Hotel Front Desk Energy Management System

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Prepared for:

Prepared by:

Preface

PROJECT TEAM

This project is sponsored by San Diego Gas & Electric's (SDG&E®) Emerging Technologies Program (ETP) with Abdullah Ahmed (aahmed1@semprautilities.com) as the project manager. Bob Levine, General Manager, was the contact and project manager for the Best Western Plus Island Palms Hotel & Marina (Best Western). Daryl DeJean (daryldejean@gmail.com) of Emerging Technologies Associates, Inc. (ETA) provided project consulting and coordination of all parties involved and the Western Cooling Efficiency Center (WCEC) provided technical consulting and conducted data collection and analysis for the project.

DISCLAIMER

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Abbreviations and Acronyms

A Amp

AC Air Conditioning

DDC Direct Digital Control

DR Demand Response

EER Energy Efficiency Ratio

EMS Energy Management System

ETA Emerging Technologies Associates, Inc.

ETP Emerging Technologies Program

F Fahrenheit

GE General Electric

GMIC Green Meeting Industry Council

HVAC Heating Ventilation and Air Conditioning

kW Kilowatt

kWh Kilowatt hours

NW Northwest

OAT Outdoor Air Temperature

PG&E Pacific Gas & Electric

PTHP Packaged Terminal Heat Pump

SDG&E® San Diego Gas & Electric

SE Southeast

TMY Typical Metrological Year

V Volt

WCEC Western Cooling Efficiency Center

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Executive Summary

Occupancy-based controls reduce energy use when spaces are unoccupied. These type of controls are commonly used in lighting systems and space heating and cooling but have not been widely adopted in hotel guest room HVAC systems. This lack of adoption can be attributed to hotel management's concern about the time delay in returning an unoccupied room to the guest's desired temperature when occupancy resumes.

Great advancements have been made in HVAC control technology where sophisticated controls can calculate setback/setup (adjusted) temperatures based upon the amount of time the HVAC equipment needs to bring the room back to the guest or hotel's defined setpoint (pre-determined) temperature. This technology addresses the hotel management's concern about the time delay of returning an unoccupied room back to the guest's desired temperature.

San Diego Gas and Electric's (SDG&E®) Emerging Technologies Program (ETP) had previously conducted an assessment project on occupancy-based digital direct control (DDC) thermostats with the following features:

- When a hotel room is occupied, an occupancy sensor allows the HVAC to maintain the guest desired temperature settings
- When the hotel room is unoccupied, the DDC will either turn off the system or allow the system's thermostat to maintain preset energy-saving temperature settings programmed by the hotel management

Due to the results of the previous assessment project, SDG&E® was interested in determining if extending the control to the hotel front desk via an energy management system (EMS) would provide any additional energy savings. SDG&E® hoped that even deeper setbacks could be implemented on rooms that were vacant or unoccupied for extended periods of time to further increase the energy savings. More importantly, the hotel front desk could also adjust the room temperature prior to guest check-in to bring the room to a comfortable level, thereby increasing market adoption.

The Best Western Plus Island Palms Hotel & Marina (Best Western) was interested in participating in this project since its ownership was seeking deeper energy savings to reduce operating costs throughout its portfolio of hotels. The ownership believed that the guest room control concept with a hotel front desk EMS provided an opportunity to achieve this goal.

The key elements of the scope of work included energy efficiency and ensuring the comfort and satisfaction of hotel guests. Of particular interest was the total installed cost of the system including the central EMS. SDG&E® was interested in the installation cost for the following reasons:

- what level of control is available and acceptable to the market place

- the potential program required to fuel market adoption given San Diego County's significant hospitality market
- determine whether the technology is market ready

The Best Western ownership installed the occupancy-based DDC thermostats integrated with a hotel front desk EMS in forty-eight rooms of a new addition to their hotel. For this project, twelve rooms were selected based upon their orientation, to monitor, analyze data and determine the system's performance. The twelve rooms were divided into three groups of four rooms:

- Baseline: the digital thermostat was manually controlled by the guest
- Occupancy Controls: DDC thermostat with integrated occupancy sensor and energy saving controls
- Occupancy Controls + EMS: the occupancy-based DDC was integrated with the hotel front desk EMS. The EMS is expected to enable deeper temperature setbacks for unsold rooms and the ability to activate an automatic load shed during demand response events

The results of the project indicated that energy consumption was in fact reduced in the Occupancy Controls and Occupancy Controls + EMS group. The results are shown in Table 1.

Table 1: Energy Savings from EMS

Group	Annual Energy Usage (kWh)	Annual Energy Cost ($)	Annual Energy Cost Savings per Room ($)
Baseline	400	64	-
Occupancy Controls	330	53	11
Occupancy Controls + EMS	300	48	16

The results of this project are more in line with the report published by PG&E[1] and substantially reduces the projected savings in the previous SDG&E® report[2].

As a result of this project, hotels can slightly enhance their energy efficiency, improve their greenhouse gas emissions, market themselves as complying with guidelines of the Green Meeting Industry Council (GMIC)[3] and participate in demand response (DR) programs to better control peak demand for power. GMIC is the gatekeeper for the meeting planning industry tasked to develop standards for meeting venues including the lodging industry.

