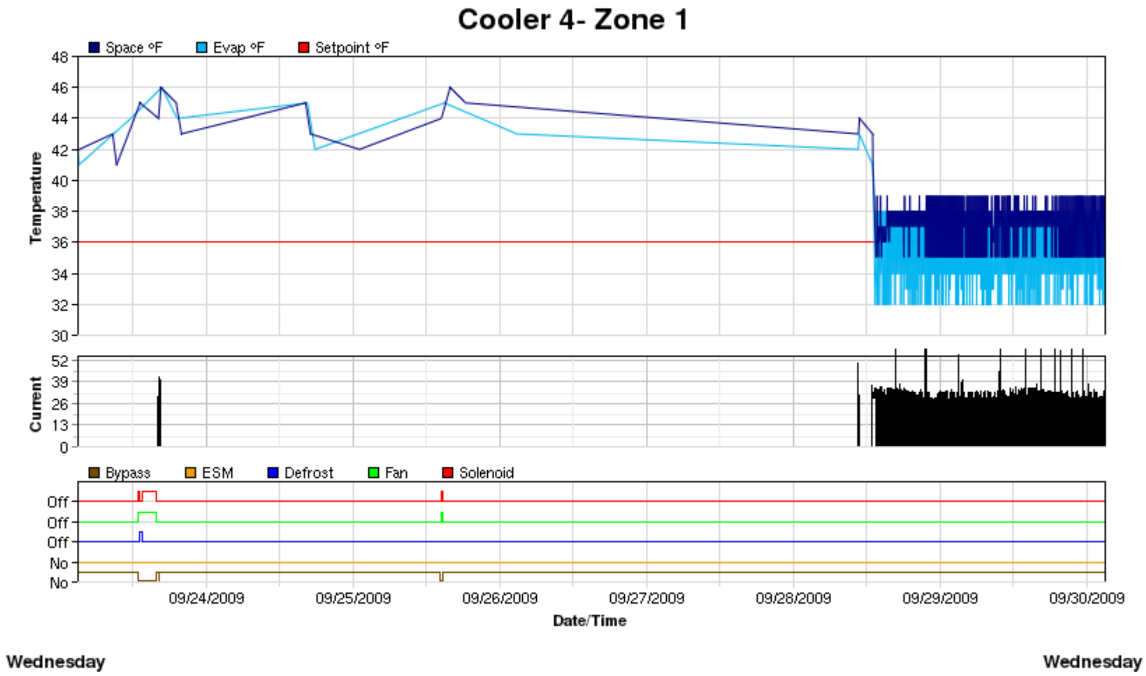


FIGURE 26 C4Z1 COMPRESSOR NOT RUNNING

LOW REFRIGERANT CHARGE

Figure 27 below shows the compressor for the C3Z3 refrigeration unit was short cycling at night and, as a result, the space temperature was not being maintained around the setpoint. Short cycling at night when outdoor temperatures are cooler is an indication that the unit was low on refrigerant. Adding refrigerant to this system reduced the problem of the compressor short cycling at night. While this may not seem to be a significant problem, it should be noted that this and the identical C3Z2 refrigeration unit were the two largest units at this site with each unit serving four large evaporators of three fans per evaporator. Refer to C.U. 6 of Table 4 Elements Monitored, in Appendix A for compressor specifications. When a compressor is short cycling during a call for cooling, it takes much longer to reach setpoint, causing the evaporator fans to run longer. The goal is to achieve setpoint as quickly as possible so the evaporator fan strategies can be employed to save energy.

As a reference, before the required refrigerant was added, the energy consumption for this C3Z3 unit alone between noon on 9/16/09 and noon on 9/17/09 was 417.6 kWh per day. After the low refrigerant charge condition was corrected, the power requirement increased accordingly and the space temperature was maintained. Between noon on 9/17/09 and noon on 9/18/09, the energy consumption was 495.6 kWh per day.

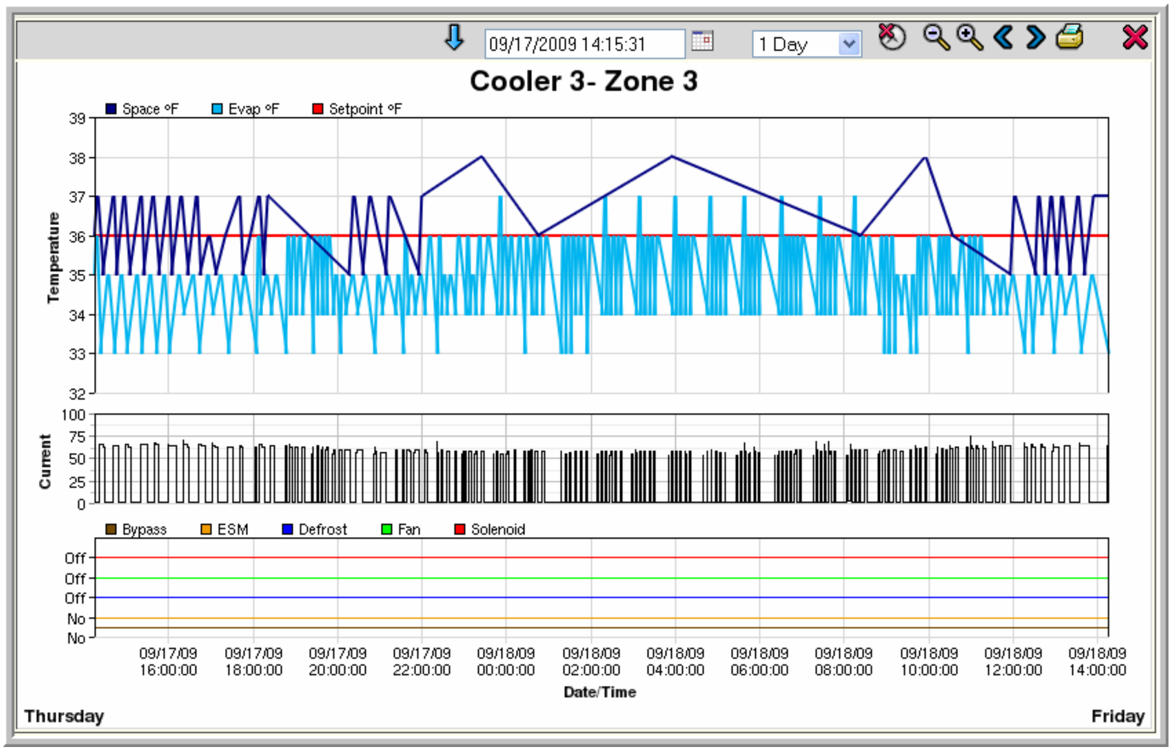


FIGURE 27 C3Z3 SHORT CYCLING AT NIGHT

Figure 28 below shows the drop in temperature at night as recorded from a radiation -shielded temperature sensor located on the roof of the warehouse. Notice the correlation to increased compressor cycling of C3Z3 in Figure 27 with decreasing outdoor nighttime temperatures.

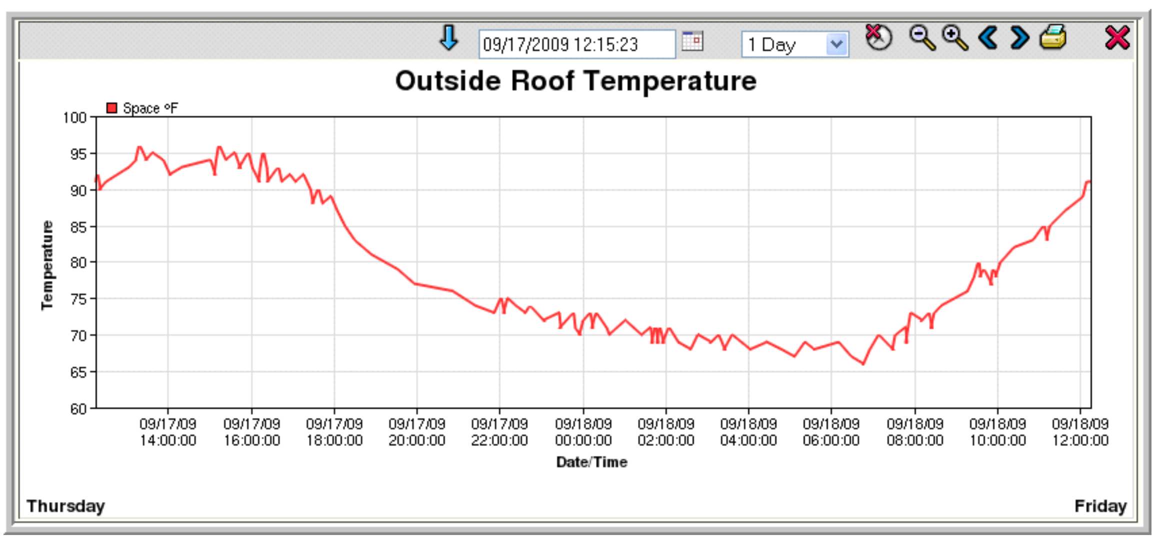


FIGURE 28 OUTSIDE ROOF TEMPERATURE

The following (highlighted) statements are taken directly from the IBRMCS website and copied here as an example to show the difference in energy consumed before and after the adjustment to the refrigerant charge of the C3Z3 unit:

Power meter reading at 12:00:27 PM on September 16, 2009 was 3,194.2 KWH.

