Demand Response Strategies Using Two-Way Connectivity for Commercial Ice Machines

DR 07.07 Report

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ABBREVIATIONS AND ACRONYMS

DR	Demand Response
ZigBee	Wireless network communications over IEEE 802.15.4
MDL	Micro Data Loggers
CT	Current Transducer
CTAC	Customer Technology Application Center
CSV	Comma Separated Value
HAN	Home Area Network
LAN	Local Area Network

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EXECUTIVE SUMMARY

This project evaluated control strategies and technologies that would allow commercial customers to participate in demand response (DR) programs by shedding load from ice machines. These control strategies and technologies were tested at different customers' sites to better understand performance and deployment challenges as well as customer acceptance. A secondary objective of this project was to work with the foodservice industry in developing recommended DR strategies on how ice machines can respond to DR events. The goal of the recommended DR strategies was to reduce as much ice making load as possible, during a DR event, with minimal impact on customers. This information would be important in creating preset strategies to be made available to the foodservice industry and customers to encourage participation in a potential DR program offering. An additional objective was to test ice machines of different vintages, configurations, brands, and sizes to determine their impact on the implementation of the DR strategies. This project allowed Southern California Edison (SCE) to start engaging ice machine manufacturers to work towards making commercially available DR-enabled ice machines. This project was performed in anticipation of leveraging the Edison SmartConnect™ infrastructure for advanced load control and management in the near future.

PROJECT DESCRIPTION

SCE is in the initial stages of deploying the advanced metering infrastructure known as SmartConnect™. SmartConnect™ will give the utility the ability to have real time, two-way connectivity to each residential and commercial customer's meter. The infrastructure will also enable transmission of DR signals within a home or business using a ZigBee radio that will be embedded inside the meter.

For this project, commercial ice machines at three different sites (a conference and education center kitchen facility, a full service pizza restaurant, and a quick service restaurant) were retrofitted with advanced controls having ZigBee communications, which provided connectivity to a simulated SmartConnect™ meter (a secondary ZigBee radio with web connection). When DR event signals were sent, the ice machine controller would receive the ZigBee signal, via the simulated meter, and respond to the DR event by invoking DR strategies implemented into the ZigBee profile in the controller.

PROJECT FINDINGS

Ice machines show a high potential to respond to a DR event due to their ability to store large quantities of ice. The typical operation of ice machines in the foodservice market sector showed potential to implement DR strategies. The benefit for the utility was verified, when ice machines responded to DR events during the on-peak period (noon to 6 pm). The DR strategies proposed, and successfully tested, in this project made it possible to safely curtail the ice machine loads during peak periods.

A user interface was developed to manage ice machine information and run DR events. A simulated SmartConnect™ infrastructure was used, given than the SmartConnect™ infrastructure has not been fully deployed yet, to curtail and verify curtailment of ice production process during a DR event.

The proposed DR strategies were dependent on three parameters: a Critical Bin Threshold, a Normal Bin Threshold, and a Bin Level Drop Rate. The Critical Bin Threshold is the lowest ice level in the bin, before it cancels or does not allow participation in a DR event. The Critical Bin Threshold proposed for this project was 25%, which left customers with enough ice until the ice making process is reengaged. The Normal Bin Threshold is the ice level upper limit in the bin, before an ultra sonic sensor can cancel a DR event. The Normal Bin Threshold proposed for this project was 50%. The Bin Level Drop Rate represents the ice removal rate from the bin. The Bin Level Drop Rate proposed for this project was 10% drop in 5 minutes. Once ice level is below the Normal Bin Threshold, but above the Critical Bin Threshold, if the ice level dropped 10% in a five-minute time period, the DR event would be cancelled. By providing a 25% Critical Bin Threshold and/or a 10% Bin Level Drop Rate with a Normal Bin Threshold of 50%, the DR strategy protected the customers' ice production needs.

These DR strategies were successfully implemented in two different brands of ice machines: Hoshizaki and Scotsman. The retrofit was also successful in two different ice machine configurations: self-contained ice machines and remotely cooled ice machines. By testing the DR strategies and ZigBee connectivity on different brands and configurations of ice machines, the project was able to demonstrate DR capabilities are applicable to different commercial ice machine manufacturers.

PROJECT RECOMMENDATIONS

The following activities can further enhance the availability of reliable DR-ready commercial ice machines in the near future.

- **ENGAGEMENT OF ICE MACHINE MANUFACTURERS**. Continue discussion with the ice machine manufacturers and control vendors to develop smarter and DR-ready ice machine controllers.
- **A CONTROLLER THAT IS ABLE TO BASELINE ICE PRODUCTION AND SCHEDULES.** With the ice production and schedules history, the controller would be able to make ice dependent on ice demand. Thus increasing the opportunity for more sophisticated DR strategies.
- **A CONTROLLER WHICH HAS THE ZIGBEE RADIO, SMART ENERGY PROFILE, AND DR LOGIC INTEGRATED INTO THE ICE MACHINE.** This integration would enable the registration of the ice machine with SCE's SmartConnect™ infrastructure, which would be ideal and most cost effective way to have high market penetration with SCE service territory.
- **AN INTERFACE FOR CUSTOMERS TO CUSTOMIZE DR STRATEGIES EMBEDDED IN THE ICE MACHINE CONTROLLER**. Engage the ice machine manufacturers, control vendors, and the foodservice industry to help in the development of specifications for an interface to customize the DR strategies.

INTRODUCTION

This project evaluated control strategies and technologies that would allow commercial customers to participate in demand response (DR) programs by shedding load from ice machines.

Southern California Edison (SCE) is in the initial stages of deploying its advanced metering infrastructure known as SmartConnect™. As part of the SCE's SmartConnect™ program, old, standalone mechanical meters will be replaced with a new "smart" meter driven by digital electronics that will empower customers to manage their energy use in new ways.

When fully deployed, SCE's SmartConnect™ will connect customers to an intelligent grid. For example, communicating thermostats will receive and transmit signals to let consumers monitor and control energy consumption and cost. Eventually lighting, smart appliances, pool pumps, plug-in hybrid vehicles, will all be able to connect to the system.

The SmartConnect™ infrastructure will give the utility the ability to have real time two-way connectivity to each residential and commercial customer's meter. The infrastructure will also enable customers to participate in DR programs sponsored by SCE. The utility will transmit DR signals within a home or business using a ZigBee radio that will be embedded into the meter.

ZigBee radio enables low-power devices to communicate over an unregulated portion of the radio spectrum using a new wireless personal area network standard known as IEEE 802.15.4 standard. The ZigBee radio consists of three layers:

- Application Profile
- Stack Profile
- Wireless Radio Hardware

The ZigBee application profile is the logic within a piece of equipment that decides what to do with a particular ZigBee signal. The stack profile is the communication protocol for the signal. The stack protocol defines the type of signals that are sent, security, encryptions, and commands. The last layer is the ZigBee wireless radio hardware. ZigBee communicates over the IEEE 802.15.4 standard.

For utility purposes, a special application profile has been created. This application profile is called the Smart Energy profile. For this project, only a critically rated DR event was evaluated in the Smart Energy profile. Each DR event has a rating of 1 to 7. A rating of 1 is the least critical and a rating of 7 is the most critical. Ratings 1 thru 6 imply economically driven events, while a rating of 7 implies reliability driven even. Rating the DR events at different levels of criticality enables users to decide how to participate in a DR event.

BACKGROUND

Ice machines are widely used in the United States in many commercial sectors[1], as shown in Figure 1. There are about 3 million commercial ice machines in operation in the United States with over 250 thousand in California.[2] Ice machines are rated by how many pounds of ice they can create per day. The majority of ice machines sold to customers in the United States and California range from 200 to 800 lbs of ice per day.

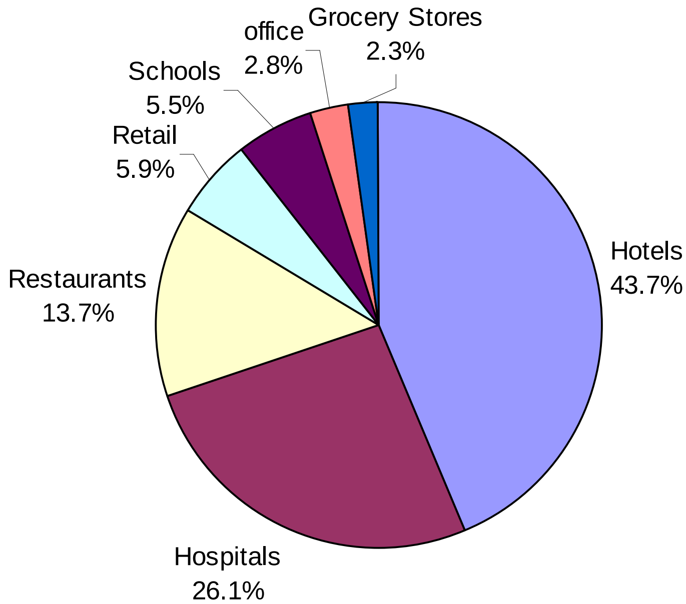


FIGURE 1. ICE MACHINES SOLD TO COMMERCIAL SECTORS AS A PERCENTAGE OF TOTAL SALES

There are tree types of ice machines: ice making head, self-contained, and remote condensing. Ice making head ice machines have the ice-making mechanism (compressor) and the condensing unit in a single package, but with a separate ice storage bin. They are generally designed to accommodate a variety of ice storage capacities. Self-contained ice machines have the ice-making mechanism, condensing unit, and storage compartment integrated into a single package. Remote condensing unit ice machines have the ice-making mechanism and the condensing unit separate. Typically, this type of ice machines has the condensing unit in roof of the building. Ice making head and self-contained ice machines can be either air- or water-cooled. Air-cooled ice machines are less efficient, but more affordable, thus the most common. Remote condensing ice machines are air-cooled only. Most self-contained ice machines are below 250 lbs of ice per day, while ice making head ice machines are in the range of 200 to 1200 lbs of ice per day. Typically, remote condensing ice machines are above 1000 lbs of ice per day.

USING ICE MACHINES TO RESPOND TO DR EVENTS

Ice machines show a high potential to respond to DR events due to their ability to store large quantities of ice. Ice machines consist of main two components: the ice maker and a storage bin. An ice machine controller typically creates ice until the storage bin is completely full.This control strategy presents a prospect for DR due to the fact that, typically, the demand for ice in foodservice facilities does not deplete the stored ice all at once; thus providing an opportunity for the ice machine to respond to a DR event while replenishing the ice at a later time. The potential benefit for the utility is to reduce the ice machine load during the on-peak period of noon to

6 pm (12:00 – 18:00). Once SmartConnect™ is deployed, SCE will have a large network of easily accessible meters to broadcast DR signals to commercial customers.

For the average 500-lb ice machine sold within the United States and California, the power demand requirement is over 2 kW.[3] Of the estimated over 250,000 ice machines in California, between 75,000 and 100,000 ice machines are within SCE service territory. To verify the reasonableness of the number of ice machines within SCE territory, the SCE customer database was searched to find the number of buildings in each commercial sector identified in the 1996 Arthur Little report.[1] A statistical average of ice machines per building type was used from the 1996 Arthur Little report,[1] although these statistics are dated, the ratio of ice machines per building type was assumed to be applicable, although, for some building types (particularly, restaurants and groceries), the ratio of ice machine per building seems low (see Appendix A, Table B). By combining both data sets, it resulted in over 70,000 ice machines in SCE service territory (see Appendix A, Table A and Table B). With such a large number of ice machines, a DR program would have high potential (141 MW) to effectively curtail load during critical peak hours of the day.