[1] http://www.etcc-ca.com/images/pge_hrc_occ_sens_rpt-_final_042610-2.pdf
[2] http://www.etcc-ca.com/images/hotel_guest_room_controls_final.pdf
[3] http://www.greenmeetings.info/

SDG&E® has two main climate zones in its service territory: Coastal and Inland. The selected hotel was located in the Coastal climate zone (climate zone 7) which is the southernmost coastal region of CA. The very mild climate in this zone is due to its latitude and the warm ocean water which affects the air temperature over it, which in turn moderates temperatures over the coastal strip. Weather in the summer is warm and comfortable, though hot enough on some days that cooling is necessary. Likewise, in the winter, heating is necessary at times[4].

Due to its mild and tolerable climate conditions, the Coastal climate zone is marked by a low energy consumption. Therefore, it is recommended that future projects be conducted in Inland climate zones, which require more heating and cooling for thermal comfort[5], and include a larger sample size as well. For national impact, a study should also be conducted in other areas such as Desert and Mountain.

4 http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zone_07.pdf

5 http://www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/arch/climate/california_climate_zone_10.pdf

Introduction

A large fraction of hotel energy use and peak energy demand can be attributed to space conditioning loads. Hotel occupants are generally not concerned with HVAC energy use because there is no immediate cost impact to the occupant. This can lead to occupants lowering and raising setpoint temperatures in the summer and winter, respectively. This adjustment of the setpoint results in a greater load on the HVAC equipment. Additionally, occupants may not change the setpoint when leaving their room, resulting in a lot of space conditioning energy use and peak energy demand when rooms are unoccupied.

Technological advances in HVAC control technology in the last ten years led to an increased interest in how such controls can perform in the hospitality industry. Typically, hotel guest rooms still have simple manually controlled digital thermostats. The trend in the past several years has been that some of the major chains have adopted the use of direct digital control (DDC) thermostats, conducting their own tests to prove energy savings.

The Hotel Front Desk Energy Management System project assessed the performance of the integration of individual guest room DDC and a hotel front desk energy management system (EMS). The performance of the integrated system was determined by correlating outside air temperature to HVAC energy consumption.

Project Objectives

SDG&E® ETP conducted the Hotel Front Desk Energy Management System with the following objectives:

- potential incremental energy and demand savings
- cost effectiveness of a central EMS providing the hotel front desk staff control of guest room HVAC
- determine ease of use and functionality of the control technology for the hotel front desk staff
- effectiveness of the EMS for DR programs

Project Background

TECHNOLOGICAL OVERVIEW

The manually controlled digital thermostat is the most basic temperature control device in a hotel guest room. These thermostats offer no automatic control over the energy used in conditioning the room. The hotel guest sets the temperature where they desire. The room maintains that temperature regardless of whether the guest is in the room or not.

DDC thermostats adjust the HVAC temperature settings based upon the room's pre-programmed setpoints. However, even with the DDC thermostats, there still exists an opportunity for even greater savings when a room is unoccupied for a long period of time. Hotel operators can adjust room temperature settings to deeper energy saving setpoints when a room is unsold for less than seventy-two hours. However, hotel operators are usually reluctant to do this due to their concern about room temperature and guest satisfaction, an issue that is prevalent across the hospitality industry. A possible solution to overcome this problem would be to minimize the amount of time it takes for the guest room temperature to reach a comfortable level upon guest arrival.

The market entry of a hotel front desk EMS integrated to the DDC may provide the mitigation of the risk hotel owners and managers believe are inherent in deep energy saving temperature adjustments. The system claims to deliver optimum energy savings without compromising guest comfort. When a room is occupied, the temperature selected by the guest is maintained in the systems memory. Once the room is unoccupied, the thermostat temperature is adjusted to energy saving setpoints.

The system is continually performing calculations that evaluate how far each guest room's temperature can drift from the guest's preferred temperature setting to maximize energy savings. This is known as recovery time and is selected by hotel management upon installation of the system. This type of hotel guest room control system may provide more opportunity for hotels to participate in DR programs since management can have confidence in a quick recovery time.

The following control strategies were selected by the hotel management for both the Occupancy Controls and Occupancy Controls + EMS groups:

- SOLD guest rooms - the control strategy of the thermostat with the integrated passive infrared occupancy sensor is to switch to setback mode after 10 unoccupied minutes during the day and 45 unoccupied minutes during the night. In setback mode, the room temperature is allowed to drift to the setback temperature. This temperature is calculated at the end of each duty cycle by looking at the recovery time necessary to return the room to the setpoint temperature last set by the user. In the case of this study, the recovery time is programmed to be 12 minutes with a setback of no more than 8°F. After 24 hours of unoccupied status the thermostat will go into a deep setback which changes the recovery time to 15 minutes with a setback of no more than 10°F.

- UNSOLD guest rooms (unoccupied for a period of seventy-two hours or more) - the integrated EMS is another energy saving tool that aims to reduce heating and cooling costs in hotel rooms. When a guest room is unsold, the cooling setpoint is changed to 74°F and the range of allowable setpoint temperatures is broadened from 68°F-80°F to 70°F-75°F. All of the occupancy controls work the same as in sold rooms (see above). The EMS is connected to the hotel front desk check in system notifying the individual guest room DDC thermostats of the SOLD/UNSOLD status of guestrooms through a gateway.

MARKET OVERVIEW

The hospitality industry is one of the top industries in the State of California, ranking second to agriculture. It is estimated that hotel rooms are vacant or unoccupied from 30% to 70% of the time. San Diego County has a total of 570 hotel properties with 57,345 rooms. Currently, less than 5% of these properties have any type of controllable thermostat installed.