Power meter reading at 12:00:02 PM on September 17, 2009 was 3,611.8 KWH.

Power meter reading at 12:00:06 PM on September 18, 2009 was 4,107.4 KWH.

From these statements, the energy usage between 9/16/09 and 9/17/09 can be calculated as the difference in these two readings. The C3Z3 unit consumed therefore, 417.6 kWh per day before the refrigerant charge was corrected.

After the refrigerant charge level was corrected, the C3Z3 unit was more effectively able to produce cooling to the space at an energy consumption of 495.6 kWh per day between 9/17/09 and 9/18/09.

DIRTY REFRIGERANT LINE FILTERS

The monitored suction and discharge pressure sensors indicated restriction in the refrigerant lines typical of dirty line filters. The refrigerant line restrictions were removed and refrigeration performance improved when the filters were replaced.

DIRTY EVAPORATOR AND CONDENSER COILS

Air flow through the evaporator and condenser coils is critical to the heat transfer process. Heat cannot effectively be absorbed by the evaporator nor dissipated by the condenser unless the air pathway is clear. After defrosting all ice-blocked evaporator coils, the condenser coils for all units were cleaned as part of the refrigeration system maintenance procedure.

INCORRECT THERMOSTAT SETPOINT

Figure 29 shows the average space temperature in C3Z2 to be below the thermostat setpoint of 36°F. The C3Z2 unit is the second of the two largest refrigeration units at this site so a setpoint that is lower than necessary is a very large energy usage penalty. Specifically, from the IBRMCS historical data, the energy used by this refrigeration unit alone between noon on 9/17/09 and noon on 9/18/09 was 506.5 kWh per day. The apparent setpoint for the C3Z2 unit was 2-3°F lower than the required 36°F needed to maintain the quality of the cheese products that cannot be frozen.

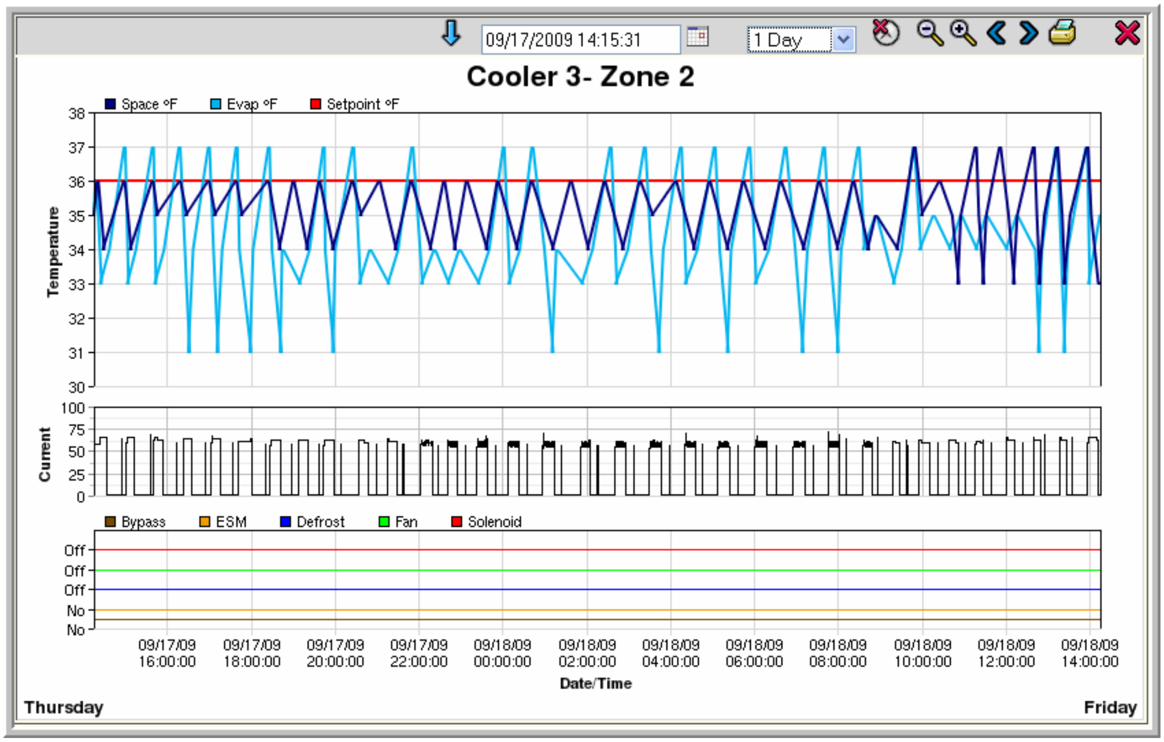


FIGURE 29 C3Z2 INCORRECT THERMOSTATIC SETPOINT

POST-MAINTENANCE BASELINE

The purpose of the post-maintenance baseline step is to eliminate confusion regarding energy savings due to the IBRMCS technology versus energy savings due to maintenance. When evaluating promising new technologies, the true performance of the technology can be masked in the energy savings attained through performing overdue maintenance. Based on this premise, the post-maintenance baseline step is identified to capture and isolate any energy savings attained through maintenance-only events.

SAVINGS FROM MAINTENANCE

Table 5 in Appendix A shows the energy consumption of the four largest refrigeration units as well as the SCE site meter data. All readings are cumulative so energy consumed over a given period is calculated as the difference in the readings between two dates. Initial monitoring for these cooler zones began on the evening of 9/9/09 and the SCE power meter began reading data on 9/21/09. The pre-maintenance energy consumption of these coolers was averaged over a 14-day period beginning 9/10/09 then compared to the 14-day average energy consumption after maintenance was performed. The differences in average daily energy consumption shown in the table are captured as the result of maintenance only.

The energy consumption measured by the SCE power meter was averaged over only 2 days for the pre-maintenance period instead of 14-days as were the individual coolers. All post-maintenance data, however, was averaged over the 14-day period beginning 9/28/09.

Note the increase in the average daily energy consumption of C3Z3 after the refrigerant charge was corrected. This is consistent with expectations as the unit was better able to provide cooling to the space with the proper refrigerant charge. The net reduction in energy usage over all the refrigeration units confirms this expectation. Refer to Table 5.

ENERGY EFFICIENCY MEASURE IMPACT

Several strategies were employed to achieve energy savings with the IBRMCS technology in Control (Run) mode as outlined below. These are the strategies implemented with the IBRMCS technology. The results from these strategies are compared to the post-maintenance baseline performance data.

SAVINGS FROM MEASURE:

ALTERNATING RUN TIMES

The scheduling software within the gateway serving cooler 1 was used to make periodic changes in the differential space temperature and differential evaporator temperature settings of the controllers for Zone 1 and Zone 2. This was done in order to achieve more even compressor run times between the two refrigeration units for this cooler. For example, using the scheduler, the differential space temperature setting alternated every 3 hours between 2°F and 4°F so that Zone 1 was at a 2°F space temperature differential while Zone 2 was at 4°F differential. Then, every three hours, they are switched. This was done primarily to ensure even run times to both cooler zones and results in a more even average cooler temperature. It also ensures even wear to both refrigeration units thus saving on equipment costs. Notice the differentials of Zone 1 in Figure 30 are opposite to the differentials of Zone 2 in Figure 31 below.