OBJECTIVE

The project objective was to field evaluate control strategies and technologies that would enable commercial customers to participate in demand response (DR) programs by shedding load from ice machines The control strategies and technologies were tested in different customer's sites to better understand performance and deployment challenges as well as customer acceptance.

A secondary objective of this project was to work with the foodservice industry in developing recommended DR strategies on how ice machines can respond to DR events. The goal of the recommended DR strategies was to reduce as much ice making load as possible, during a DR event, with minimal impact on customers. This information would be important in creating preset strategies to be made available to the foodservice industry and customers to encourage participation in current and future DR program offering.

An additional objective was to test ice machines of different vintages, configurations, brands, and sizes to determine their impact on the implementation of the DR strategies. This will allow SCE to start engaging ice machine manufacturers to work towards making commercially available DR-enabled ice machines. This project was performed in anticipation of leveraging the SCE's SmartConnect™ infrastructure for advanced load control and management in the near future.

APPROACH

Figure 2 illustrates the general concept of advanced metering infrastructure, similar to SCE's SmartConnect™ infrastructure. This type of infrastructure allows 2-way connectivity to the customer's advanced meter, which provides a host of benefits from operational to energy conservation to Smart Grid support.

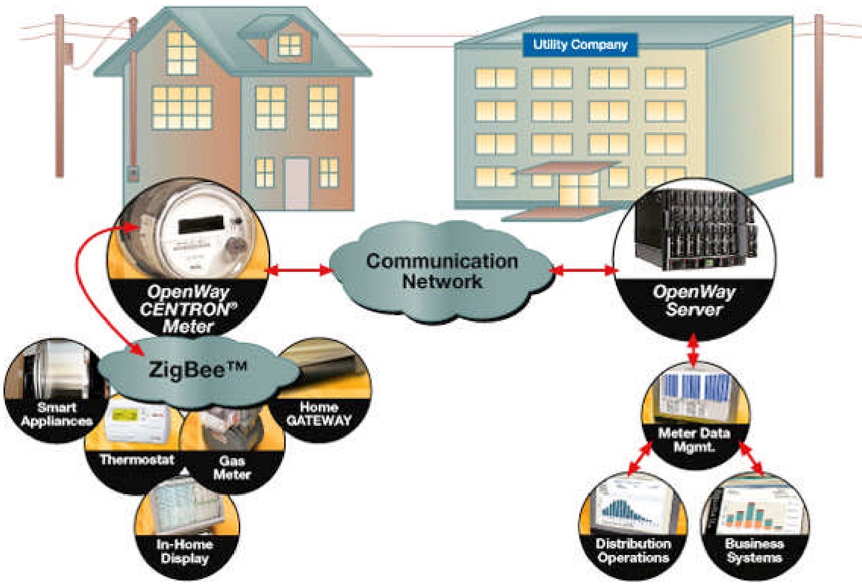


FIGURE 2. ADVANCED METERING INFRASTRUCTURE (COURTESY ITRON INC.)

The SmartConnect™ infrastructure offers the ability to broadcast DR events directly to customers' meters. The meter receiving the DR signal rebroadcasts the signal using its built-in ZigBee radio to a nearby smart communicating appliance or a local area network (LAN)/home area network (HAN) leveraging the ZigBee Smart Energy profile.

For this project, it was assumed that the customer would voluntarily participate on a DR event (DR events with critically 1 thru 6 as defined in the Smart Energy profile). Once the ice machine receives the DR event and it is criticality rating, its application profile will decide what actions are necessary and it is ability to participate in the event.

Given that the SmartConnect™ infrastructure is not fully deployed and the SmartConnect™ meters are not widely installed, a simulated meter and infrastructure was developed for this project. An internet-based, remote data management system was created to emulate SCE's infrastructure while the SCE's meter was simulated thru ZigBee radio kit with web connectivity as shown in Figure 3.

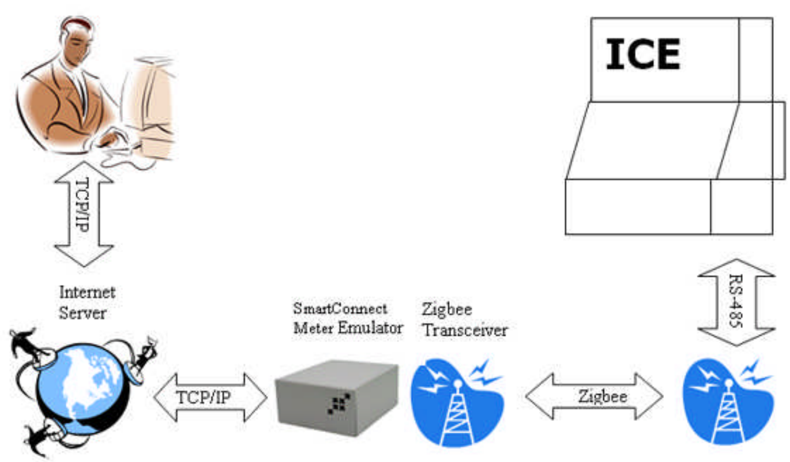


FIGURE 3. PROJECT ICE MACHINE CONTROL SYSTEM

Figure 3 illustrates how the remote data management system and simulated meter will emulate the SmartConnect^{TM} infrastructure and meter for this project. A DR event is initiated by the utility (SCE) or a third party aggregator. The DR event is transmitted to the meter through internet connectivity (TPC/IP) and is received by a cellular gateway in the simulated meter. The simulated meter receives the DR event and broadcasts the event through a ZigBee link to the ice machine (a ZigBee link consists of ZigBee transceiver kit at the simulated meter and a ZigBee transceiver kit at the ice machine controller). The ice machine will receive the DR event and choose to participate depending on the DR control strategies implemented into the ice machine controller. The website allows the utility, not only, to initiate/terminate DR events, but also to receive ice machine status information in real time.

TECHNOLOGY EMPLOYED

To evaluate the DR control strategies and technologies that would allow commercial customers to curtail load associated with ice machines, an interface was created to emulate the SmartConnect^{TM} infrastructure. Hardware was chosen and ice machines were retrofitting for this project. Controls Products, Inc. was selected to implement the retrofit of the ice machines due to their expertise on ice machine controllers and its working relationship with the different main ice machine manufacturers. The objective was to develop an interface to emulate the SmartConnect^{TM} infrastructure and retrofit three ice machines to be compatible with the emulated SmartConnect^{TM} infrastructure.

INFRASTRUCTURE, METER, AND ICE MACHINE HARDWARE DESCRIPTION

The simulated infrastructure and meter consisted of four main components:

- a wireless gateway
- a single board computer
- a communication board
- an enclosure

A wireless gateway was used to enable web-based, two-way connectivity to the simulated meter. A Digi International wide area network (WAN) gateway (Digi Connect WAN) was selected to provide a link to the internet through cellular technology. By choosing cellular technology, it provided the ability to test at any site with cellular reception. A Technology Systems single board computer (Ts 7250) was used for two-way conversion of the data from the communication board and the wireless gateway. An Ember ZigBee development kit (EM260) was used as the communication board. The communication board used preset ZigBee stacks to an attached ZigBee radio. These three pieces of hardware were enclosed in a black plastic case for protection as pictured in Figure 4.

The various ice machines were retrofitted with two pieces of hardware: a communication board (Ember EM260 kit) and a Madison ultrasonic sensor (U3M-148) as shown in Figure 5. The communication board was connected onto the ice machine controller through an RS 485 cable. The communication board provided two-way connectivity through the ZigBee link to the simulated meter.

On two of the ice machines, the ultrasonic sensor was connected to the communication board, while on the third ice machine; the sensor is offered as manufacturer's built-in option.

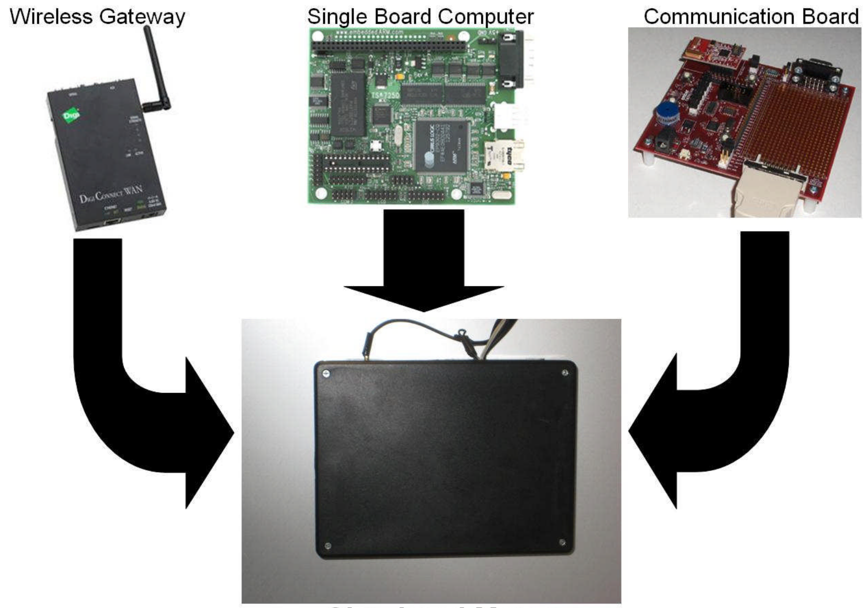


FIGURE 4. HARDWARE COMPONENTS FOR THE SIMULATED METER

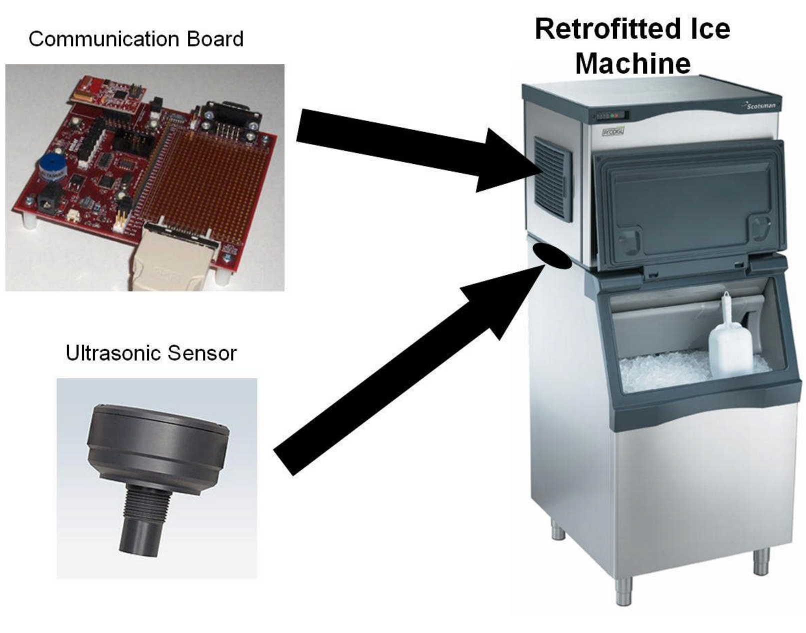


FIGURE 5. HARDWARE COMPONENTS FOR A RETROFITTED ICE MACHINE

The ultrasonic sensors were configured to take readings of the ice machine bin level. This sensor data gives customers the ability to safely respond to DR events. This is accomplished by setting limits to the bin level and bin level drop rates. If a bin setting limits were passed, the ice machine would automatically cancel or not participate in a DR event.