The adoption of advanced HVAC control systems in the hospitality industry has been slow due to high installation cost, need for ongoing maintenance, concern for guest comfort and the lack of verifiable energy savings. With the introduction of wireless technology into HVAC controls and fine tuning of features allowing for improved recovery time, the business case for implementing the technology should be more favorable and accepted.

As discussed in the technology overview section, the most common thermostat in the hospitality market is the manual digital thermostat due to cost and ease of replacement. While the DDC is gaining interest, there still remains skepticism over its ability to meet the need for guests' comfort. The EMS may provide all the required enhancements to fuel adoption.

A properly designed incentive or rebate program has to be in place to promote market adoption. The program has to be lucrative enough in order for hotel owners and managers to "buy" down the high initial first cost of the hotel front desk EMS. Along with incentives or rebates, proper education and outreach campaigns must occur to raise awareness of the benefits of the technology and the need for ongoing maintenance of the system. This outreach can be targeted marketing or seminars for the hospitality industry.

Methodology

HOST SITE INFORMATION

The Best Western Plus Island Palms Hotel & Marina (Best Western) located on the northern side of San Diego Bay was looking for ways to significantly reduce energy waste. The owner, who has numerous other hotels in the San Diego area, was concerned about future increase in energy costs and had a desire to become a more "sustainable and green" hotel group. By participating in this assessment project, he could validate the claim of potential additional energy savings from a hotel front desk EMS integrated with guest room DDC technology. And due to the planned expansion of Best Western, he wanted to pilot the technology in forty-eight new rooms.

The Best Western's Casa Marina building has forty-eight rooms facing SE or NW on three floors (Figure 1). The building was constructed in 2009. Each room also has a packaged terminal heat pump (PTHP) manufactured by GE (model AZ75H12DACM1). The unit can run with the fan on, cooling on, heating on with heat pump only, or heating on with backup resistance heat. All units were new when installed during building construction in 2009.

Figure 1: Best Western Plus Island Palms Hotel & Marina, Casa Marina

THE MEASUREMENT PLAN

SDG&E® retained ETA to manage the Hotel Front Desk Energy Management System project and coordinate the participants and stakeholders. The WCEC conducted the data collection and analysis for the project. Out of the twelve rooms that were used in the study, four were assigned to the baseline group (Baseline), four to the test group with occupancy controls (Occupancy Controls) and four to the test group with occupancy controls plus EMS (Occupancy Controls + EMS). Data was collected for the groups in the following manner:

- Baseline for the entire summer
- Occupancy Controls for the first half of the summer
- Occupancy Controls + EMS for the second half of the summer. This strategy was chosen because the EMS was not functional until August 1st, 2010

The following plan was designed to quantify energy savings between test room and baseline rooms. The room and supply temperatures were measured and used along with unit power to determine the mode of operation (i.e. fan/cool/heat). The power used during cooling periods for all units was plotted against outdoor air temperature to develop a linear fit between cooling power and outdoor air temperature. Then cooling energy consumption was calculated using the same fit for all units along with the outdoor air temperature and cooling run time. The total cooling energy use data for each day was then grouped (binned) by average daily outdoor air temperature and compared between data groups (bins) to determine energy savings.

The groups were chosen to, as much as possible, be matching in room orientation and floor number. All rooms have a patio door switch that disables the air conditioning and heating when the patio door is open. The occupancy sensor was disabled in the rooms for the baseline test so that the thermostats functioned like a manually controlled digital thermostat. Weather data was obtained from a local weather station at the airport (approximately 3 miles away).

The complete methodology used for this project may be found in Appendix A.

EQUIPMENT

Each room has the following monitoring equipment installed:

- 0 A - 20 A current transducer and logger installed on the heat pump power source
- temperature transducer and logger in the supply air vent
- temperature transducer and logger to monitor room temperature
- room occupancy sensor with door switch, recorded by a state data logger

CURRENT TRANSDUCER
ACCURACY: ± 0.5%

TEMPERATURE TRANSDUCER
ACCURACY: ± 0.63°F from 32°F - 122°F

The placement of each piece of equipment was identical in each room and is shown below in Figure 2.