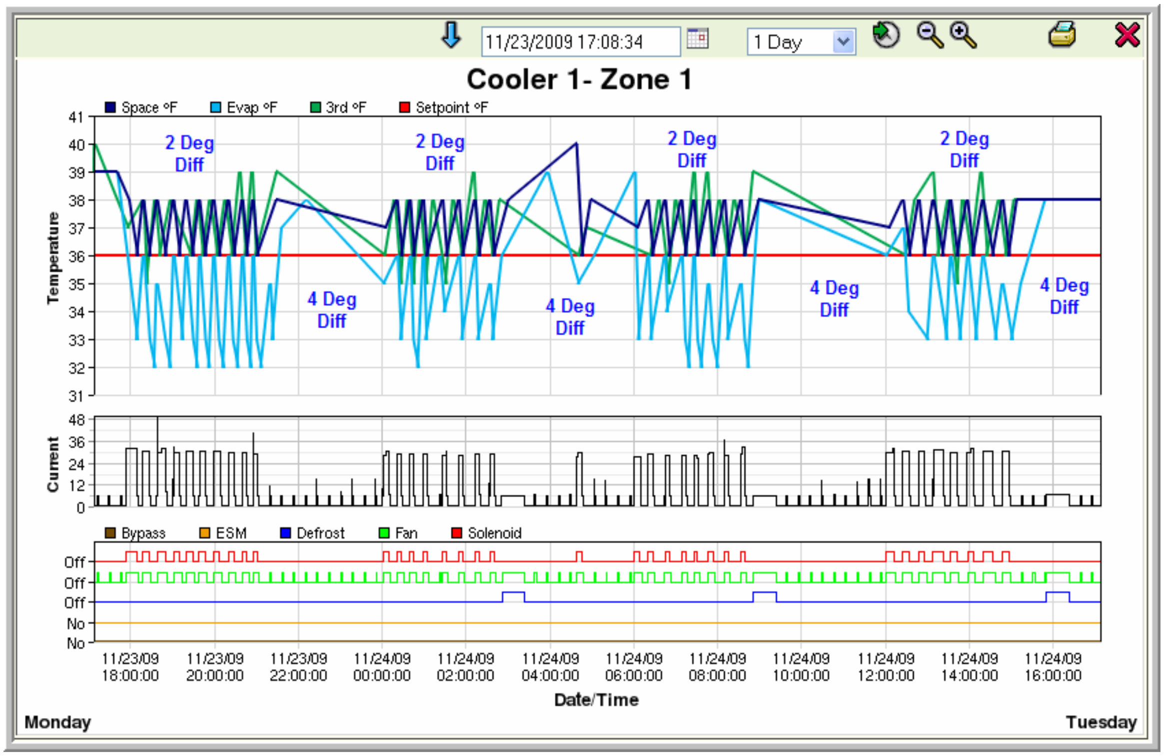


FIGURE 30 C1Z1 SPACE TEMPERATURE AND EVAPORATOR TEMPERATURE DIFFERENTIALS

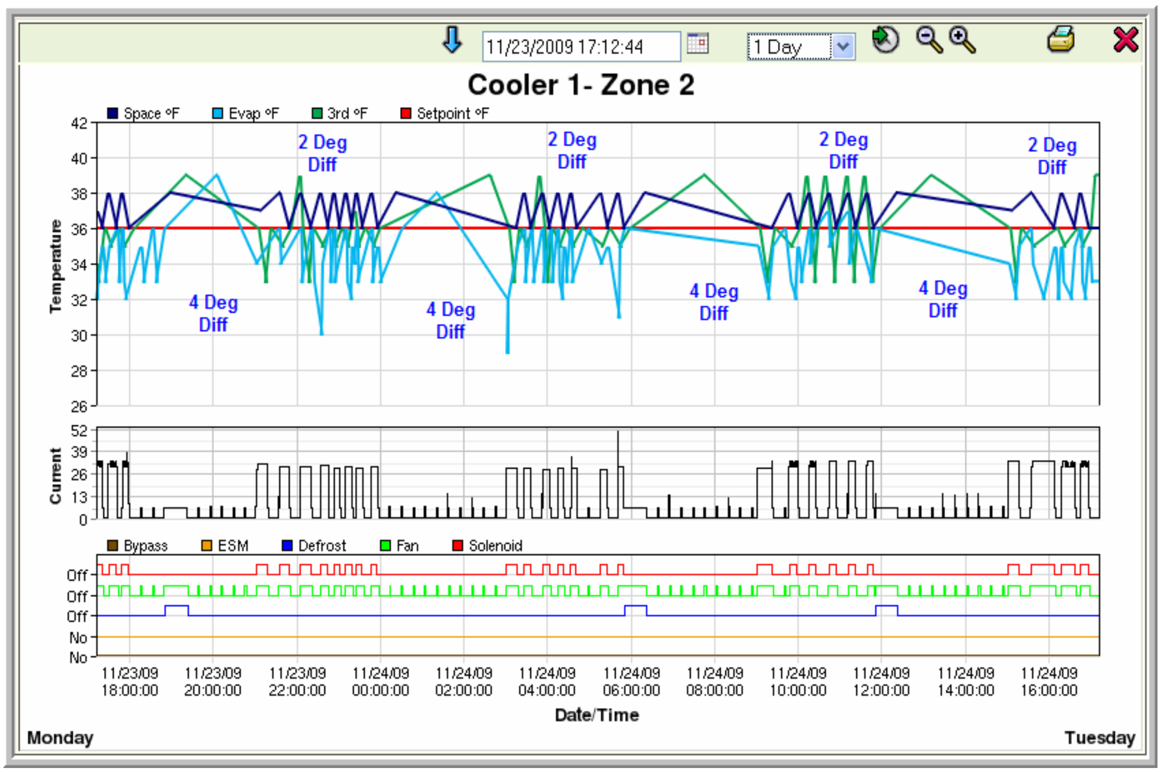


FIGURE 31 C1Z2 SPACE TEMPERATURE AND EVAPORATOR TEMPERATURE DIFFERENTIALS

Less Frequent Compressor Cycling

Figure 24, discussed previously, shows C2Z2 taken out of bypass mode on 10/15/09 at 2:23 pm at the end of post-maintenance baseline. Adjustments were made in Control (Run) mode with the IBRMCS beginning shortly after midnight of 10/19/09.

The adjustments were refined on 10/21/09 after about 2:00 pm when the compressor began cycling less frequently and the evaporator temperature began to average around the setpoint temperature.

Less Overall Compressor Run Time

Table 7 in Appendix A shows every compressor at this site reduced overall run time with the exception of the one small unit (C3Z1) that only provided cooling 0.7% of the time. This is an average reduction in compressor run time of 26.7% and is a direct impact toward the overall energy savings related to this IBRMCS technology.

Correct Setpoint Temperature

The setpoint temperature of C3Z2 was corrected from 35°F to 36°F. This reduced the compressor run time while maintaining product temperature. The energy wasted in association with over-cooling the space is disproportional to the benefit of the lower storage temperature.

ECM Evaporator Fans save Energy

Electronically commutated motors consume 65% less energy than the shaded pole (SP) motors that are typically used in evaporator fans. The fan motors of the freezer and coolers in the retail store were replaced with ECMs. The evaporator fan motors in the remaining coolers were not changed as the 460 Vac version of the ECM for these fans was not yet available.

Reduced Evaporator Fan Run Time

Prior to implementing the IBRMCS technology at this site, the existing SP evaporator fans ran 100% of the time. Using the IBRMCS in Control mode, the operation of the fans was reduced by an average of 57.4%. See Figure 32 below.

Marquez Brothers City of Ind. 1
15480 Valley Blvd, City Of Industry CA 91746
Tel: (626) 330-3310

Ontario Intl Arpt, CA
Last Updated on Nov 6 2009, 1:53 pm PST - Fair
Temperature 71°F, Humidity 44%, Dewpoint 48°F

Log Out: emrejs5
Help

Note fan run time that used to be 100%

NRM Mini CoolTrol			Temperature °F					Status					Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	3rd	SP	24hr	Mode	Dfrst	Sol	Fan	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Cooler 1- Zone 1	_		36	33	36	36	37.8	Run	Off	Off	On	6.4	39	39	72	27.1	27.7	44.5	20.9	21.6	38.8
Cooler 1- Zone 2	_		37	32	36	36	37.6	Run	Off	On	On	33.2	29	29	66	27.5	28.4	44	23.4	24.2	40.1
Cooler 2- Zone 1	_		40	37		38	39.5	Run	Off	Off	On	1.2	42	42	73	15.5	17.8	35.7	15	17.4	35.2
Cooler 2- Zone 2	_		40	36		38	39.4	Run	Off	On	On	33.5	70	70	72	24.3	16.7	44.7	18	14.5	38.9

Marquez Brothers City of Ind. 2
15480 Valley Blvd, City Of Industry CA 91746
Tel: (626) 330-3310

Ontario Intl Arpt, CA
Last Updated on Nov 6 2009, 1:53 pm PST - Fair
Temperature 71°F, Humidity 44%, Dewpoint 48°F