POWER MONITORING HARDWARE DESCRIPTION

Micro data loggers (MDL), current transducers (CT), and Watt nodes were installed in the electrical breaker servicing each ice machine at the three sites. The MDL logged power data coming from the Watt node. The Watt node generates pulses from voltage readings tapped into the circuit and amperage readings from the CTs (generically, power = voltage x amperage) as shown in Figure 6. Power data measured in 6-second intervals and averaged into 30-second data points. The power data was used to verify operational status being logged by the simulated SmartConnect™ infrastructure as well as to baseline and estimate the demand reduction potential.

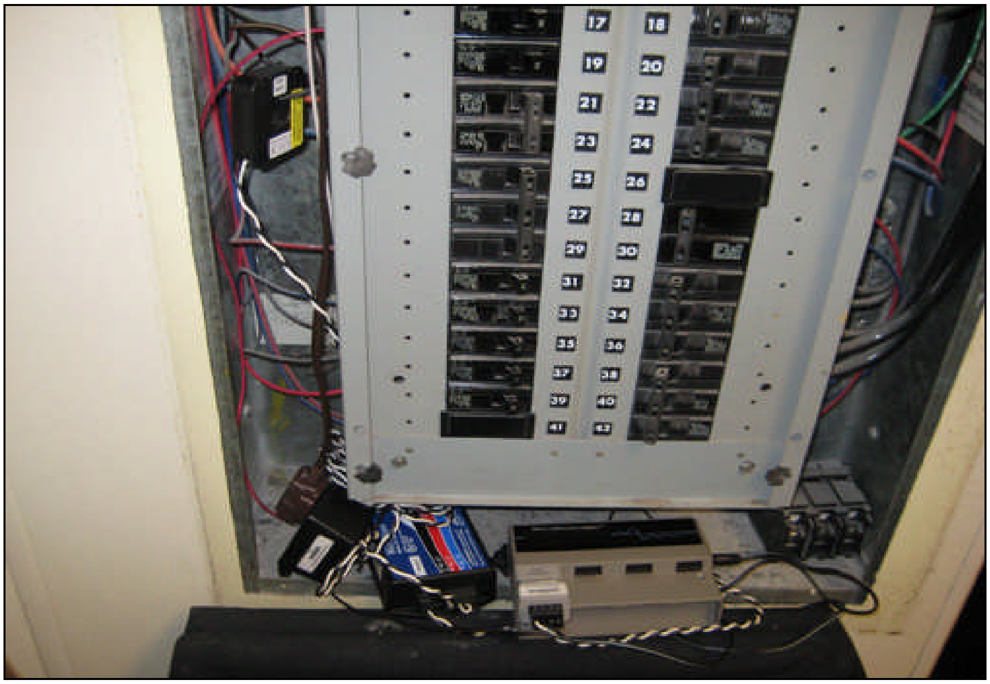


FIGURE 6. MDL INSTALLATION

SOFTWARE DESCRIPTION

The software development for the project consisted of three major components: the software to simulate the SmartConnect™ meter communication, the software to provide the logic for the DR controls and strategies associated with the ice machines, and the software to manage and process data from the ice machine and to schedule DR events. The simulated SmartConnect™ meter communication and the DR controls and strategies software components interoperate through the ZigBee communication link (the ZigBee link consists of ZigBee transceiver kit/communication board in the simulated meter and a ZigBee transceiver kit/communication board in the ice machine controller as shown in Figure 3). The ZigBee software employed was the Ember ZNet PRO 3.2 which is a ZigBee certified stack supporting the Smart Energy application profile.

The software for the simulated SmartConnect™ meter (wireless gateway, single board computer, and ZigBee communication board) receivers the bin level and operating mode of the ice machine every 60 seconds. This information is collected from the ice machine through the ZigBee communication link. The single board computer uploaded this information to the remote data management website server every 15 minutes through the wireless gateway. The remote data management software processes the logged data and makes it available in the remote data management web site.

DR events are sent from the remote data management website to the simulated SmartConnect™ meter through the wireless gateway. The single board computer in the SmartConnect™ meter forwards the DR event via the ZigBee communication link to the ice machine controller. Then the ice machine controller makes the decision of whether or not, and how best, to respond to the DR event based on logic (DR strategies and controls) implemented into the controller.

The software on the ZigBee communication board on the ice machine is responsible for monitoring the bin level and the operation mode of the machine and commanding the machine ice to turn on or off (curtail load). All the DR control strategy settings can be defined by the user (or utility) through the remote data management website software, developed in this project.

DEPLOYMENT

The foodservice market sector was chosen to field test the DR strategies and controls because this sector is a large user of ice machines and it is likely to adopt them based on discussions with ice machine manufacturers, controls vendors, and foodservice customers. The three types of foodservice facilities selected for this project were: a commercial kitchen in a conference and education center, a small full service pizza restaurant chain, which also does high-volume institutional orders, and a large quick service chicken restaurant chain.

An additional objective of the project was to demonstrate the ability to implement DR strategies and controls on commercial ice machines of different vintages, configurations, brands, and sizes. Therefore, the selected facilities were screened to provide variation in ice machine vintages, configurations, brands, and sizes.

SITE DESCRIPTIONS

CONFERENCE AND EDUCATION CENTER

The commercial kitchen at SCE’s Customer Technology Application Center (CTAC) in Irwindale, California, was used to represent the conference and education center facility. Given it easy of access, the CTAC location was used to field verify the DR strategies and controls capabilities before implementing them at the two customers’ sites. The CTAC normal operating hours are from 6:00-16:00 (6 am to 4 pm) Monday through Friday, with occasional Saturday operation. The CTAC kitchen provides food and beverages for various meetings and seminars in its large auditoriums and many meeting rooms. The ice machine installed was an air-cooled Scotsman model CME506 with a 500-lb Scotsman storage bin model BH550. This model was selected in order to test the simulated SmartConnect™ meter communication with an older vintage ice machine. This ice machine was originally used in an earlier 2006 SCE DR project (DR 06.06). As a result of the earlier DR project, an ultrasonic sensor was already installed. Only the ZigBee communication board was retrofitted onto the ice machine for the project. The simulated SmartConnect™ meter was placed on top of a stainless steel refrigerator about 8 feet away, as shown in the upper left corner of Figure 7.

FIGURE 7. CONFERENCE AND EDUCATION CENTER INSTALLATION

FULL SERVICE PIZZA RESTAURANT

The second site was a full service pizza restaurant in Chino Hills, California. This site is part of a small sit-down and delivery restaurant chain. The restaurant also does high volume institutional and corporate pizza sales. This site was chosen due to its unique operations and customers. The hours of operation are 11:00-21:00 (11 am to 9 pm), Monday through Thursday and 11:00-22:00 (11 am to 9 pm), Friday through Sunday. Ice is mainly used to fill fountain drink ice bins for beverages. The ice machine installed was an air-cooled Scotsman Prodigy B530 with a 300-lb Scotsman storage bin model BH300. The Prodigy line of Scotsman is the newest line of ice machines, which has as a calibrated ultrasonic sensor available as an option to the customer. The new line of Scotsman Prodigy machines was chosen to evaluate the simulated SmartConnect™ meter communication to a newer model ice machine. Only the ZigBee communication board was retrofitted onto the ice machine for the project since the ice machine was acquired with the ultrasonic sensor already installed from the manufacturer. The simulated SmartConnect™ meter was placed on top of a switch box about 10 feet away, as shown in the upper right corner of Figure 8.

FIGURE 8. FULL SERVICE PIZZA RESTAURANT INSTALLATION

QUICK SERVICE CHICKEN RESTAURANT

The third site was a quick service chicken restaurant in Newhall, California. This site is part of a large quick service chicken restaurant chain. The location was chosen for its high volume of customers and large need of ice. The hours of operation are 9:00-23:00 (9 am to 11 pm), Sunday through Saturday. Ice is mainly used for beverages and chicken preparation. The ice machine installed was a remotely air-cooled Hoshizaki 1340 MRH with a 700-lb Kloppenberg storage bin model 705-SBB. The Hoshizaki ice machine was chosen for its remote air-cooled configuration (remote condenser) and its large 1300 lbs of ice per day rating. The Hoshizaki machine was retrofitted with an ultrasonic sensor and a ZigBee communication board. The simulated SmartConnect™ meter was placed on top of a refrigerator about 6 feet away from the ice machine, as shown in the upper left corner of Figure 9.

FIGURE 9. QUICK SERVICE CHICKEN RESTAURANT INSTALLATION

TEST PLAN

The test plan consisted of laboratory testing and field implementation. Both were needed to properly evaluate the DR strategies and controls for commercial ice machines at different customers' sites via the ZigBee connectivity and leveraging the ZigBee Smart Energy application profile.

LABORATORY TESTING

Laboratory testing was needed to verify that all the retrofit components and related software to implement the DR strategies and controls were working properly. The laboratory testing occurred at Controls Products' facilities in Chanhassen, Minnesota. Programming of the ZigBee communication link between the simulated SmartConnect™ meter and the ice machine controller was tested at the laboratory as well. Testing of the ultrasonic sensor and the ZigBee communication board was performed on the similar controllers to be installed on the Hoshizaki and the Scotsman ice machines. The Scotsman Prodigy ice machine, which included the ultrasonic sensor, was fully tested in the laboratory prior to field deployment. The testing was performed with the ZigBee communication board retrofitted onto the ice machine controller.

Software testing also was performed in the laboratory. The capability to initiate and terminate a DR event through the data management website was tested. The ability to implement DR strategies with each of the ice machine controllers (Hoshizaki, Scotsman, and Scotsman Prodigy) was tested. Also tested was the ability of responding and/or canceling a DR event based on the Bin Level Drop Rate and Critical Bin Threshold. After the laboratory testing was performed, the hardware was shipped to each of the sites.

FIELD TESTING

Field testing occurred at three different commercial sites. The older Scotsman and Hoshizaki ice machines had the ZigBee communication board and the ultrasonic sensor installed on site. After the ultrasonic sensor installation, "empty and full" readings were recorded to determine user acceptable (customer defined) bin level limits. For the Scotsman Prodigy ice machine, hardware was already retrofitted in the laboratory.

The simulated SmartConnect™ meters were placed in direct line of sight of the ice machine, given that the goal of the project was not to test ZigBee connectivity capabilities. End use power monitoring equipment was installed at each site to verify ice machine operations and related power consumption. A baseline for each ice machine was established by recording two weeks of operation data and power data (though this does not represent the overall ice usage per day during a given year, it does profile the ice usage for the time that the tests were conducted). The ice machine baseline data provide each site's demand response testing potential. Four DR events were done at each site. Each DR event lasted about five hours. Also, critical bin level logic was tested at each site.

Testing was first performed with the CTAC ice machine to verify the infrastructures logic and functionality. The testing with the CTAC ice machine confirmed that the proposed DR strategies and controls were dependent on three parameters: a Critical Bin Threshold, a Normal Bin Threshold, and a Bin Level Drop Rate. The Critical Bin Threshold is the lowest ice level in the bin, before it cancels or does not allow participation in a DR event. The Critical Bin Threshold proposed for this project was 25%, which left customers with enough ice until the ice making process is reengaged. The Normal Bin Threshold is the ice level upper limit in the bin, before the ultra sonic sensor can cancel a DR event. The Normal Bin Threshold proposed for this project was 50%. The Bin Level Drop Rate represents the ice removal rate from the bin. The Bin Level Drop Rate proposed for this project was 10% drop in 5 minutes. Once ice level is below the Normal Bin Threshold, but above the Critical Bin Threshold, if the ice level dropped 10% in a five-minute time period, the DR event would be cancelled. By providing a 25% Critical Bin Threshold and/or a 10% Bin Level Drop Rate with a Normal Bin Threshold of 50%, the DR strategy protected the customers' ice production needs.