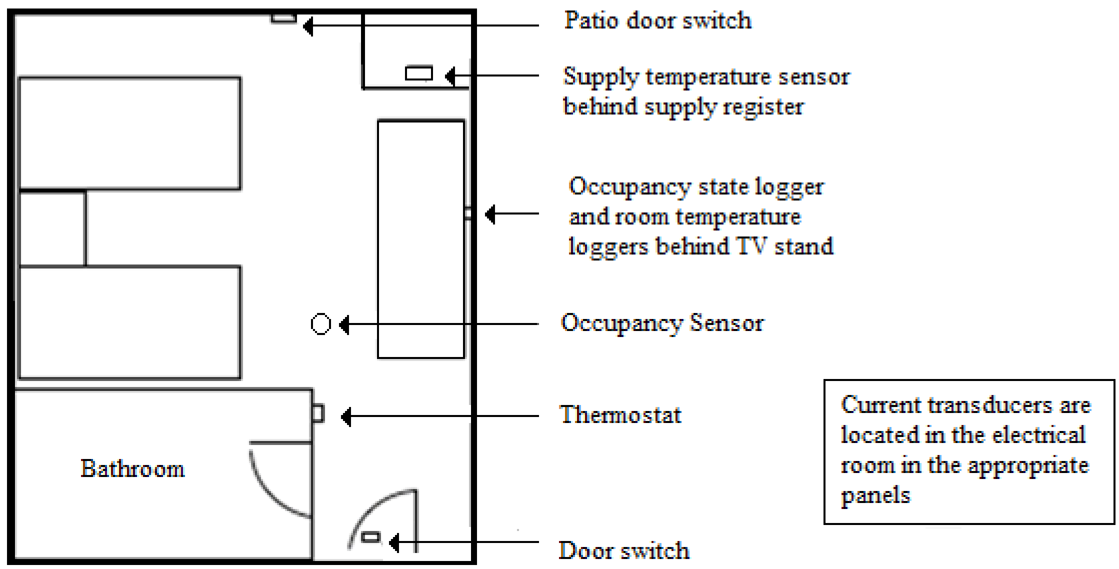

Figure 2: Room layout showing monitoring equipment

Project Results

Analysis of room occupancy showed a very similar occupancy pattern across all rooms in the project. The rooms were sold, meaning they were rented to a customer overnight, between 77% - 79% of the sampled days. The average time a room was actually occupied by the guest was 56% - 57% of the time. This provided for a consistent energy usage in all rooms in the project and is illustrated in Table 2.

Table 2: Analysis of Room Sold Percentage and Occupancy Percentage by Group

Group	Sample Size (Days)	Days Sold (%)	Room Occupancy Time (%)
Baseline	316	79	57
Occupancy Controls	359	77	56
Occupancy Controls + EMS	277	79	57

HVAC energy usage generally correlates to outdoor air temperature. Hotter daily temperatures increase the heat load on a building causing the AC to work harder to cool down the guest rooms. Since this assessment project considered the average results from varying occupant behavior, the applicable correlation is cooling fan energy and outdoor air temperature. The results based upon this correlation are shown below in Figure 3.

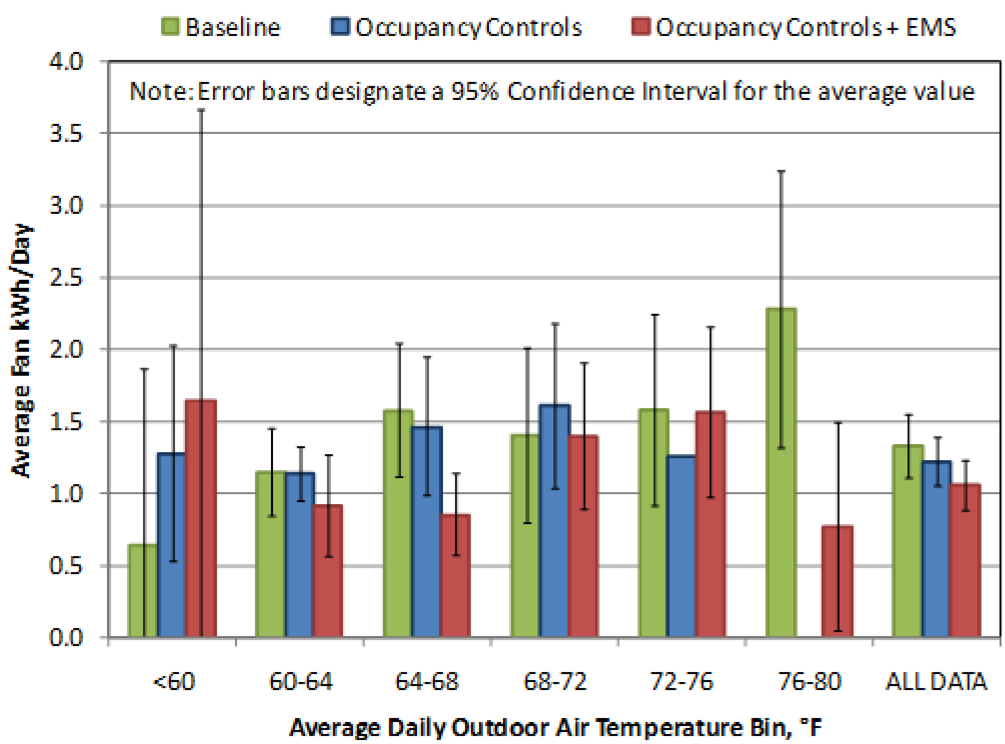

Figure 1: Graph of average fan energy consumption vs. average daily outdoor temperature

However, guest behavior is most likely to be the driving force of energy consumption in the hospitality industry since guests may choose different setpoints, turn off the HVAC entirely when they leave the room for a long period of time, open windows which are not connected to the DDC, and occupy rooms at different times throughout the day.

ENERGY EFFICIENCY

Based upon an analysis of the data collected during the assessment project, the results of the groups are as follows:

- Baseline: rooms use 400 kWh per room annually
- Occupancy Controls: rooms use 330 kWh per room annually
- Occupancy Controls + EMS: rooms use 300 kWh per room annually

These results are shown in Table 3 below.