Log Out: em
Help

Fans used to run 100%

NRM Mini CoolTrol			Temperature °F				Status					Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	SP	24hr	Mode	Dfrst	Sol	Fan	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Cooler 3- Zone 1	_		38	37	36	37.6	Run	Off	Off	On	1.4	51	0	80	24.4	0	42.2	20.5	6.8	39.1
Cooler 3- Zone 2	_		36	33	36	37.3	Run	Off	Off	Off	1	0	0	0	0	0	100	8.5	5.8	48.3
Cooler 3- Zone 3	_		36	33	36	37.6	Run	Off	Off	Off	1	19	0	75	8.7	100	41.6	15.9	46.9	38.5
Cooler 4- Zone 1	_		35	34	36	37.2	Run	Off	Off	Off	0	71	0	101	14.7	0	38.9	14.1	5.6	38.4
Cooler 4- Zone 2	_		36	36	36	37.5	Run	Off	Off	Off	0	67	0	111	15.8	0	42.8	14.5	4.7	41.1

FIGURE 32 SUMMARY TABLES SHOWING COOLER FAN RUN TIMES

EVAPORATOR FAN DELAYED START

Installing the IBRMCS provided the option to control the evaporator fans where they had previously operated 100% of the time. The IBRMCS control mode also provides more detailed information on how the refrigeration systems respond to the control system. It is now known when a call for cooling is initiated and how long it takes the compressor to respond.

Note in Figure 33 below, the fans always turn on with a call for cooling but since the compressor is controlled by pressure, there is sometimes a delay before the compressor turns on. This delayed compressor start causes evaporator fans to operate longer and introduce heat into the space.

Normally, the compressor turns on within a few seconds of a call for cooling. The call for cooling opens the liquid line solenoid valve, causing an immediate change in suction pressure that triggers the compressor's pressure control switch to turn on the compressor. See the yellow highlighted portions of Figure 33 below.

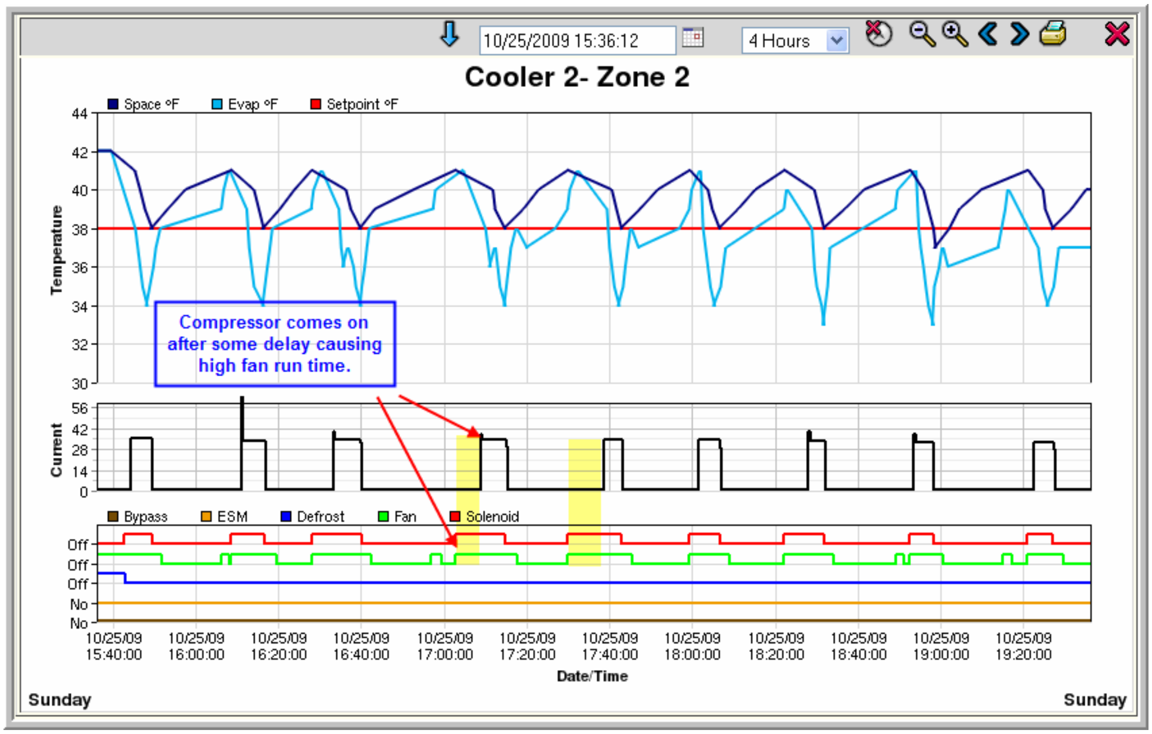


FIGURE 33 C2Z2 FANS VERSUS COMPRESSOR STARTS

After the IBRMCS system indicated this problem, the service contractor set the pressure control to a lower pressure which resolved the problem. The resulting fan run times can be seen highlighted in the Figure 34 summary table below.

Marquez Brothers City of Ind. 1
15480 Valley Blvd, City Of Industry CA 91746
Tel: (626) 330-3310

Ontario Intl Arpt, CA
Last Updated on Oct 26 2009, 7:53 am PDT - A Few Clouds
Temperature 65°F, Humidity 24%, Dewpoint 27°F

Log Out: emrejs5
Help

NRM Mini CoolTrol			Temperature °F					Status					Starts 24 Hr.			% Run 24 Hr.			% Run 7 Days		
Description	Content	Status	Space	Evap	3rd	SP	24hr	Mode	Dfrst	Sol	Fan	Amps	Sol	Comp	Fan	Sol	Comp	Fan	Sol	Comp	Fan
Cooler 1- Zone 1	_		36	36	37	36	37.5	Run	On	Off	On	6.4	30	49	75	19.4	20.2	37.1	26	26.8	43.2
Cooler 1- Zone 2	_		38	38	39	36	37.6	Run	Off	Off	Off	0.8	21	39	68	22.2	23.1	38.8	27	27.8	43.1
Cooler 2- Zone 1	_		38	32		38	39.5	Run	Off	Off	On	1.1	37	38	79	13	13.2	30.9	16.5	16	36
Cooler 2- Zone 2	_		40	39		38	39.6	Run	Off	Off	Off	1.2	50	50	75	27.2	15.1	45.1	29.4	17.1	47.9

FIGURE 34 FAN RUN TIME SUMMARY TABLE

EVAPORATOR FAN DELAYED SHUT OFF

When the call for cooling is satisfied and the compressor turns off, there is still residual cooling available since there is always some refrigerant left in the coil and from the thermal mass of the evaporator. By controlling the evaporator fans with the IBRMCS to remain ON for up to 255 seconds after the compressor has turned OFF, the residual cooling in the evaporator can be harvested and put into the space. In this way only the energy required to operate the fans is required to take advantage of the remaining cooling energy in the coil after the compressor turns off.

Evaporator Defrost Controls

The IBRMCS allows for defrost control to prevent ice buildup on the evaporators where no defrost control other than off-cycle previously existed. Additionally, if frost or ice buildup became an issue, the IBRMCS server would identify the problem and send an alarm message to the appropriate user.

Destratification fans

The destratification fans, described previously, operate 100% of the time to continually circulate the air to thermally equalize the space temperature between the floor and the ceiling. The 18 units consume only 30-35 watts each at the benefit of better mixing within the space, longer compressor off times, and longer evaporator fan off times.

Freezer electric defrost

The retail freezer was the only refrigeration unit to have an electric defrost mechanism. As previously shown in Figure 22, defrosts were occurring four times per day with the IBRMCS in Bypass mode. The IBRMCS offers three options for controlled defrost: Scheduled defrost with real-time clock, interval defrost or Smart Defrost.

Using the Smart Defrost algorithm of the IBRMCS in Control mode, the unit was able to maintain setpoint temperature with only one defrost cycle every two days. See Figure 35 below.