To minimize possible disruption to daily operation of the full service and quick service restaurants, the testing of the DR events were performed with a higher Critical Bin Threshold limit of 30% and 35%, respectively.

WEB INTERFACE/PERFORMING A DR TEST

The following set of screen-captures illustrates the functionality and sequences of setting up and following through a DR event. The web based controls developed for this project were used to control the ice machine and monitor its performance for the duration of the tests. In order to access the data management website, the user begins with the login screen shown in Figure 10.

FIGURE 10. REMOTE DATA MANAGEMENT WEBSITE LOGIN SCREEN

Once logged in, the user is able to select from a variety of web-enabled functions. The web controller consists of three tabs: Device, Status, and Real Time. Through all of the tabs, the "logger name" is displayed on the left-hand side. The logger name is highlighted by a user clicking on the logger name. The web interface only interacts with the highlighted device. Table 1 lists the logger names and their corresponding ice machine information.

TABLE 1. LOGGER ICE MACHINE INFORMATION

LOGGER NAME	BRAND	CONFIGURATION	BIN SIZE	INSTALLED AT
Edison1	Scotsman	Air-cooled	500 lbs	CTAC, Irwindale
Edison2	Scotsman	Air-cooled	300 lbs	Full Service Pizza Restaurant, Chino Hills
Edison3	Hoshizaki	Remotely air-cooled	700 lbs	Quick Service Chicken Restaurant, Newhall

The Device tab, shown in Figure 11, displays the last 100 readings and its corresponding time stamp, logged by the website. The readings taken by the website are the "op_mode" and the "bin_level". The "op_mode" stands for the ice machines current operational state (mode). The operational states are displayed as a numeric value. Each numeric value stands for a specific operation processed by an ice machine. Operational mode values have different meaning between the two manufacturers used for this project.

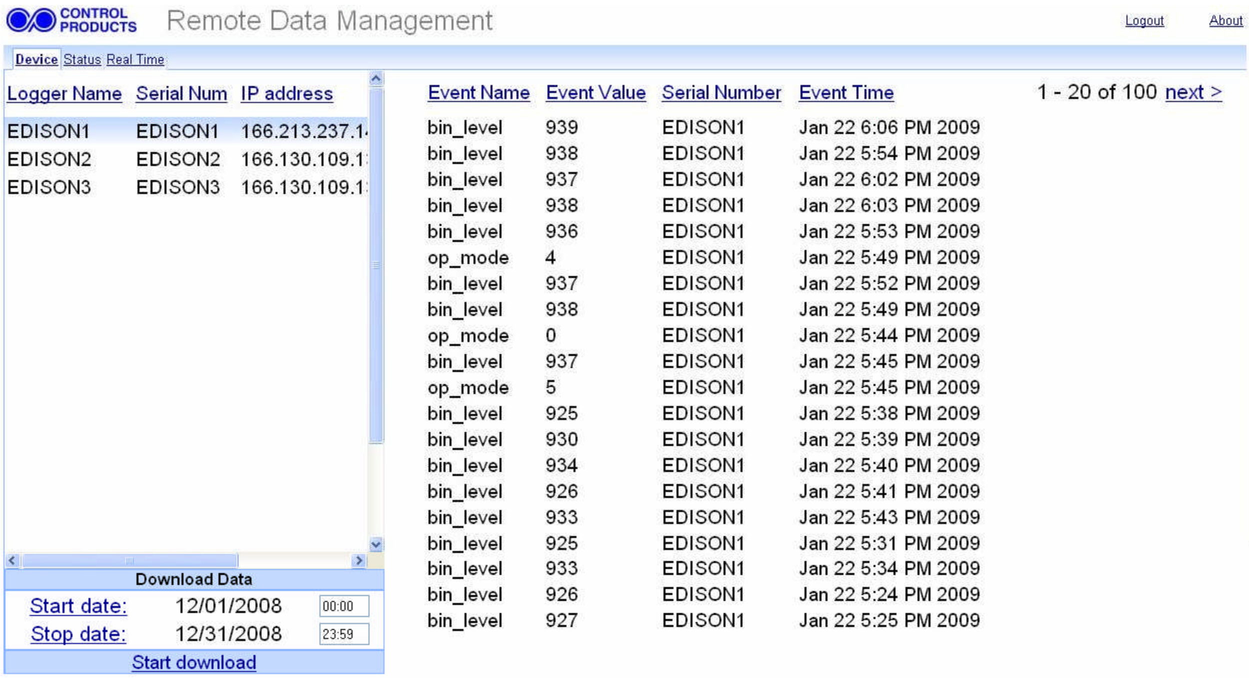


FIGURE 11. DEVICE TAB INTERFACE

Table 2 and Table 3 show the different operational modes and their corresponding values. “Bin_level” uses the incorporated ultra sonic sensor to represent the ice bin levels with numerical values. In the older vintage ice machines, as “bin_level” values increase, the ice bin is fuller. In the newer model ice machine, as “bin level” values decrease, the fuller the ice bin. The Device tab also allows the user to download an ice machine readings for a specific date and time range. Readings can be downloaded by setting the date and time range at the bottom left of the screen. Once configured, clicking on the “start download” link will start the download. The download data is comma separated value (csv) file format.

TABLE 2. HOSHIZAKI ICE MACHINE OPERATIONAL MODE

OP_MODE VALUE	ICE MACHINE OPERATIONAL MODE
0	Bin Full/Dropped signal
1	Power_up
2	Drain
3	Fill
4	Freeze
5	Harvest
6	Alarm
7	Off

TABLE 3. SCOTSMAN ICE MACHINE OPERATIONAL MODE

OP_MODE VALUE	ICE MACHINE OPERATIONAL MODE
0	Dropped signal
2	Immediate off
3	Off
4	Freeze
5	Harvest
6	Restart Refrigeration
7	Bin full
9	Error Shutdown

The Status tab, shown in Figure 12, provides simple graphs for bin levels and operational modes. These graphs only show one day at a time for any specified date. The software filters out any dropped bin level and operational mode events. It plots these filtered results into a simple graph. For best results, raw data should be downloaded from the Device tab and should be adjusted using power consumption data from the end use power monitoring equipment (MDL loggers).

FIGURE 12. STATUS TAB INTERFACE

The Real Time tab, shown in Figure 13, is the interface used to program the ice machine ZigBee communication board and the interface to run and respond a DR event. A Modbus protocol is used for the communication between ZigBee communication board and the ice machine controller. Modbus defines various types of registers that can be used in different situations. The Modbus protocol consists of four components: the register type, the register address, the slave address, and the write data. A Modbus register type is always "4", which is defined as a holding register. The register address is the register description that is being read and written data into it. The register addresses, descriptions, and values are shown in Table 4. The slave address is also a Modbus definition. If there were multiple Modbus devices on the same bus, each would need its own address. For this project there was only one device and its address was assigned to "1". Write data is where a parameter value is assigned to a register address. Write data allows the user to run DR events and define the DR strategies and controls to respond to a DR event. The user defined parameters are the Critical Bin Threshold level, the Normal Bin Threshold level, the Bin Level Drop Rate, and the Ice Usage Amount. Table 4 also shows how to calculate each parameter. When writing a parameter, the "write" check box must be checked. If the write check box isn't checked, the register address will be read for its parameter value. When reading a register address, the parameter value will be populated in the upper right hand corner of the screen.

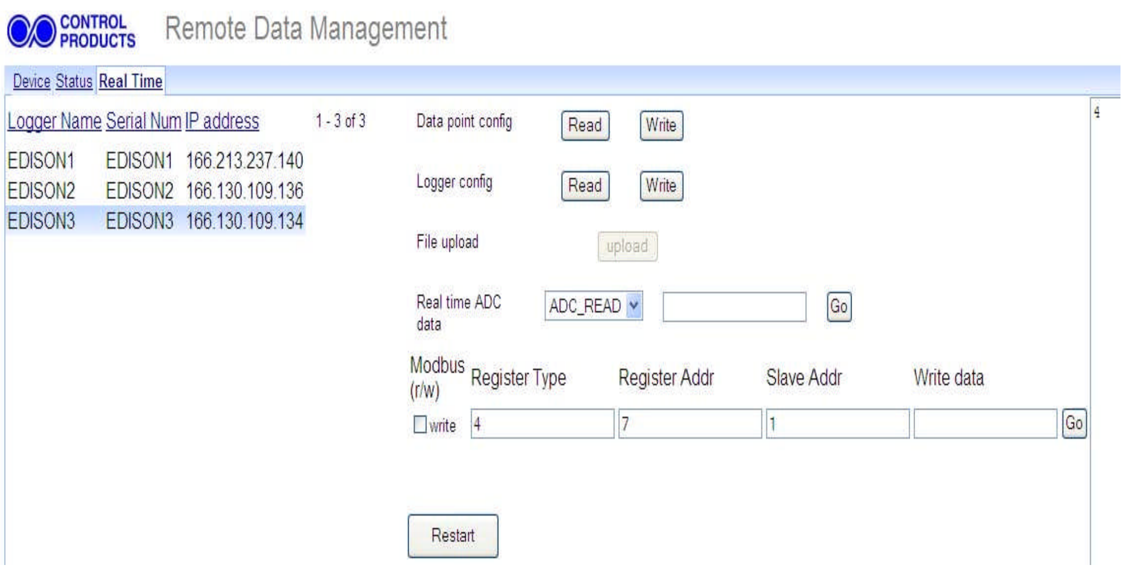


FIGURE 13. REAL TIME TAB INTERFACE

TABLE 4. REGISTER ADDRESS INFORMATION

Register Address	Register Description	Write Data Value
1	Bin Level	(Read Only)
2	DR event start/stop	67 to start DR event / 84 to stop DR event
3	Critical Bin Threshold Level	[(FullBinValue – EmptyBinValue) x 0.25] + EmptyBinValue
4	Normal Bin Threshold Level	[(FullBinValue – EmptyBinValue) x 0.50] + EmptyBinValue
5	Bin Level Drop Rate	0.200 seconds x 1500 = 300 seconds = 5 minutes
6	Usage Amount	(FullBinValue – EmptyBinValue) x 0.1
7	Operational Mode	(Read Only)

RESULTS

Commercial ice machines have the potential to respond to DR events. In this project, ice machine power was curtailed using a simulated the SmartConnect™ meter and a ZigBee link to the ice machine controller. These results are the first steps into understanding the requirements to implement DR strategies and controls for commercial ice machines leveraging the ZigBee Smart Energy application profile.