Table 3: Energy Savings from EMS

Group	Annual Energy Usage (kWh)	Annual Energy Cost ($)	Annual Energy Cost Savings per Room ($)
Baseline	400	64	-
Occupancy Controls	330	53	11
Occupancy Controls + EMS	300	48	16

Based upon the results of this assessment, it appears that the contribution of the hotel front desk EMS integrated with the DDC offers energy efficiency potential but not as significant as expected, unless rooms go unsold longer than seventy-two hours. This project confirms that for the climate zone the project was conducted and for a hotel that has a high occupancy rate, the technology costs are significant and may not warrant investment in a hotel front desk EMS. Further, if the hotel management is willing to allow for deeper setbacks when as soon as a room goes unsold, higher energy efficiency potential may be greater. In this project, hotel management required a rather lengthy period of time to elapse before considering the room unsold and permitting deeper energy efficiency setbacks.

Simple Payback

The incremental cost of the Occupancy Controls + EMS is $426.52 per room. Once installed the expected maintenance costs or operational costs would be minimal. Using an electricity rate of $0.16 per kWh and an estimated yearly energy savings of 100 kWh per room, the extremely long payback period of 28 years in Coastal climate zone does not justify the investment based purely on energy efficiency. The relatively long payback period is partly due to the already low baseline cooling energy use in Coastal climate zone. Although the technology performed very well with 25% cooling energy savings, using a 10 year lifecycle does not allow the technology to be fully paid off in Coastal climate zone within its lifetime.

DEMAND RESPONSE

Demand response (DR) is simply simply a temporary reduction or shift in electricity use during peak periods of electricity usage. When electric supply is anticipated to be low, SDG&E® will contact the hotel to request a reduction in their energy consumption. In return for their reduction, they can receive monthly bill credits, low year-round discounts, and even cash incentive payments for the installation of equipment or control software supporting DR.

SDG&E® offers various DR programs designed to facilitate reduced energy use, generate real savings, and help hotels thrive. The Base Interruptible Program (BIP) allows customers to earn bill credits by proposing or “bidding” their own power reduction levels. For example, customers can earn monthly bill credits of up to $7 per kW for their commitment. Customers can earn credits with this program even when no reduction is required. The Capacity Bidding program allows customers to earn monthly payments by pledging or “bidding” their own power reduction levels. Customers only have to reduce their consumption by the amount they pledged at the beginning of the month. This program allows customers to choose how they want to participate each month. With the Critical Peak Pricing program, customers can earn a year-round rate discount by reducing their power usage on hot summer days. The Critical Peak Pricing – Emergency program works in a similar manner as the Critical Peak Pricing program with the exception that customers can enjoy even a lower year-rate discount by reducing their power usage on short notice (within 30 minutes). Some of the DR programs have penalties assessed if the customer fails to meet the committed reduction level. All of these programs allow the customer to use kWickview to monitor their energy consumption online.

Through the Technical Assistance and Technology Incentives (TATI) program, customers can sign up for the Automated Demand Response Program (Auto-DR). This program allows SDG&E® to send customers DR signals and implement load reductions automatically through their facility’s control system. SDG&E® may provide cash incentive payments for the installation of equipment or control software supporting DR[6].

Guest comfort is at the core of any hotel business. Hotel management is usually reluctant to participate in DR events due to the possible negative impact on revenue. However, hotels can participate in DR in ways that are virtually invisible to guests. Some ways hotels can participate in a DR event include:

- Reducing non-essential lighting such as hallway, meeting rooms, display and ornamental lighting
- Turning off fountains and swimming pool pumps
- Delaying dishwashing and laundry processes
- Raising cooling thermostat settings by a few degrees[7]
- Cycling AC in 15-30 minute intervals

Best Western decided to reduce their energy consumption and participate in a DR event by reducing their HVAC load. In addition to the energy efficiency potential of the integrated control, the control system was tested for the potential to allow the hotel to participate in a DR event or program. A qualified HVAC technician installed a DR unit near the compressor on the central air conditioning unit. The four rooms that had the DDC and the four that had the DDC integrated with the hotel front desk control were sent a signal from SDG&E® to determine the ability to respond to the signal and reduce the HVAC load.

Although minimal difference in cooling energy consumption was observed between the Occupancy Controls and Occupancy Controls + EMS group, the potential benefit of the EMS is the ability to shed load during peak DR events. This can potentially help the utility manage load when electricity supply is in short supply on hot days. On September 27th, 2010 when the outdoor air temperature peaked above 90°F, a test DR event was issued to all forty-eight rooms at the hotel, with the exception of the four rooms that were in the Baseline group. At that time, five of the forty-four rooms were being monitored to record the response (Figure 4). A signal was received by the hotel front desk EMS which responded by turning off the guest room HVAC. Occupants in the room were allowed to override the signal. The signal was issued at 12 pm, 1 pm, 2 pm, and 3 pm.

[6] http://www.sdge.com/business/rebatesincentives/programs/allPrograms.shtml
[7] http://www.sdge.com/campaigns/reduce/index.shtml