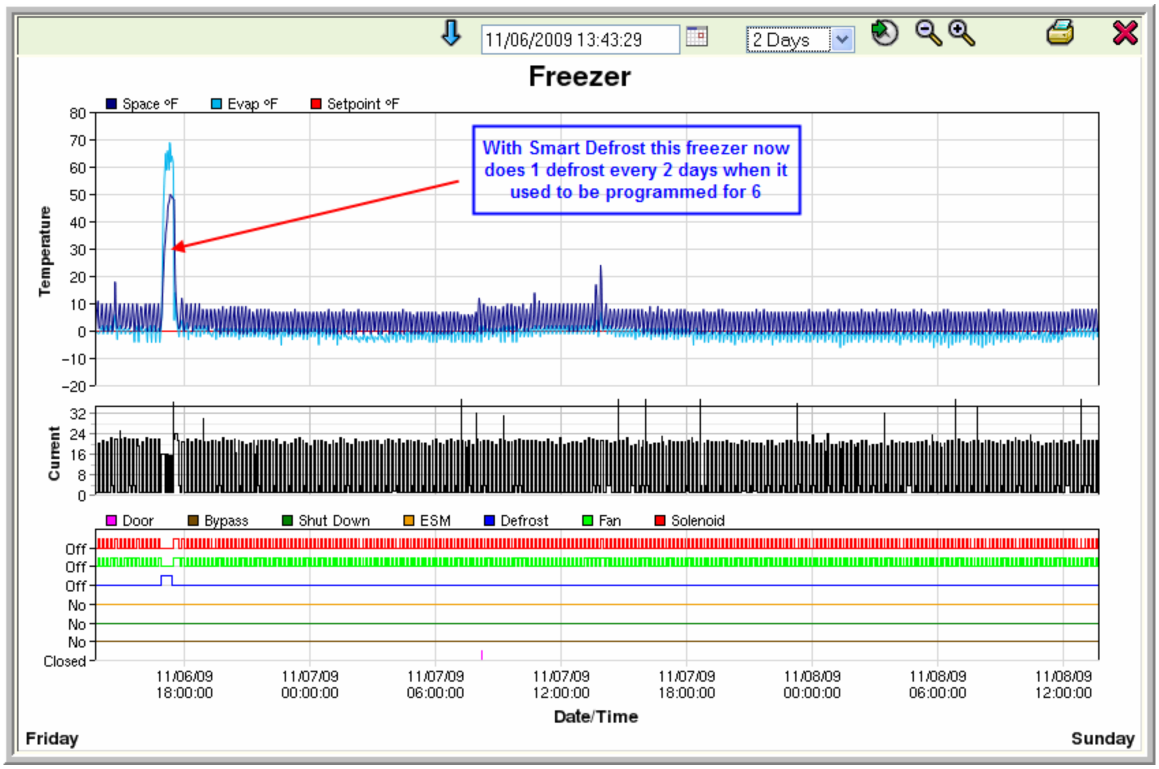


FIGURE 35 FREEZER DEFROST WITH CONTROL IMPLEMENTED

ANTI-SWEAT HEATER CONTROLS

The glass doors of the freezer and coolers in the retail store were equipped with anti-sweat heaters that operated at 100% power. The humidity sensor of the controller installed in the store was used to monitor both dry bulb temperature and dew point temperature. The input from this sensor was used to determine the best operation of the anti-sweat door heaters. The results are shown in Figure 36 below.

Note the summary table at the top of Figure 36 that indicates the heaters for the freezer doors operating 48.4% of the time and those of the cooler doors operating 12% of the time where each of these had previously been operating 100% of the time. The actual savings values from controlling the anti-sweat heaters are greater than the savings values projected at the beginning of the project.

Additionally, the savings attributable to the anti-sweat door heaters are not included in the overall calculations of energy consumption for this project.

FIGURE 36 ANTI-SWEAT DOOR HEATERS

The results achieved from the refrigeration units in this project during the post-maintenance test comparison are detailed in Table 6 and Table 7 of Appendix A.

Table 6 of Appendix A shows the results from the power measurements recorded on the largest compressor and evaporator fan units along with the main SCE pulse meter data.

Table 7 of Appendix A shows the results from the actual power measurements recorded on all compressors and evaporator fan units as well as the averages for each listed parameter.

The two weeks of post-maintenance baseline data is the same time period in both Table 6 and Table 7. Likewise, the two weeks of measure data is the same time period in both Table 6 and Table 7.

The important highlights of this data are that the average compressor run time was reduced by 26.7% and the average evaporator fan run time was reduced by 57.4%. These reductions were achieved while maintaining the average space temperatures 0.9°F lower than the previous settings while consuming less energy.

CONCLUSIONS

The results of this technology evaluation are compelling. Table 3 below shows the annualized energy consumption of the four largest refrigeration units at this site based on the 14-day measurement period comparing post-maintenance operation to IBRMCS controlled operation. If the two week measured energy consumption data recorded by the supplemental SCE power meter installed for this project can be projected over one year, the estimate of energy savings would be in the range of 250,000 kWh for this site alone.

This is in addition to the savings attained by performing any needed maintenance. Maintenance is often neglected as equipment owners and operators have no visibility into the current or historical performance of the equipment. With implementation of this technology however, owners and operators have the ability to perform continuous commissioning. This technology provides visibility into equipment performance that is directly correlated to energy consumption.

TABLE 3 14-DAY MEASURED ENERGY CONSUMPTION ANNUALIZED SAVINGS

Coolers	14-day Savings (kWh)	Annualized Savings (kWh)	Savings at $0.14 /kWh
Cooler 1 Z1	975.6	25,366	$3,551
Cooler 1 Z2	525.3	13,658	$1,912
Cooler 3 Z2	1,799.7	46,792	$6,551
Cooler 3 Z3	4,243.1	110,321	$15,445
SCE Power Meter	9,580.4	249,090	$34,873

Table 7 of Appendix A shows the energy savings due to the reduction in compressor and evaporator fan run times for each refrigeration unit at this site. The average compressor run time was reduced 26.7% and the average evaporator fan run time was reduced 57.4% while the average temperature in the refrigerated space was reduced 0.9°F. The information in Table 7 confirms that the energy savings opportunity in the cold storage and refrigerated warehouse market segment is compelling and should be targeted for future energy efficiency programs.

The benefits of the IBRMCS go beyond the measured energy savings achieved by implementing this technology. Some of the long-term benefits are:

- Less energy consumed translates into a lower overall electricity bill for the customer.
- The IBRMCS technology allows more precise control of refrigeration equipment than was previously possible with the added benefit of historical trend data to be able to make intelligent adjustments to equipment operation going forward.
- The IBRMCS adds a layer of reliability upon which end users can depend. These end users will then continue to use and maintain the system resulting in persistence of savings.
- There is also the benefit of discrete control of the refrigeration components. Evaporator fans that previously ran 100% of the time can now be strategically controlled to optimize cooling and minimize the amount of heat introduced into the refrigerated space.

- The IBRMCS technology provides the benefit of continuous commissioning of the refrigeration equipment based on real-time and historical performance. Problems can be identified as soon as data begins to trend away from normal operation.
- The IBRMCS can be put into Bypass mode for simplicity of maintenance if necessary or it can even be used as a diagnostic tool to help resolve maintenance problems.
- The method in which the data is recorded as change of value provides the benefit of a true weighted average compared to a time interval data method. This implies a higher resolution of data, i.e., a more true trend.
- The user interface is simple and intuitive to use. It is easy to navigate and the web pages load quickly because only a picture of the requested data is transmitted – not the actual data file.
- The web server was shown to present operational data in easy to understand statistical and graphical format.
- SCE moves toward achieving company energy savings performance goals.
- SCE reaffirms the company position as the customer's trusted energy advisor.

Since installation of this project, this customer has authorized installation of identical systems in their Phoenix, Las Vegas, Fresno and Sacramento facilities. From their corporate offices in San Jose, CA they are able to use the system to view and manage performance of their important refrigeration equipment as well as monitor the perishable products being stored.

The primary results of this evaluation project are that small to medium sized cold storage facilities and refrigerated warehouses offer significant, predictable energy savings and that the opportunity for energy savings in such facilities can be a tremendous asset to SCE's EE programs.

RECOMMENDATIONS

This technology has been implemented in a few hundred locations throughout the United States with documented energy savings success. Recently, this technology has become popular in the southwestern U.S. due to the large need for cold food storage in a warm climate region of increasing population. There are certainly hundreds more application opportunities in these regions.