LABORATORY TESTING

SCOTSMAN CME506 ICE MACHINE (CTAC) & HOSHIZAKI REMOTELY COOLED ICE MACHINE (QUICK SERVICE RESTAURANT)

The older Scotsman ice machine (CME506) and the Hoshiazaki ice machine were not tested in the laboratory. The testing of their retrofit components (the ZigBee communication board and the ultrasonic sensor) was done on the bench. An external ultrasonic bin level sensor was used and was connected to the ice machine communication board. The bin level was simulated by pointing the ultrasonic sensor to a near object (wall) and then to a far object (ceiling). During the testing, the simulated SmartConnect™ meter, the ice machine ZigBee communication board, and the ice machine controller were sitting on bench. Each piece of hardware was within a foot of each other. The DR commands were tested and verified to work by sending them through the remote data management website. Each of the ice machine controllers responded immediately to the DR events by implementing preprogrammed DR strategies (such turning off the ice machine) when they received the DR event signal. The laboratory testing verified the ability to control and log the functions of ice machines. It was also noted that occasionally a bin level or op-mode was dropped and logged as a zero to the server. It was not determined where in the communication link these packets were getting lost.

SCOTSMAN PRODIGY ICE MACHINE (FULL SERVICE RESTAURANT)

This ice machine was brand new and was sent to Controls Products laboratory to be retrofitted and tested. The ice machine was retrofitted with the ZigBee communication board. This newer model ice machine already had a built-in ultrasonic sensor to read the bin level. To test this ice machine, the simulated SmartConnect™ meter was placed about 6 feet directly to the left of the ice machine. The ZigBee communication board inside the ice machine was also located on the left side of the ice machine. The ice machine was allowed to create ice and DR event commands were tested and verified to work by sending them through the remote data management website. During the testing, it was noted the ice machine finishes its ice production cycle before turning off in response to a DR event. It was also noted that occasionally the ice machine would miss a DR command but would always respond if the command was sent 4 to 5 times.

FIELD TESTING

SCOTSMAN CME506 (CTAC)

After the laboratory testing, the hardware was shipped to the CTAC. The ice machine ZigBee communication board was installed inside the ice machine. Once it was in place, the ZigBee communication board was connected to the ice machine controller through an RS-485 connection. The ultrasonic sensor was placed into the ice machine bin and connected to the ZigBee communication board. After the installation, the ultrasonic sensor was calibrated by removing all the ice from the bin and reading its bin level value on the data management website. Removing the ice from the bin, gave the numeric value the ultrasonic sensor would be reading, if the ice bin were empty. Then the ice machine was allowed to run until the bin was completely full. The full bin level value was also recorded. The bin level value was 644 when empty and 1169 when full. With those two values, all other DR strategy parameters where calculated as listed in Table 5.

TABLE 5. OLDER SCOTSMAN ICE MACHINE DR STRATEGY PARAMETERS

Register Address	Register Description	Write Data Value
3	Critical Bin Threshold Level	[(1169 – 644) x 0.25] + 644 = 775
4	Normal Bin Threshold Level	[(1169 – 644) x 0.50] + 644 = 905
5	Bin Level Drop Rate	0.200 seconds x 1500 = 300 seconds = 5 mins
6	Usage Amount	(1169 x 644) x 0.1 = 53

Before any DR events were simulated, a baseline on the ice machine operation was measured. Figure 14 illustrates a typical operational day power data for the CTAC ice machine. Each peak represents a freeze operational mode. Freeze mode is when ice is being formed on the ice coils, which lasts for about 18 minutes. The end of the peak is the harvest mode. The harvest mode lasts about 3 minutes and is when the ice machine defrosts the coils to drop the ice into the storage bin. The freeze mode and harvest mode represent the ice production cycle. The older Scotsman ice production cycle draws about 1.3 kW. The baseline graph starts at noon because the ice machine was typically producing ice during the peak hours of 12:00 to 18:00. Since the ice machine was typically on during peak times, the data on the graph makes it easier to see the ice machine recover during the early off peak hours. CTAC uses a medium volume in the morning and a high volume of ice a little before 12:00. Depending on scheduled events at the facility, ice usage was typically minimal after 12:00. This typical operation suggests the ice machine at CTAC has potential to respond to a DR event.

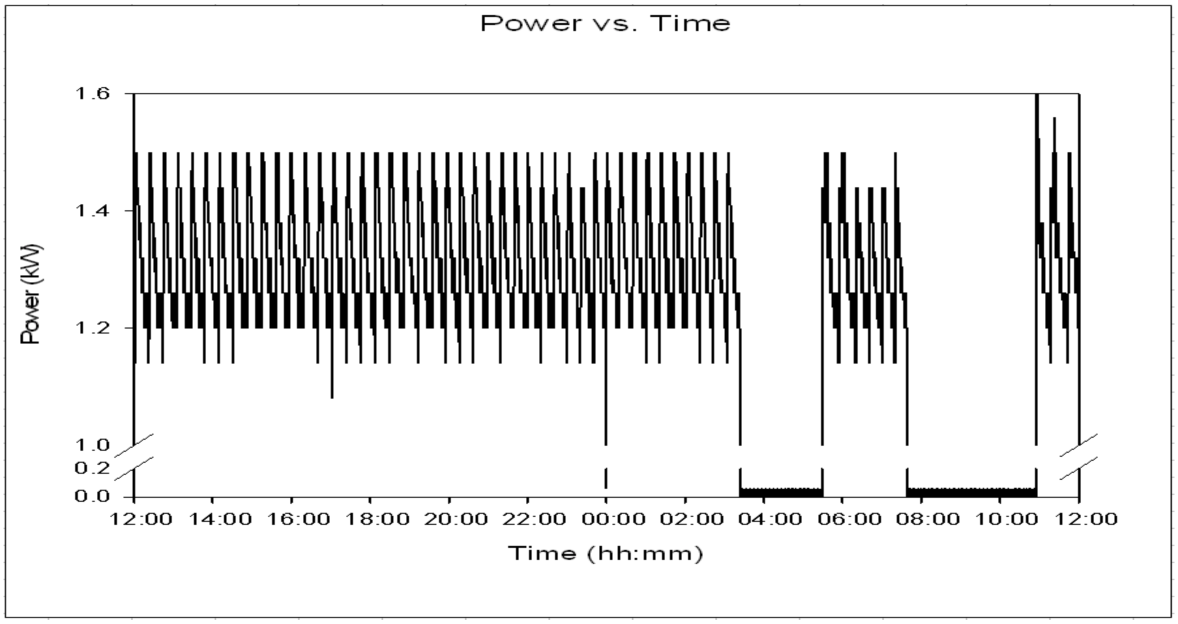
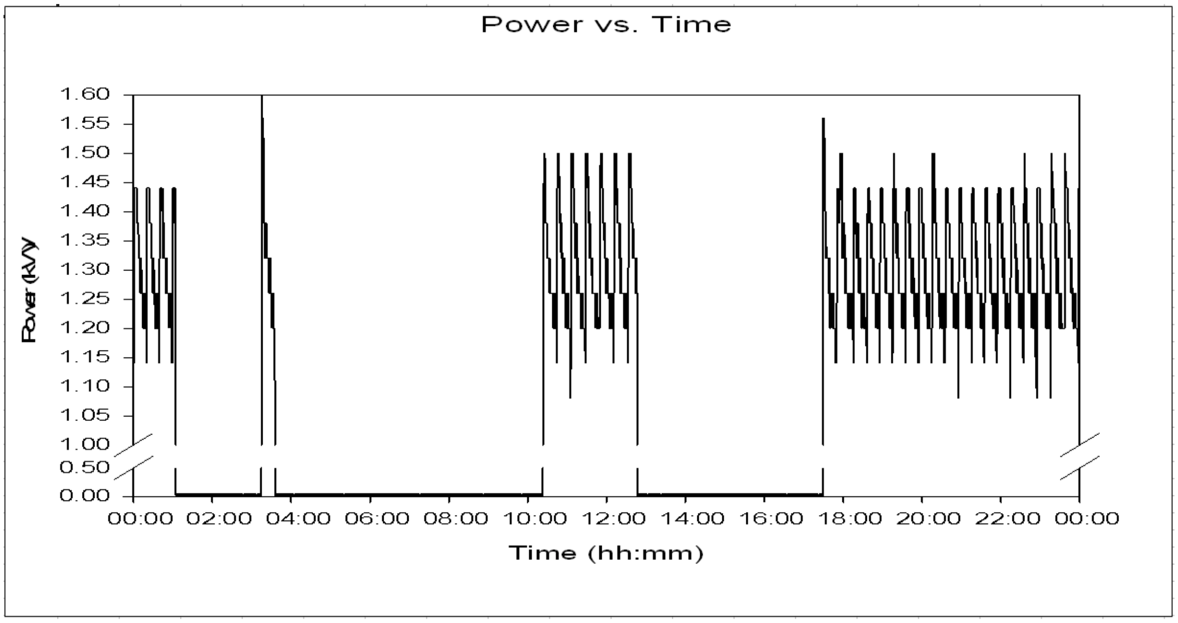


FIGURE 14. TYPICAL ODER SCOTSMAN ICE MACHINE POWER CONSUMPTION (CTAC)

Figure 15 displays the power consumption and the bin level of the older Scotsman ice machine during a DR event test day. Power data was used to compare and verify the Op_mode value registered on the data management website. It was noted that on some occasions, the data management website dropped Op_mode information somewhere in the communication link. Also, when testing a DR event, commands to start and stop a DR event had to be sent multiple times with no confirmation. Confirmation became important because it was unknown whether the simulated SmartConnect™ meter and ice machine communication board received the DR signal. Without confirmation, it was unknown where in the communication link data was being lost. The only signal confirmation was the ice machine's operational state of on or off. In this particular example, the ice machine recovered from previous day ice usage at about 1:00 (1 am) and basically remained off until 10:00 (10 am). At 10:00, 25% of the bin's ice capacity was used and the ice machine controller began creating ice. Around 12:45 (12:45 pm), a DR event was sent to the ice machine. The ice machine was able to participate in the DR event since the bin level was not very low. The DR event lasted until 17:30 (5:30 pm) and the ice machine controller began producing ice again. The ice machine was able to fill the ice bin up by 4:30 (4:30 am) the following morning.



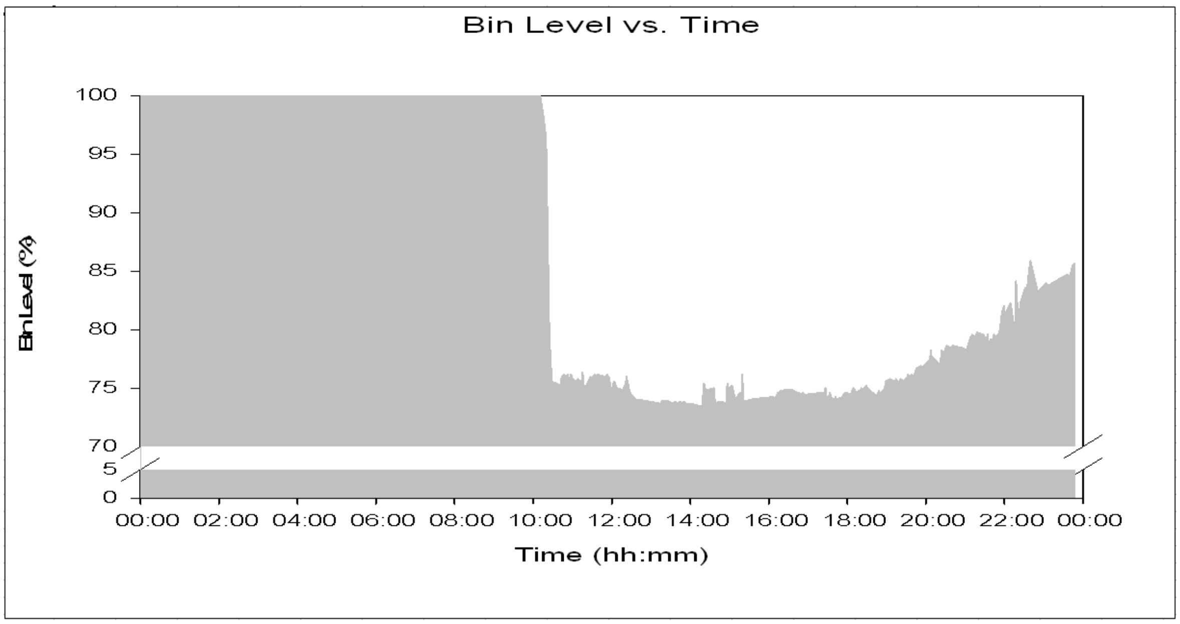


FIGURE 15. DR EVENT EXAMPLE AT CTAC KITCHEN (OLDER SCOTSMAN ICE MACHINE)

Figure 16 displays the type of tests performed only at the CTAC kitchen facilities because these tests could be performed without affecting the customer's operations. These tests were used to verify the ability of the proposed DR strategies to override a DR event. The tests verified the ability to override a DR event if a) the Critical Bin Threshold level of 25% was reached or b) the Bin Level Drop Rate of 10% in a 5-minute period with Normal Bin Threshold level under 50% was reached.