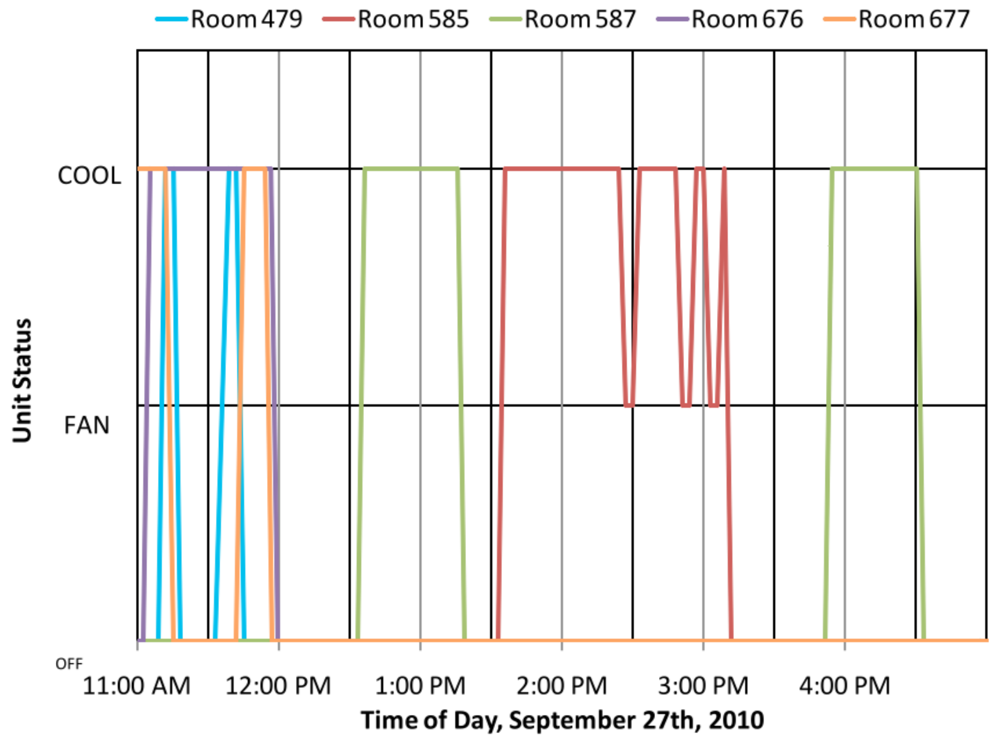

Figure 4: Unit response in five rooms to DR signal that attempted to shut the unit off at 12 pm, 1 pm, 2 pm and 3 pm

The results show that the 12 pm signal worked well, shutting off the air conditioning in rooms 676 and 677, which were on at the time of the event. However, there were problems with the subsequent commands that day. Rooms 585 and 587 did not respond to the signal. The logs from the EMS show that the DDC in rooms 676 and 677 temporarily lost connection to the EMS and did not receive the EMS' signal. Because the system relies on wireless communication, signals can be lost. Because the sample size was small, it is unclear what percentage of the guest rooms in the hotel did not receive the signal. Ensuring connectivity between the DDC and EMS is critical to ensure receipt of DR signals. The hotel staff did not receive any guest complaints during the load shed.

The project data indicates that each hotel guest room could contribute a reduction of 0.28 kW for fan consumption and 1.04 kW for total cooling load if the HVAC is operating in a DR event. However, the guest may change the thermostats settings to their desired temperature resulting in negating the potential reduction in HVAC load.

Due to the hospitality market's overriding concern and need for customer satisfaction which allows for guests to override the DR signal parameters, it appears that the hotel front desk EMS would only be effective with proper outreach and education to drive a paradigm shift in the hospitality market. The combined impact of the technology being allowed to function as designed and the educational outreach program may provide the energy and demand savings required to make the investment in the hotel front desk EMS more compelling.

Conclusion

The hotel front desk EMS project provided clarification of the actual energy efficiency and DR potential of such a system. The project demonstrated that the climate zone and occupancy pattern of the hotel plays large role in energy savings and demand reduction. More importantly, the temperature range parameters allowed by hotel management drives the energy efficiency potential of the EMS. Further, allowing customers to override load shed during a DR event impedes financial justification for the EMS.

Based upon the results of this assessment, it appears that the contribution of the hotel front desk EMS integrated with the DDC offers energy efficiency potential but not as significant as expected unless rooms go unsold longer than seventy-two hours. The system had minimal potential from an energy efficiency standpoint, offering a reduction of only 100 kWh per room annually compared with the manual digital thermostat and 30 kWh per room annually over DDC thermostats.

The real potential of the EMS is the ability to shed load during peak demand periods and participate in the utility DR programs. The project data indicates that each hotel guest room could contribute 0.28 kW for fan consumption and 1.04 kW for total cooling load if the HVAC is operating during peak periods or in a DR event. However, the guest may change the thermostats settings to their desired temperature negating the potential reduction in HVAC load. While the ability to shed the entire HVAC load is attractive at $300 per kW reduced, there are inherent concerns as to the ability for the hospitality market to actual participate and contribute the load to be shed. These concerns center on:

- What percentage of air conditioners or fans will be running during the peak period or DR event? If the unit is not running, credit cannot be taken for the power reduction.
- What percentage of rooms will get the signal from the EMS? We found that some rooms lost connection during the DR event, and therefore did not receive the signal.
- Will guests override the signal? Our monitoring was not interfered by guests. However, the ability to override exists and could negate any DR participation.

Due to the hospitality market's overriding concern and need for customer satisfaction, it appears that the hotel front desk EMS may prove prohibitively expensive to implement with the lack of incentives due to the hospitality markets actual ability to participate in utility key programs such as demand response. It would take a targeted marketing outreach and educational initiative to drive a paradigm shift in the hospitality market. The market must be ready to allow for the HVAC load to be reduced at a predictable level during DR events or during peak periods. Until that happens, no existing utility program would have a significant impact for energy efficiency or DR programs to achieve the required persistent reductions in energy and demand.