Based on the results of this evaluation project, it is highly recommended that this technology be considered for inclusion in SCE's EE incentive programs. Some of the criteria that require careful consideration in creating a program for this type of technology are:

- Customers are generally very cautious when making decisions that affect their refrigeration equipment. This could be due to the value of the products stored, lack of understanding about refrigeration equipment, or simply that they tend to be risk-averse about making changes to procedures and processes they have had in place for years or even decades.
- Existing energy management systems for cold storage units are minimal systems at best. More often, they are simply non-existent (as was the site chosen in this project). So, implementing a control system with an EE strategy such as this is highly recommended.
- Through training, practice, and experience, technicians can develop greater confidence and skill in operating and managing refrigeration equipment.
- Customers are usually doubtful of the savings that can be achieved as they feel like they would have done it years ago if the new strategies could actually produce the projected results. Good references and results from this report should help ease those concerns.
- An advantage of the IBRMCS technology is the ability to view how systems are operating in Bypass mode prior to making changes to the system. This Monitor-Only mode can also be used to diagnose issues that were not previously apparent without the IBRMCS technology.
- Actual energy savings results can vary somewhat, depending on the condition of the equipment. However, projected savings are realistic in that most refrigeration systems are oversized for worst case load conditions.
- Proven technologies sponsored by utility programs and incentives help add credibility when customers may have reservations.
- The IBRMCS system provides visibility into equipment performance and repair results that customers and technicians can view simultaneously.
- Having real-time access to data and the means to measure and view performance eventually leads to a sophisticated level of control that makes the end user a better manager of the energy consumed by the refrigeration system.
- The results achieved in other similar facilities can be readily verified and the previous measured data presented to SCE, if requested.

It is also recommended to provide education and training about this technology to end users, contractors and refrigeration technicians. This training will encourage use of the technology rather than turning it off or defeating its operation simply because it is not understood. When users understand the technology, they quickly realize how it can help them in their own tasks and the energy savings benefit is realized by all.

APPENDIX A

TABLE 4 ELEMENTS MONITORED

Element	Quantity	Rated Parameters
CU 1		
Comp	1	460V/3Φ /29.0 RLA
Cond Fan	2	460V 3Φ 3/4 HP 2.4 FLA
Disch Press	1	500 psig
Suct Press	1	250 psig
Evap Fan	4	460V/1Φ 1/2 HP 1.7FLA
Liquid Line Solenoid	2	-
CU 2		
Comp	1	460V/3Φ /29.0 RLA
Cond Fan	2	460V 3Φ 3/4 HP 2.4 FLA
Disch Press	1	500 psig
Suct Press	1	250 psig
Evap Fan	4	460V/1Φ 1/2 HP 1.7FLA
Liquid Line Solenoid	2	-
CU 3		
Comp	1	230V/3Φ /43.6 RLA
Cond Fan	2	230V 1Φ 1/2 HP 3.7 FLA
Evap Fan	4	230V 1Φ 3/4 HP 4.4 FLA
Liquid Line Solenoid	1	-
CU 4		
Comp	1	230V/3Φ /43.6 RLA
Cond Fan	2	230V 1Φ 3/4 HP 5.0 FLA
Evap Fan	4	230V 1Φ 3/4 HP 4.4 FLA
Liquid Line Solenoid	1	
CU 5		
Comp	1	460V/3Φ /71.0 RLA
Cond Fan	3	460V 3Φ 1 1/2 HP 3.5 FLA
Disch Press	1	500 psig
Suct Press	1	250 psig
Evap Fan	12	460V 1Φ 1/2 HP 1.7 FLA
Liquid Line Solenoid	4	-
CU 6		
Comp	1	460V/3Φ /71.0 RLA
Cond Fan	3	460V 3Φ 1 1/2 HP 3.5 FLA
Disch Press	1	500 psig
Suct Press	1	250 psig
Evap Fan	12	460V 1Φ 1/2 HP 1.7 FLA
Liquid Line Solenoid	4	-
CU 7		

Element	Quantity	Rated Parameters
Comp	1	230V/3Φ /31.5 RLA
Cond Fan	1	230V 1Φ 1/3 HP 2.1 FLA
Evap Fan	3	230V 1Φ 3/4 HP 4.4 FLA
Liquid Line Solenoid	1	-
CU 8		
Comp	1	230V/3Φ /43.6 RLA
Cond Fan	2	230V 1Φ 3/4 HP 4.7 FLA
Evap Fan	4	230V 1Φ 3/4 HP 4.4 FLA
Liquid Line Solenoid	1	-
CU9		
Comp	1	230V/3Φ /34.8 RLA
Cond Fan	2	230V 1Φ 3/4 HP 3.8 FLA
Evap Fan	4	230V 1Φ 3/4 HP 4.4 FLA
Liquid Line Solenoid	1	-
Retail Store		
Freezer		
Comp	1	230V/3Φ /30.3 RLA
Cond Fan	1	230V 1Φ 3/4 HP 3.8 FLA
Evap Fan	3	230V 1Φ 1/4 HP 1.8 FLA
Liquid Line Solenoid	1	-
Cooler A		
Comp	1	230V/3Φ /8.7 RLA
Cond Fan	1	230V 1Φ 1/3 HP 2.1 FLA
Evap Fan	3	115V 1Φ 1/4 HP 2.0 FLA
Liquid Line Solenoid	1	-
Cooler B		
Comp	1	230V/3Φ /21.4 RLA
Cond Fan	1	230V 1Φ 3/4 HP 3.8 FLA
Evap Fan	8	115V 1Φ 1/4 HP 2.1 FLA
Liquid Line Solenoid	2	-
Door Close Switches	20	N/A
Antisweat Door Heaters	80	230V/3Φ
SCE Totalizing Meter	1	460V/3Φ

TABLE 5 PRE-MAINTENANCE VERSUS POST-MAINTENANCE FOR THE LARGEST REFRIGERATION SYSTEMS AT THIS SITE

	Pre-Maintenance					Post-Maintenance (Prior to Control)			Difference
Coolers	9/10/09 1:30pm	9/22/09 1:30pm	9/24/09 1:30pm	9/28/09 1:30pm	Avg kWh/day	9/28/2009 1:27pm	10/12/2009 1:27pm	Avg kWh/day	ΔAvg kWh/day
C1 Z1	2,616.4	Value Not Used Here	6,829.3	Value Not Used Here	300.9	7,306.2	10,038.0	195.1	105.8
C1 Z2	1,494.5	Value Not Used Here	4,091.9	Value Not Used Here	185.5	5,095.3	7,496.5	171.5	14.0
C3 Z2	2,661.0	Value Not Used Here	8,734.0	Value Not Used Here	433.8	9,815.7	14,419.0	328.8	105.0
C3 Z3	2,006.3	Value Not Used Here	6,694.4	Value Not Used Here	334.9	8,750.8	16,393.5	545.9	-211.0
SCE Power Meter	Not yet installed	4,609.4	14,212.8	34,200.0	4,227.2	27,836.6	80,899.9	3,790.2	437.0

TABLE 6 POST-MAINTENANCE VERSUS EE MEASURE FOR THE LARGEST REFRIGERATION SYSTEMS AT THIS SITE

	Prior to Control				With Controls				Difference		
Coolers	9/28/2009 1:27pm	10/12/2009 1:27pm	14 day kWh	Avg kWh/day	10/17/2009 1:27pm	10/31/2009 1:27pm	14 day kWh	Avg kWh/day	14 day kWh	Avg kWh/day	% reduction
C1 Z1	7,306.2	10,038.0	2,731.8	195.1	11,202.1	12,958.3	1,756.2	125.4	975.6	69.7	35.7%
C1 Z2	5,095.3	7,496.5	2,401.2	171.5	8,141.7	10,017.6	1,875.9	134.0	525.3	37.5	21.9%
C3 Z2	9,815.7	14,419.0	4,603.3	328.8	16,051.7	18,855.3	2,803.6	200.3	1,799.7	128.6	39.1%
C3 Z3	8,750.8	16,393.5	7,642.7	545.9	18,652.1	22,051.7	3,399.6	242.8	4,243.1	303.1	55.5%
SCE Power Meter	27,836.6	80,899.9	53,063.3	3,790.2	101,342.2	144,825.1	43,482.9	3,105.9	9,580.4	684.3	18.1%