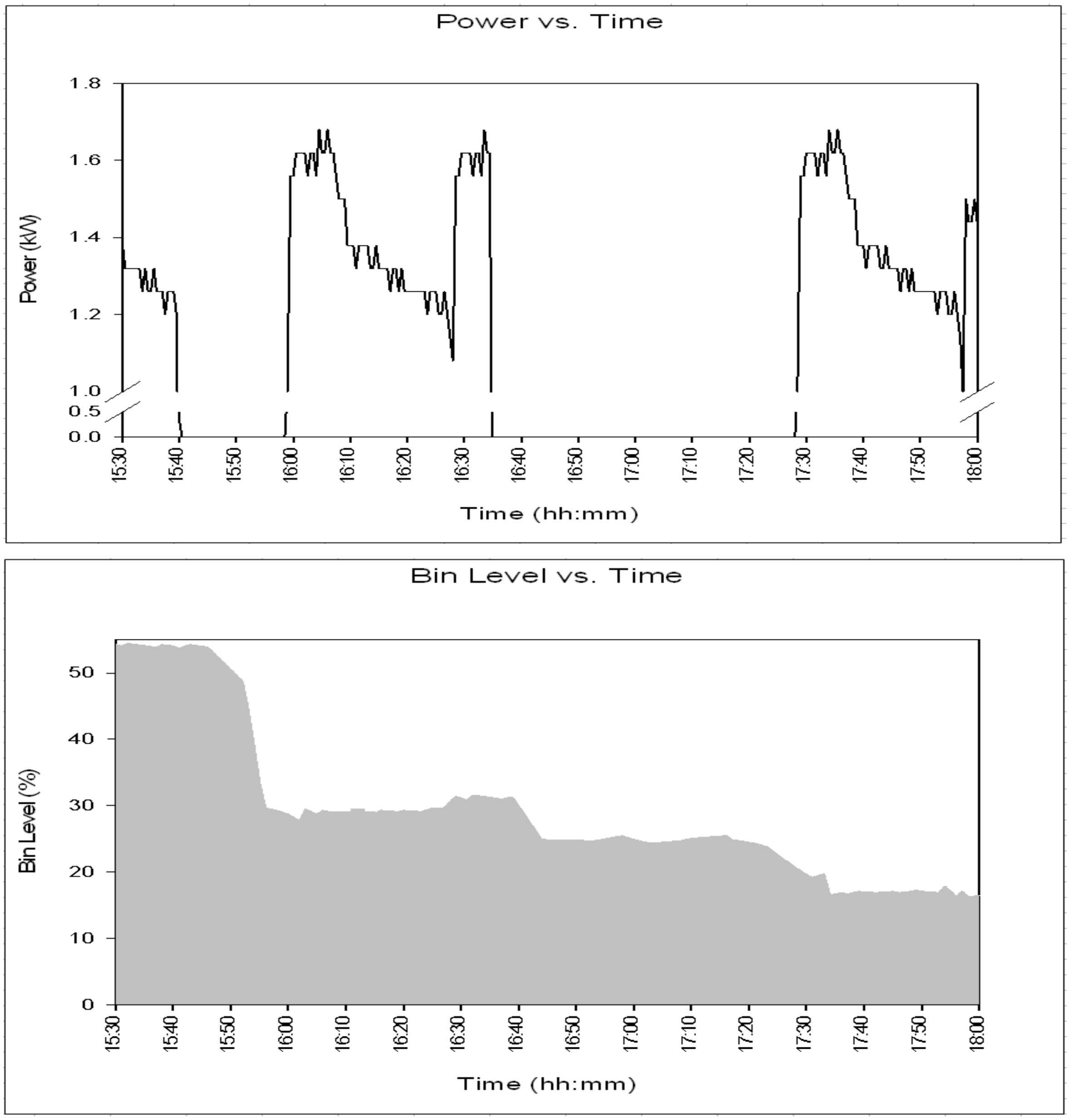


FIGURE 16. OVERRIDE DR EVENT TESTS (CTAC)

The Normal Bin Threshold level was around 50% at the start of the test. At 15:40 (3:40 pm), a DR event was sent to the ice machine. The ice machine participated in the DR event. At 15:50 (3:50 pm), ice was scooped out of the bin to simulate a 10% drop in ice. At 15:58, the ice machine ZigBee communication board commanded the ice machine controller to cancel the DR event and to begin produce ice. One cycle of ice is allowed to be completed. At 16:35 (4:35 pm), another DR event sent to the ice machine. It participates in the event and no longer creates ice. The ice is removed from the bin at a slower rate until the 25% Critical Bin Threshold level is reached. Once that occurred, the ice machine canceled the DR event and began to produce ice again at 17:28 (5:28 pm).

SCOTSMAN PRODIGY (FULL SERVICE PIZZA RESTAURANT)

The Scotsman Prodigy ice machine is a brand new model and was sent to Controls Products laboratory to be retrofitted and tested. The ice machine was retrofitted with the ZigBee communication board. This newer model ice machine already had a built in calibrated ultrasonic sensor to read the bin level. The bin level value was 29 when the bin is empty and 7 when full. With those two values, all other DR strategies and controls parameters where calculated as listed in Table 6.

TABLE 6. SCOTSMAN PRODIGY ICE MACHINE DR STRATEGY PARAMETERS

Register Address	Register Description	Write Data Value
3	Critical Bin Threshold Level	[(7 – 29) x 0.25] + 29 = 18
4	Normal Bin Threshold Level	[(7 – 29) x 0.50] + 29 = 24
5	Bin Level Drop Rate	0.200 seconds x 1500 = 300xseconds = 5 mins
6	Usage Amount	(7 – 29) x 0.10 = 3

Before any DR events were simulated, a baseline on the ice machine operation was measured. Figure 17 illustrates a typical operational day power data for full service pizza restaurant ice machine. Each peak represents a freeze operational mode. Freeze mode is when ice is being formed on the ice coils, which lasts for about 15 minutes. The end of the peak is the harvest mode. The harvest mode lasts about 3 minutes and is when the ice machine defrosts the coils to drop the ice into the storage bin. The freeze mode and harvest mode represents the ice production cycle. The Scotsman Prodigy ice production cycle draws about 1.2 kW. The baseline graph starts at noon because the ice machine was typically producing ice during the peak hours of 12:00 to 18:00. Since the ice machine was typically on during peak times, the data on the graph makes it easier to see the ice machine recover during the early off peak hours. Full service pizza restaurant uses a medium volume of ice a little before 12:00 (noon) to fill the fountain drink ice bins. A higher volume of ice is needed to fill the fountain drink ice bins again around 17:00 (5 pm) for the dinner rush. It takes the ice machine until around 23:00 (11 pm) to recover the ice bin levels. This typical operation suggests the ice machine at the full service pizza restaurant has a high potential to respond to a DR event.

Although, the baseline for full service pizza restaurant indicated a high potential to respond to DR events, the data management website was only able to read the bin level and operational mode of the ice machine. It is unclear why the data management website was unable to send DR events to the ice machine at the site, given that it worked in the laboratory.

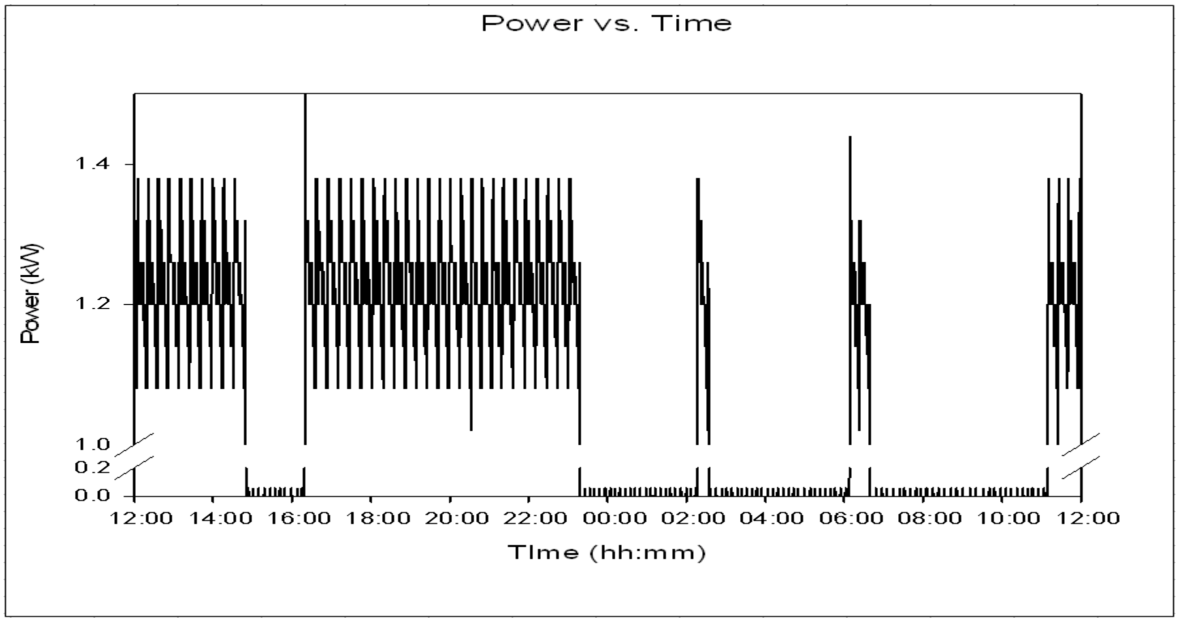


FIGURE 17. TYPICAL SCOTSMAN PRODIGY ICE MACHINE POWER CONSUMPTION (FULL SERVICE RESTAURANT)

HOSHIZAKI REMOTELY COOLED ICE MACHINE (QUICK SERVICE CHICKEN RESTAURANT)

After laboratory testing, the hardware was shipped to the quick service chicken restaurant. The ice machine ZigBee communication board was installed inside the ice machine. Once it was in place, the ZigBee communication board was connected to the ice machine controller through an RS-485 connection. The ultrasonic sensor was placed into the ice machine bin and connected to the ZigBee communication board. After the installation, the ultrasonic sensor was calibrated by removing all ice inside the bin and reading its bin level value on the data management website. Removing the ice from the bin gave the numeric value the ultrasonic sensor would be reading if the ice bin were empty. Then, the ice machine was allowed to run until the bin was completely full. The full bin level value was also recorded. The bin level value was 450 when empty and 945 when full. With those two values, all other DR strategy parameters where calculated as listed in Table 7.