Appendix A

1.1 Packaged Terminal Heat Pump (PTHP) Testing

Prior to the beginning of the test period, the air filters in each PTHP unit were replaced and the outdoor air dampers were closed. An efficiency measurement of each unit in cooling mode was taken to assure that they were all operating similarly. The efficiency measurement required obtaining the flow rate, enthalpy drop across the evaporator, and power draw of the unit. The flow rates of both fan speeds were measured using a flow hood. The temperature and humidity of both the supply and return air were measured to get the enthalpy drop across the evaporator while the power draw was being monitored (Figure 5). The supply temperature/humidity sensor was placed in the middle of the air stream (which is not necessarily the average). The objective of the check was to confirm the equipment was operating within reason and that there were no glaring problems rather than providing an accurate measurement of performance. Each air conditioner was operational with an energy efficiency ratio (EER), at high fan speed, between 11 and 14 at an outdoor air temperature (OAT) of 63°F - 71°F (Table 4). The range is most likely due to error in the supply temperature measurement.

Figure 5: Measuring Energy Efficiency Ratio for each PTHP in cooling mode

Table 4: Energy Efficiency Ratio for each PTHP in Cooling Mode

Room #	OAT (°F)	Room (°F)	EER High Fan	EER Low Fan
479	70.6	69.0	11.9	10.9
480	61.5	66.2	11.2	11.2
581	71.1	74.4	14.2	12.3
585	62.9	70.0	11.7	10.5
587	70.2	69.2	11.3	10.9
672	69.3	69.6	14.4	12.8
674	68.9	69.8	13.0	11.6
676	69.5	70.3	11.6	12.3
677	69.8	74.3	12.3	12.4
678	65.6	73.0	13.8	11.8
680	67.6	68.6	13.7	13.0
683	69.5	70.5	11.8	10.9

1.2 Analysis Methods

Determining Unit Mode

The data loggers recorded data every three minutes (0.05 hrs) for 90 days, with the exception of the state logger which recorded when a state change was observed. After 90 days, the data from the loggers was downloaded and the loggers were reset to obtain more data for the remainder of the cooling season, for a total monitoring period from June 1st to November 2nd, 2010. On November 3rd, the remaining data was downloaded and the loggers were removed.

On the three-minute interval, the current room temperature and supply temperature in each room were used to determine the unit mode. The logic for this is described in Table 5 below. The current draw of the unit was used to determine the difference between "Off", "Fan", and "On". The difficulty is that cooling and heating (in heat pump mode) use approximately the same amount of current. Therefore, supply and room temperature data were used to determine whether the unit was heating or cooling. The unit also has a second stage resistance heat mode with a high current, but this mode was not used by occupants during the study period.

Table 5: Logic to Determine Status of Package Unit

Mode	Current Logic	Temperature Logic	Alternate Logic if Absolute Value (Supply Room) < 5°F
Off	Current < 0.1 A	N/A	
Fan On	0.1 A < Current < 1 A	N/A	
Cooling On	Current > 1 A	Supply Room < 5°F	Supply temperature decreasing with time
Heating On	Current > 1 A	Supply Room > 5°F	Supply temperature increasing with time
Heating w/Resistance Heat	Current > 8 A		

Loss of data was caused by the following events:

- Loss of loggers (presumably by occupant theft)
- Battery failure (even though battery life was checked at install)
- Incorrect launching of the logger during setup
- A two week delay in resetting the loggers mid-summer when they were full

When current data was available but supply and/or room temperature data was lost, the following assumptions were made in order to make use of the current data:

- When room temperature was lost, the room temperature was assumed to be 75°F. Checking this assumption against the data set where room temperature was known showed no error from applying this assumption.
- When supply temperature was lost and the average daily temperature exceeded 64°F, the unit was assumed to be in cooling mode when the current exceeded 1 A. Therefore, a small error may occur from

incorrectly counting heating energy consumption as cooling energy consumption. Checking this assumption against the data set where supply temperature was known showed less than a 3% error from applying this assumption, meaning that on warm days heating energy use is extremely small compared to cooling energy use. When the supply temperature was lost and the average daily temperature was less than 64°F, the data was discarded

Additionally, two other events required excluding data from the study. Enabling the EMS, which happened during the last week of July, disrupted the programming of the test groups for one week. This was corrected by August 4th, 2010. Additionally, room 587 flooded from a plumbing failure in early September, and could not be sold to guests until repairs were completed two weeks later. The neighboring room in the study, 585, was also not sold during this period (presumably because of noise during repairs). The final data set included 316 room days in the Baseline group, 359 room days in the Occupancy Controls group, and 277 room days in the Occupancy Controls + EMS group.

Estimating Energy Consumption

Power consumption in fan mode was measured during the basic test of each unit, with the result being 0.27 kW-0.28 kW. There was no difference in power consumption between fan "low" mode and fan "high" mode. When the unit was in fan mode, the 0.05 hour time interval was multiplied by 0.28 kW to determine electricity consumption in kWh.

Because air conditioning power consumption is a function of outdoor air temperature, a linear function was used to convert cooling runtime to energy consumption based on outdoor air temperature. The current draw of all units in cooling mode over the course of the study was converted to estimated power by multiplying the current by the nominal voltage (205 V) and power factor (0.98) measured during the basic test of each unit. The power consumption vs. outdoor air temperature for each data point during the study is plotted in Figure 6. Noise in the data is attributed to fluctuations in supply voltages, spikes from the unit turning on/off, differences between current transducers, and potentially differences in unit performance. The average of all data points was used to determine a linear fit. When the unit was in air conditioning mode, the power was multiplied by the 0.05 hour time interval to determine electricity consumption in kWh.