TABLE 7 POST-MAINTENANCE VERSUS EE MEASURE FOR ALL REFRIGERATION SYSTEMS AT THIS SITE

	Prior to Control			With Controls			Difference		
Coolers	Compressor Run	Evap Fan Run	Avg temp	Compressor Run	Evap Fan Run	Avg temp	Compressor Run	Evap Fan Run	Temp delta
Retail Cooler A	27.1%	100%	40.6 °F	18.5%	36.9%	39.5 °F	-31.7%	-63.1%	-1.1 °F
Retail Freezer* **	52.2%	100%	8.9 °F	34.5%	44.1%	4.6 °F	-33.9%	-55.9%	-4.3 °F
Retail Cooler B	35.9%	100%	38.0 °F	22.7%	51.1%	37.6 °F	-36.8%	-48.9%	-0.4 °F
Cooler 1 Z1	31.7%	100%	37.7 °F	29.0%	45.9%	37.5 °F	-8.5%	-54.1%	-0.2 °F
Cooler 1 Z2	37.7%	100%	37.3 °F	29.4%	45.4%	37.6 °F	-22.0%	-54.6%	0.3 °F
Cooler 2 Z1	38.2%	100%	38.6 °F	15.2%	35.9%	39.6 °F	-60.2%	-64.1%	1.0 °F
Cooler 2 Z2	19.7%	100%	40.9 °F	18.0%	49.9%	39.6 °F	-8.6%	-50.1%	-1.3 °F
Cooler 3 Z1 +	0.7%	100%	37.5 °F	21.4%	44.0%	37.5 °F	2,957.1%	-56.0%	0.0 °F
Cooler 3 Z2	16.0%	100%	36.8 °F	14.9%	34.0%	37.4 °F	-6.9%	-66.0%	0.6 °F
Cooler 3 Z3	39.0%	100%	36.2 °F	20.7%	45.3%	37.7 °F	-46.9%	-54.7%	1.5 °F
Cooler 4 Z1	18.9%	100%	39.8 °F	18.3%	39.6%	37.6 °F	-3.2%	-60.4%	-2.2 °F
Cooler 4 Z2	20.6%	100%	42.0 °F	13.4%	39.3%	37.7 °F	-35.0%	-60.7%	-4.3 °F
AVERAGES	28.1%	100%	36.2 °F	21.3%	42.6%	35.3 °F	-26.7%	-57.4%	-0.9 °F

* smart defrost in control mode

** electric defrosts are down to 1 every 2 days instead of 4 per day in run mode

+ Small compressor rarely turned on during baseline test thus increase in run time appears skewed

APPENDIX B

Continental Control Systems

WATTNODE®

Advanced Pulse Output AC Power Measurement

THE WATTNODE is a true RMS AC watt-hour transducer with pulse output (solid state relay closure) proportional to kWH consumed. The WATTNODE provides accurate measurement at low cost to meet your needs for sub-metering, energy management and performance contract applications.

Easy Installation saves you time and money. The WATTNODE is small enough to fit entirely within a standard electrical panel and the screw terminals unplug for easy wiring.

The Advanced Output includes separate pulse channels for positive and negative power, for net metering and PV metering. Optional models are available with one pulse output channel per measurement phase, which can be used to monitor each phase independently or to monitor three separate single-phase circuits with one WattNode.

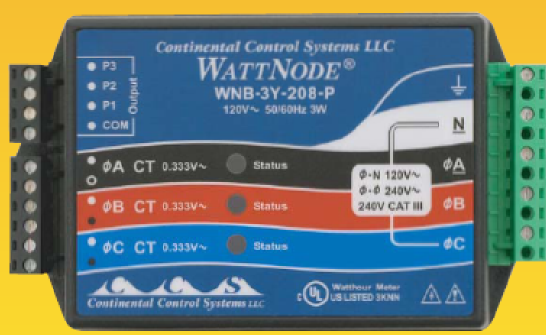
Our Diagnostic LEDs provide a per-phase indication of power (green flashing), negative power (red flashing), and advanced diagnostics (yellow flashing) to help troubleshoot connection problems, like swapped CTs, or excessive line voltage. See the User's Guide for a full description.

The Pulse Series family measures 1, 2, or 3 phases in 2, 3 or 4 wire configurations. With voltage ratings from 120 to 600 VAC and current transformer (CT) rating from 5 to 4000 amps, there is a WATTNODE combination to meet your AC power measurement requirements.

ACCURACY of the WATTNODE is is 0.5% of reading over a wide range of power factors and harmonic content. You get true kWH measurements even with switching power supplies and variable speed drives.

Our Safe CTs, with internal burden resistors produce a voltage proportional to the load current. At rated current voltage is only 0.333 VAC. Split-core CTs quickly install on existing wiring and solid-core CTs cost less for new wiring.

277/480
VAC
120/240



c UL US LISTED

(888) 928-8663

Continental Control Systems LLC
3131 Indian Road, Suite A
Boulder, CO 80301 USA
(888) 928-8663 Fax (303) 444-2903
sales@ccontrolsys.com

www.ccontrolsys.com

- **Advanced Pulse Output**
  Separate pulse channels for positive and negative power. Optional models are available with one pulse output channel per measurement phase.
- **Small Size**
  Can be installed in existing service panels or junction boxes.
- **Uses Safe CTs**
  Output limited to one volt.
- **Line Powered**
  No external power supply required.
- **Digital Signal Processing**
  Accurate kWH measurement over a wide harmonic range.
- **Detachable Terminal Blocks**
  Easy to install and remove.

SPECIFICATIONS

WATTNODE®

Advanced Pulse Output AC Power Measurement

Measurement Configurations
Single phase: 2-wire or 3-wire
Three phase: 3-wire or 4-wire

Electrical
Line Powered
Operating Voltage Range: +15%, -20% of nominal
Power Line Frequency: 50/60 Hz
CT Input: 0.333 VAC

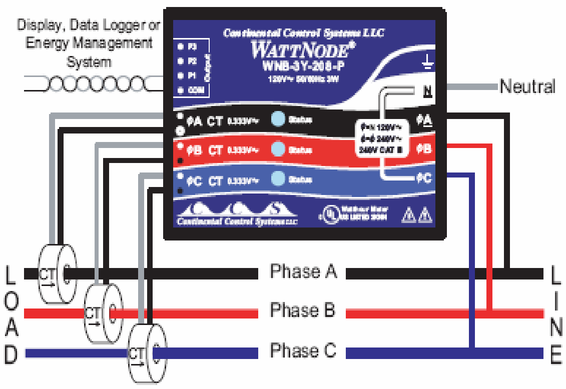
Pulse Output
Optoisolated, solid state relay closures handle up to maximum 60 VDC & to 5mA
Standard: 4.00 Hz Bidirectional Output
Optional: 0.01 Hz to 600 Hz Bidirectional Output Models
Optional: Per-Phase Output Models 0.01 Hz to 150 Hz available

Accuracy
Normal Operation: Line voltage: 80% - 115% of nominal
Power factor: 1.0
Frequency: 48 - 62 Hz
Ambient Temperature: 25°C
Current: 5% - 100% of rated current
Accuracy: ±0.5% of reading

Environmental
Operating Temperature: -30°C to +55°C (-22°F to 131°F)
Operating Humidity: 5 to 90% (RH)

Mechanical
Enclosure: High impact, UL rated, ABS plastic
Size: 3.3" x 5.6" x 1.25"
Connectors: UL, CSA recognized, detachable, screw terminals (14AWG), 600V

Optional LCD Display
Display: Eight digits, each 0.43" high
Reset: Wired remote and configurable front panel button
Enclosure: Panel mount box, 2.95" x 1.52"
Battery: Lithium 2/3A, replace every four years



MODELS

Model	VAC Line To Neutral	VAC Line To Line	Phases	Wires
WNB-3Y-208-P	120	208-240	3	4
WNB-3Y-400-P	230	400	3	4
WNB-3Y-480-P	277	480	3	4
WNB-3Y-600-P	347	600	3	4
WNB-3D-240-P	120	208-240	3	3
WNB-3D-400-P	230	400	3	3
WNB-3D-480-P	277	480	3	3

LCD Displays

Model	Displays	Units
LCDA-E	Energy	WH, kWH, or MWH
LCDA-P	Power	W or kW
LCDA-EP	Energy & Power	WH, kWH, or MWH & W or kW

OPENING CURRENT TRANSFORMERS (SPLIT-CORE)

Model	Inside Diameter	Rated Amps
CTS-0750	0.75"	5, 15, 30, 50, 70, 100, 150
CTS-1250	1.25"	70, 100, 150, 200, 250, 300, 400, 600
CTS-2000	2.00"	600, 800, 1000, 1200, 1500
CTB	Bus Bar	600, 800, 1200, 2000, 3000 (custom)

TOROIDAL CURRENT TRANSFORMERS (SOLID-CORE)

Model	Inside Diameter	Rated Amps
CTT-0300	0.30"	5, 15, 30
CTT-0500	0.50"	15, 30, 50, 60
CTT-0750	0.75"	30, 50, 70, 100
CTT-1000	1.00"	50, 70, 100, 150, 200
CTT-1250	1.25"	70, 100, 150, 200, 250, 300, 400