TABLE 7. HOSHIZAKI ICE MACHINE DR STRATEGY PARAMETERS

Register Address	Register Description	Write Data Value
3	Critical Bin Threshold Level	[(945 – 450) x 0.25] + 450 = 574
4	Normal Bin Threshold Level	[(945 – 450) x 0.50] + 450 = 698
5	Bin Level Drop Rate	0.200 seconds x 1500 = 300 seconds = 5 mins
6	Usage Amount	(945 – 450) x 0.1 = 50

Before any DR events were simulated, a baseline on ice machine operations was measured. Figure 18 illustrates a typical operational day power data for the quick service chicken restaurant ice machine. Each peak represents a freeze operational mode. Freeze mode is when ice is being formed on the ice coils, which lasts for about 30 minutes. The end of the peak is the harvest mode. The harvest mode lasts about 5 minutes and is when the ice machine defrosts the coils to drop the ice into the storage bin. The freeze mode and harvest mode represent the ice production cycle. The Hoshizaki ice production cycle draws about 2.2 kW. The baseline graph starts at noon because the ice machine was typically producing ice during the peak hours of 12:00 to 18:00. Since the ice machine was typically on during peak times, the data on the graph makes it easier to see the ice machine recover during the early off peak hours. The quick service chicken restaurant uses a medium volume of ice around 9:00 (9 am) for chicken preparation. A high volume of ice is used for the fountain drink bins around 12:00 (noon). Depending on business, ice usage typically is minimal after 12:00. This typical operation suggests the ice machine at the quick service chicken restaurant has a high potential to respond to a DR event.

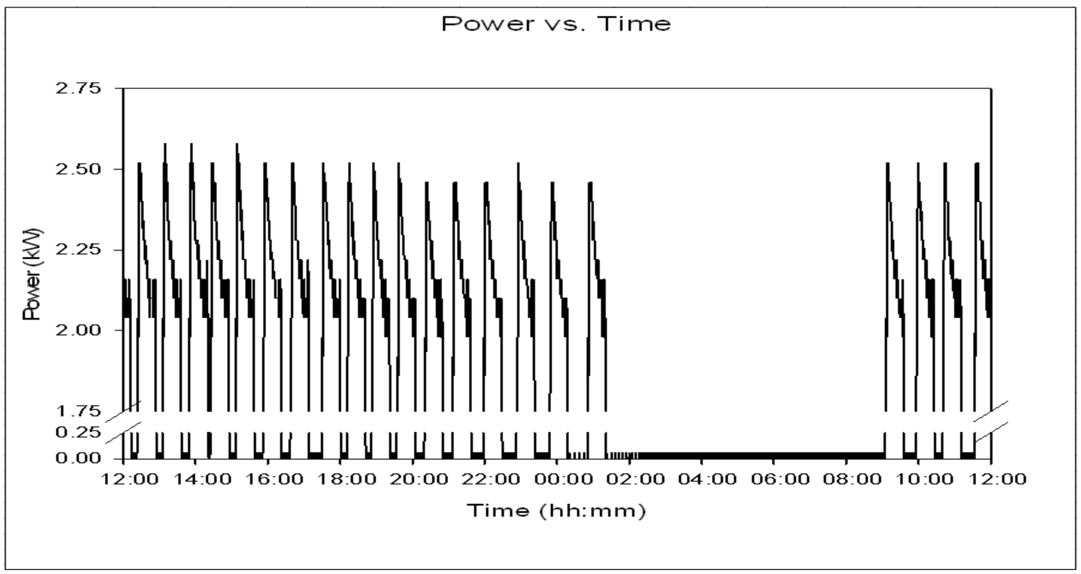


FIGURE 18. TYPICAL HOSHIZAKI ICE MACHINE POWER CONSUMPTION (QUICK SERVICE RESTAURANT)

Figure 19 displays the power consumption and the bin level of Hoshizaki ice machine during a DR event test day. Power data was used to compare and verify the Op_mode value registered on the data management website. It was noted on some occasions that the data management website dropped Op_mode information somewhere in the communication link. Also when testing a DR event, commands to start and stop a DR event had to be sent multiple times with no confirmation. Confirmation became important because it was unknown whether the simulated SmartConnect™ meter and/or ice machine communication board received the signal. Without confirmation, it was unknown where in the communication link data was being lost. The only signal confirmation was the ice machine's operational state of on or off. In this particular example, the ice machine recovered from the previous days' ice usage at about 23:00 (11 pm) that same day. The ice machine remained off until 8:00 (8 am) when a small amount of ice was used for food preparation.

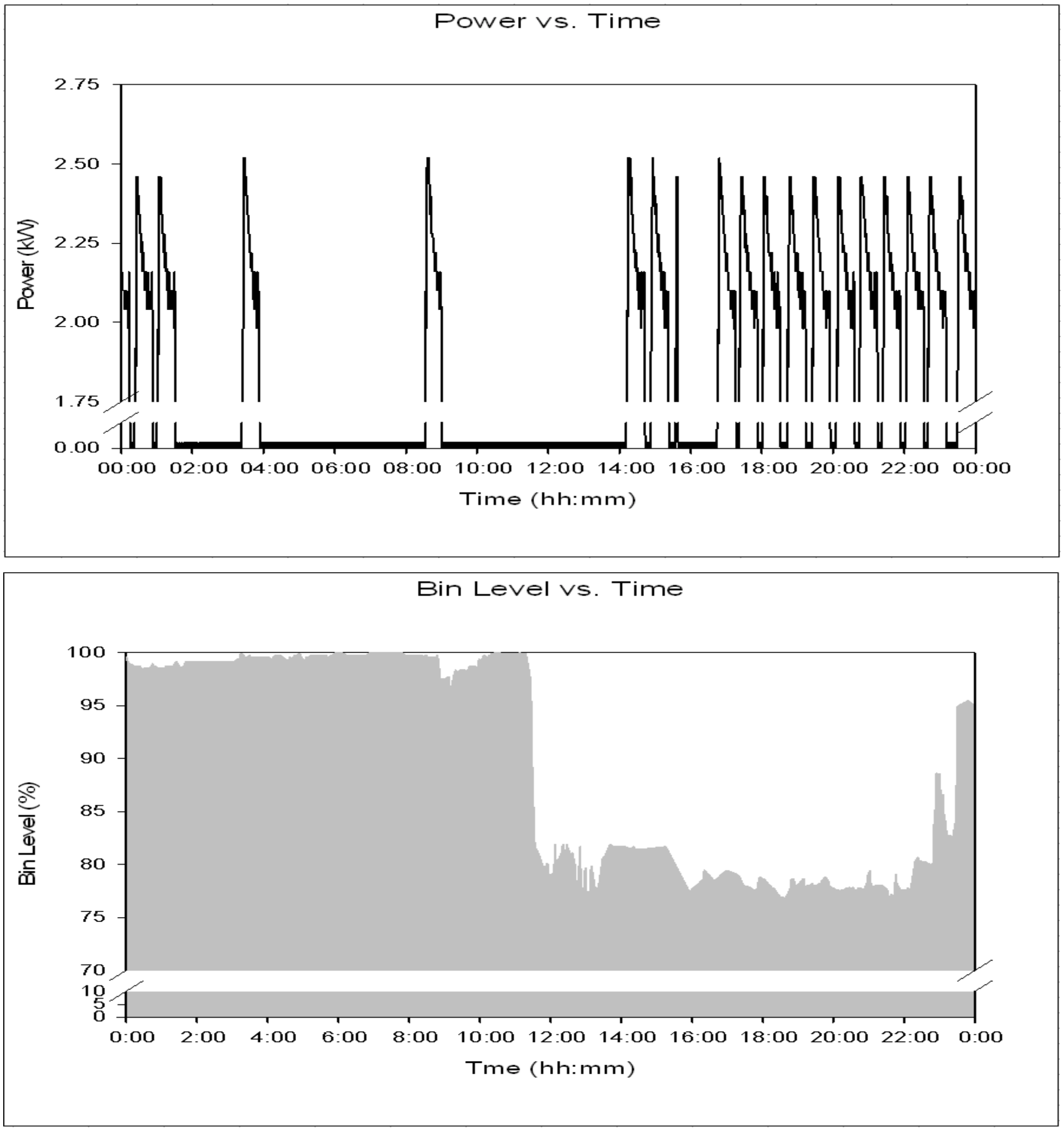
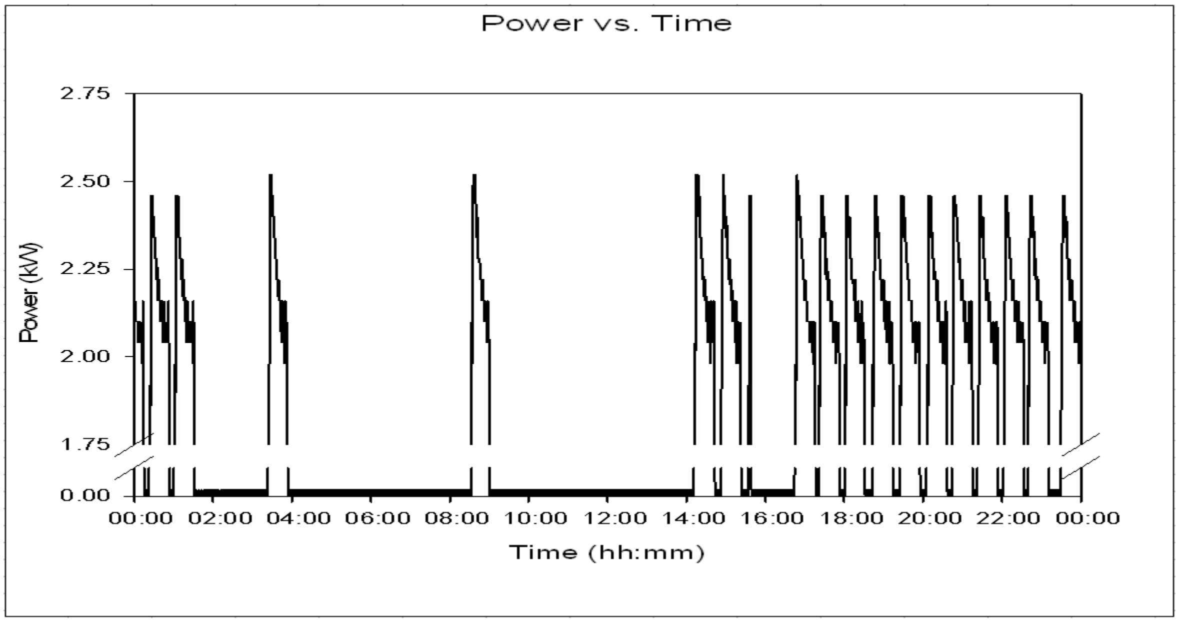


FIGURE 19. DR EVENT TEST AT QUICK SERVICE RESTAURANT (HOSHIZAKI ICE MACHINE)

At 11:30 (11:30 am), 20% of the bin's ice capacity was used and the ice machine controller began creating ice. Around 12:45 (12:45 pm), a DR event was sent to the ice machine. The ice machine was able to participate in the DR event since the bin level was not very low. The DR event lasted until 17:30 (5:30 pm) and the ice machine controller began creating ice again. The ice machine was able to fill the ice bin up by 3:00 (3 am) the next day.