Current Transformer Output Voltage: 0 - 0.333 VAC @ rated current

MADE IN THE USA

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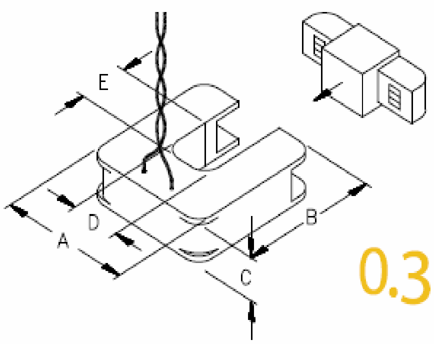
Continental Control Systems

SPLIT CORE
CURRENT TRANSFORMERS

SPLIT CORE current transformers make installation easier because they can be installed without disconnecting the circuit being measured. Split-core current transformers are available in a range of stock sizes and rated currents to meet your measurement

Model CTS-0750-(xxx) 0.75" I.D.		Model CTS-1250-(xxx) 1.25" I.D.		Model CTS-2000-(xxx) 2.00" I.D.	
Rated Amps	Model Suffix (xxx)	Rated Amps	Model Suffix (xxx)	Rated Amps	Model Suffix (xxx)
5	-005	70	-070	400	-400
15	-015	100	-100	600	-600
30	-030	150	-150	800	-800
50	-050	200	-200	1000	-1000
70	-070	250	-250	1200	-1200
100	-100	300	-300	1500	-1500
150	-150	400	-400		
200	-200	600	-600		



0.333 VAC Output

Size	CTS-0750	CTS-1250	CTS-2000
A	2.00 in. 5.08 cm	3.25 in. 6.45 cm	4.75 in. 12.1 cm
B	2.10 in. 5.33 cm	3.35 in. 8.51 cm	5.00 in. 12.7 cm
C	0.61 in 1.55 cm	1.00 in. 2.54 cm	1.20 in. 3.05 cm
D	0.75 in. 1.91 cm	1.25 in. 3.18 cm	2.00 in. 5.08 cm
E	0.75 in. 1.91 cm	1.25 in. 3.18 cm	2.00 in. 5.08 cm

Split Core

Easy Installation

- No exposed metal parts on assembled transformer.
- Internal precision burden resistor across secondary.
- Epoxy encapsulated housing.
- Leads-8ft. twisted pair, 22 AWG.
- Core interleaved at joints for accuracy.
- Phase angle is measured at 50% of rated current.
- UL & CE recognized.
- Output is 0.333 VAC at rated current.
- Accuracy ± 1% from 10% to 130% of rated current..
- Phase angle < 2 degrees for CTS-0750 models >70Amps & CTS-1250 models >150Amps.
- Snap closing/opening feature.
- Shrouded core blades for protection during installation.

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sales@ccontrolsys.com
www.wattnode.com

MSP 300 Pressure Transducer

- OEM and End User
- One Piece Pressure Port Construction
- No O-Rings
- No Silicon Oil
- No Welds

DESCRIPTION

The MSP 300 series pressure transducers from the Microfused™ line of MEAS, set a new price performance standard for low cost, high volume, commercial and industrial applications. This series is suitable for measurement of liquid or gas pressure, even for difficult media such as contaminated water, steam, and mildly corrosive fluids.

The transducer pressure cavity is machined from a solid piece of 17-4 PH stainless steel. The standard version includes a 1/4 NPT pipe thread allowing a leak-proof, all metal sealed system. There are no O-rings, welds or organics exposed to the pressure media. The durability is excellent.

MEAS' proprietary Microfused™ technology, derived from demanding aerospace applications, employs micromachined silicon piezoresistive strain gages fused with high temperature glass to a stainless steel diaphragm. This approach achieves media compatibility simply and elegantly while providing an exceptionally stable sensor without the PN junctions of conventional micromachined sensors.

This product is geared to the OEM customer who uses medium to high volumes. The standard version is suitable for many applications, but the dedicated design team at our Transducer Engineering Center stands ready to provide a semi-custom design where the volume and application warrants.

FEATURES

- One Piece Stainless Steel Construction
- Ranges up to 10k psi or 700 Bar
- mV or Amplified Outputs
- Excellent Accuracy
- Wide Operating Temperature Range

APPLICATIONS

- Pumps and Compressors
- Hydraulic/Pneumatic Systems
- Automotive Test Systems
- Energy and Water Management
- Agriculture – Sprayers and Dusters
- Refrigeration – Freon and Ammonia Based
- General Pressure Measurements

STANDARD RANGES

Range	psig	Range	Barg
0 to 100	•	0 to 7	•
0 to 250	•	0 to 17	•
0 to 500	•	0 to 35	•
0 to 1000	•	0 to 70	•
0 to 2500	•	0 to 175	•
0 to 5000	•	0 to 350	•
0 to 10k	•	0 to 700	•

MSP300 www.meas-spec.com 1008
1/3

MSP 300 Pressure Transducer

PERFORMANCE SPECIFICATIONS

Supply Voltage: 5.0V, Ambient Temperature: 25°C (unless otherwise specified)

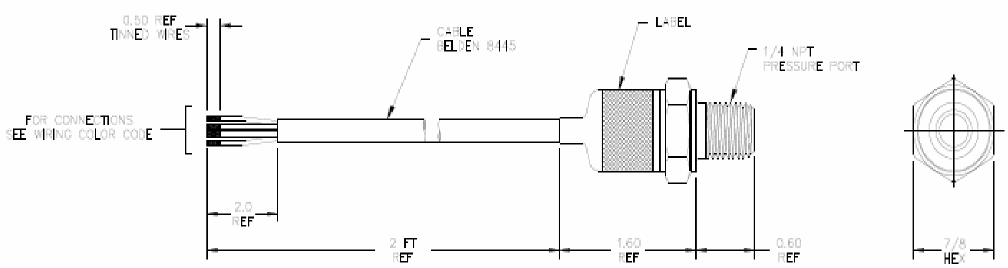
PARAMETERS	MIN	TYP	MAX	UNITS	NOTES
Span Setting	-2		2	%Span	1
Zero Pressure Output (0 – 100mV)	-3		3	%Span	1
Zero Pressure Output (Amplified)	-2		2	%Span	1
Accuracy (combined non linearity, hysteresis, and repeatability)	-1		1	%Span	2
Temperature Error – Zero	-2		2	%Span	
Temperature Error – Span	-2		2	%Span	
Supply Current (0 – 100mV, 0.5 – 4.5V)			10	mA	
Supply Current (1 – 5V)			15	mA	
Long Term Stability (1 year)	-0.25		0.25	%Span	3
Pressure Overload	2X			Rated	
Pressure Cycles (Zero to Full Scale)	10			Million	
Output Load			1	MΩ	
Compensated Temperature	0		55	°C	
Operating Temperature	-20		+85	°C	4
Storage Temperature	-40		+125	°C	4
Burst Pressure	5X			Rated	
Vibration	±20			g	5
Shock (11ms)	50			g	6
Output Noise			2	mVRMS	
Bandwidth (-3dB)	1			kHz	
Weight		82.55		grams	
Media Compatibility	All Materials Compatible with 17-4 Stainless Steel				

For custom configurations, consult factory.

Notes

1. Ratiometric to supply.
2. Best fit straight line.
3. Long term stability over a one year period.
4. Maximum temperature range for product with standard cable is -20°C to +105°C.
5. Per MIL-STD-810C, Procedure 514.2, Figure 514.2-2, Curve L.
6. 1/2 sine per MIL-STD 202F Method 213B condition A.

DIMENSIONS



MSP300 www.meas-spec.com 1008
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measurement SPECIALTIES

MSP 300 Pressure Transducer

OUTPUT OPTIONS

Code	Output	MIN	Supply (V) TYP	MAX
2	0 – 100 mV (ratiometric)	2.5	5	12
3	0.5 – 4.5 V (ratiometric)	4.75	5	5.25
4	1 – 5 V	8		30
5	4 – 20 mA	9		30

Wiring Color Code

Code	Output	+Supply	-Supply	+Out	-Out
2	0 – 100 mV (ratiometric)	Red	Black	Green	White
3	0.5 – 4.5 V (ratiometric)	Red	Black	White	N/A
4	1 – 5 V	Red	Black	White	N/A
5	4 – 20 mA	Red	Black	N/A	N/A

ORDERING INFORMATION

MSP300 - 100 - P - 2 - N - 1

- Connection (1 = 2ft Cable)
- Pressure Port (N = 1/4NPT)
- Outputs (2 = 0 - 100mVdc, 3 = .5 - 4.5Vdc 4 = 1 - 5Vdc fixed, 5 = 4 - 20mA two wire)
- Units (P = psi, B = Bar)
- Pressure Range (100 - P = 100psi, 2K5 - P = 2500psi, 05K - P = 5000psi)
- Model

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