Figure 20 displays the critical bin level threshold test. The actual critical bin level threshold is normally 25%, but going that low could affect the customer's business. Instead, the critical bin level threshold was raised to 70%. This allowed a safe verification of the ZigBee application profile.



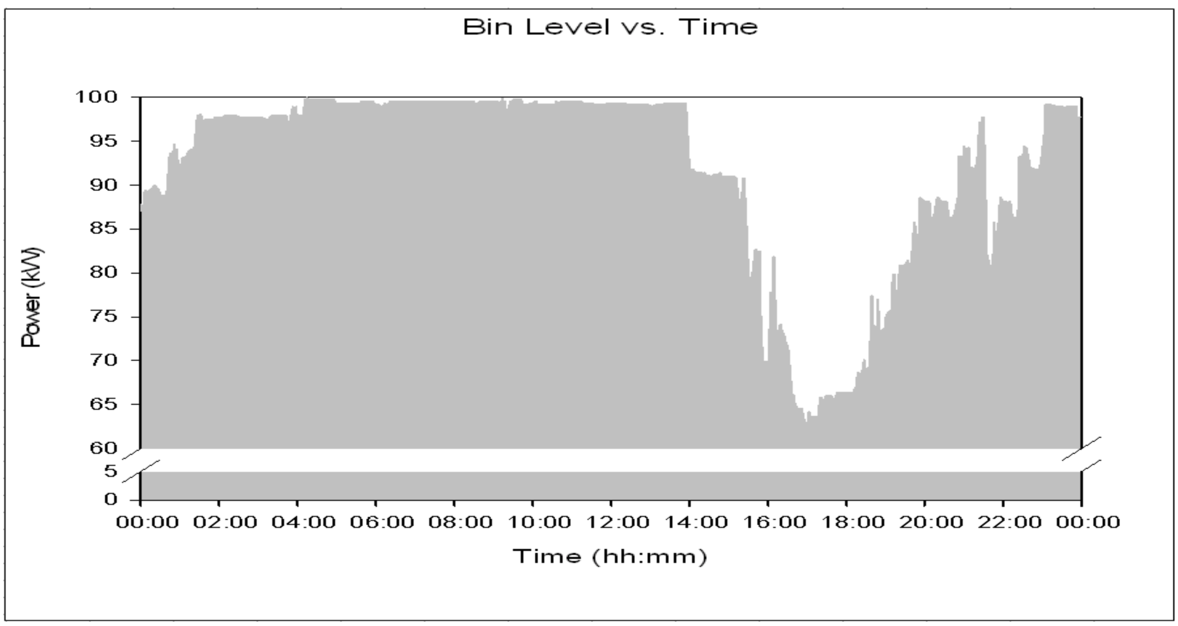


FIGURE 20. CRITICAL BIN LEVEL TEST AT QUICK SERVICE RESTAURANT

At 15:45 (3:45 pm), a DR event was sent to the ice machine. The ice machine participated in the DR event. At 17:00 (5 pm), 35% of the bin's ice capacity was used. The bin level dropped under the raised Critical Bin Threshold and the ice machine controller began creating ice again.

PROJECT CONCLUSIONS & RECOMMENDATIONS

Ice machines show a high potential to respond to a DR event due to their ability to store large quantities of ice. The typical operation of ice machines in the foodservice market sector showed potential to implement DR strategies. The benefit for the utility was verified, when ice machines responded to DR events during the on-peak period (noon to 6 pm). The DR strategies proposed, and successfully tested, in this project made it possible to safely curtail the ice machine loads during peak periods.

The goal of this project was to discover if it was possible to curtail ice machine load during on peak hours leveraging the ZigBee Smart Energy application profile. A user interface was developed to manage ice machine information and run DR events. A simulated SmartConnect™ infrastructure was used, given than the SmartConnect™ infrastructure has not been fully deployed yet, to curtail and verify curtailment of ice production process during a DR event.

The proposed DR strategies were dependent on three parameters: a Critical Bin Threshold, a Normal Bin Threshold, and a Bin Level Drop Rate. The Critical Bin Threshold is the lowest ice level in the bin, before it cancels or does not allow participation in a DR event. The Critical Bin Threshold proposed for this project was 25%, which left customers with enough ice until the ice making process is reengaged. The Normal Bin Threshold is the ice level upper limit in the bin, before an ultra sonic sensor can cancel a DR event. The Normal Bin Threshold proposed for this project was 50%. The Bin Level Drop Rate represents the ice removal rate from the bin. The Bin Level Drop Rate proposed for this project was 10% drop in 5 minutes. Once ice level is below the Normal Bin Threshold, but above the Critical Bin Threshold, if the ice level dropped 10% in a five-minute time period, the DR event would be cancelled. By providing a 25% Critical Bin Threshold and/or a 10% Bin Level Drop Rate with a Normal Bin Threshold of 50%, the DR strategy protected the customers' ice production needs.

These DR strategies were successfully implemented in two different brands of ice machines: Hoshizaki and Scotsman. The retrofit was also successful in two different ice machine configurations: self-contained ice machines and remotely cooled ice machines. By testing the DR strategies and ZigBee connectivity on different brands and configurations of ice machines, the project was able to demonstrate DR capabilities are applicable to different commercial ice machine manufacturers

The following activities can further enhance the availability of reliable DR-ready commercial ice machines in the near future.

- **ENGAGEMENT OF ICE MACHINE MANUFACTURERS**. Continue discussion with the ice machine manufacturers and control vendors to develop smarter and DR-ready ice machine controllers.
- **A CONTROLLER THAT IS ABLE TO BASELINE ICE PRODUCTION AND SCHEDULES.** With the ice production and schedules history, the controller would be able to make ice dependent on ice demand. Thus increasing the opportunity for more sophisticated DR strategies.
- **A CONTROLLER WHICH HAS THE ZIGBEE RADIO, SMART ENERGY PROFILE, AND DR LOGIC INTEGRATED INTO THE ICE MACHINE.** This integration would enable the registration of the ice machine with SCE's SmartConnect™ infrastructure, which would be ideal and most cost effective way to have high market penetration with SCE service territory.

- **AN INTERFACE FOR CUSTOMERS TO CUSTOMIZE DR STRATEGIES EMBEDDED IN THE ICE MACHINE CONTROLLER**. Engage the ice machine manufacturers, control vendors, and the foodservice industry to help in the development of specifications for an interface to customize the DR strategies.

APPENDIX A

TABLE A TOTAL COMMERCIAL ICE MACHINES IN SCE TERRITORY BY REGISTERED NAICS ACCOUNTS

BUILDING DESCRIPTION	INDUSTRY NAICS	ACCOUNTS IN SCE TERRITORY	TOTAL ICE MACHINES
Hospitals General Medical and Surgical	622110	973	5848
Hospitals Mental (except retardation)	622210	71	427
Hospitals Specialty (except psychiatric, substance abuse)	622310	32	192
		1076	**6467**
Office Buildings (multi-tenant)	531120	22104	1209
		22104	**1209**
Nursing Care facilities	623110	678	2034
Residential mental retardation Facilities	623210	3	9
Residential mental health and substance abuse	623220	160	480
Community care for elderly	623310	152	456
Homes for elderly	623312	233	699
Other Residential Care Facilities	623990	308	924
		1534	**4602**
Hotels Except casinos	721110	4052	15479
Casino Hotels	721120	19	73
Bed and Breakfast Inns	721191	21	80
Other Traveler Accommodations	721199	2	8
RV Parks and Campgrounds	721211	1187	4534

Building Description	Industry NAICS	Accounts in SCE Territory	Total Ice Machines
Recreational and Vacation Camps	721214	175	669
Rooming and Boarding Houses	721310	97	371
		5553	**21212**
Full Service Eating (seat down restaurant)	722110	13271	10888
Limited Service Eating (Fast food, pizza, takeout)	722211	17212	14121
Cafeterias	722212	294	241
Snack and Nonalcoholic Bars	722213	6435	5279
Food Service Contractors	722310	20	16
Caterers	722320	335	275
Mobile Food Services	722330	69	57
Drinking Places (Alcoholic)	722410	1481	1215
		39117	**32092**
Elementary and secondary schools	611111	4150	1135
Elementary and secondary schools	611112	565	154
Elementary and secondary schools	611113	1853	507
Elementary and secondary schools	611114	286	78
Elementary and secondary schools	611115	121	33
Elementary and secondary schools	611116	768	210
Junior Colleges	611211	378	103
Junior Colleges	611212	44	12
Colleges Universities and Professional Schools	611311	365	100
Colleges Universities and Professional	611312	575	157

Building Description	Industry NAICS	Accounts in SCE Territory	Total Ice Machines
Schools			
Business and Secretarial Schools	611410	14	4
Business and Secretarial Schools	611420	58	16
Business and Secretarial Schools	611430	4	1
Trade Schools	611511	154	42
Trade Schools	611512	57	16
Trade Schools	611513	11	3
Trade Schools	611519	477	130
Fine arts schools	611610	827	226
Sports and Recreation Instruction	611620	913	250
Language schools	611630	79	22
All other schools	611691	644	176
All other schools	611692	143	39
All other schools	611699	371	101
		12857	**3515**
Grocery Stores	445110	3313	906
		3313	**906**
Retail (Convenience Stores)	445120	2693	147
Retail (Specialty food stores)	445210	568	31
Retail (Gas Stations with Convenience Stores)	447110	3840	210
Retail (Gas Stations without Convenience Stores)	447190	769	42
		7870	**430**
Total Number of Buildings		**93424**	
Total Number of Ice Machines			**70435**

TABLE B RATIO OF ICE MACHINES PER BUILDING TYPE FROM 1996 ARTHUR LITTLE REPORT

BUILDING TYPE	BUILDING INVENTORY (1000)	ICE MACHINE INVENTORY (1000)	RATIO OF ICE MACHINES PER BUILDING TYPE
Office	614	33.6	0.05
Retail	1287	70.4	0.05
Restaurant	201	164.9	0.82
Grocery	102	27.9	0.27
School	241	65.9	0.27
Hotel	137	524.5	3.83
Hospital	52	312.8	6.02

It is highly unlikely that restaurants, even in aggregate, would have less than one (1) ice machine per restaurant (0.82). In fact, most restaurants have more than one ice machine. Similarly, it is doubtful that only about 25 percent (0.27) of groceries have ice machines. Although, not listed in the 1996 Arthur Little Report[1], drinking places (alcoholic beverages) most likely have at least one (1) ice machine.

REFERENCES

[1] U.S. Department of Energy, Office of Building Technologies, *Energy Savings Potential for Commercial Refrigeration Equipment*. Prepared by Arthur D. Little, Inc., June 1996, Final Report. Reference 46230-00. Table 4-31: Ice Machine Primary Energy Usage, Page 46.

[2] Pacific Gas and Electric, *Codes and Standards Enhancement Initiative for PY 2004: Title 20 Standards Development, Analysis of Standards Options for Commercial Packaged Refrigerators, Freezers, Refrigerator-Freezers, and Ice Makers*. Prepared by American Council for an Energy-Efficient Economy, April 2004. Page 4.

[3] Pacific Gas and Electric, Work Paper, PGECOFST108, Commercial Ice Machines, December, 2007.