Heating use was minimal over the course of the study; therefore, power and electricity consumption due to heating was not analyzed.

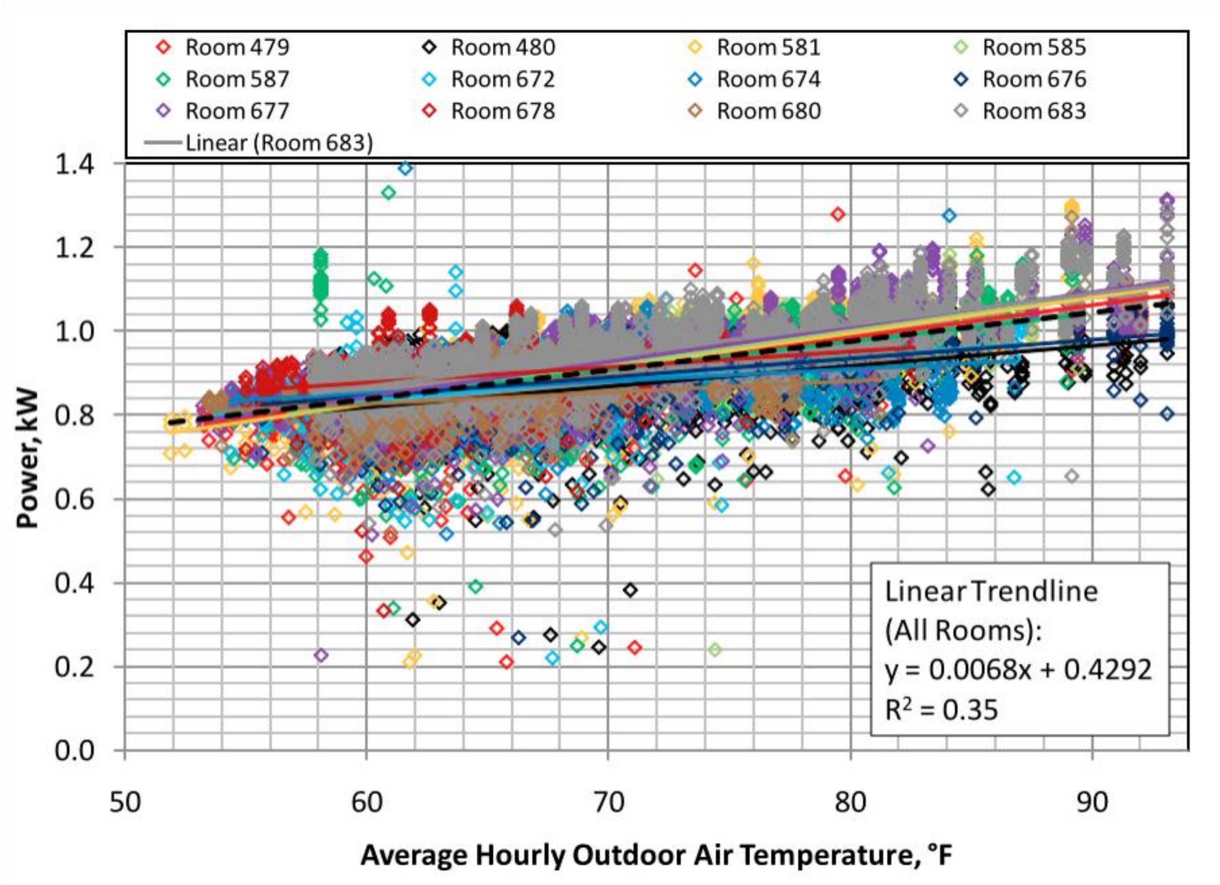

Figure 6: Graph showing power consumption vs. average hourly outdoor temperature in AC mode for each unit and the linear trend line calculation for all data in the sample

Analysis – Occupancy

An analysis of room sold data from the hotel management and occupancy data from the in-room occupancy sensors was completed to ensure there was no occupancy bias between the groups (i.e. that one group of rooms was occupied more frequently).

Analysis – Fan Energy Consumption

Fan mode energy consumption is not expected to be correlated to outdoor air temperature and a quick check of the data confirmed this assumption. Therefore, for each group, the average daily fan energy consumption for the entire sample was calculated.

Regression Analysis – Cooling Energy Consumption

Because the control and test group data was gathered over varying time periods, it was extremely important to correlate the energy consumption results to outdoor air temperature. The total cooling energy consumption per day vs. the average daily outdoor air temperature for that day for each group was plotted. A linear trendline was plotted using the least squares method. The 95% confidence interval for the predicted y-value, for a given independent variable, was determined.

The regression analysis and confidence interval was calculated for total cooling energy consumption per day vs. average daily outdoor air temperature for each of the three groups:

- Baseline (sample size = 316 days)
- Occupancy Controls (sample size = 359 days)
- Occupancy Controls + EMS (sample size = 277 days)

In addition, the regression analysis was completed for subgroups within the baseline data to determine if there was any bias due to the SE/NW orientation of the rooms or the floor that the rooms were on.

Table 6: Data Set Analyzed After Accounting for Lost Data

Group	Room #	Time Period	Room Orientation	Floor #	Sample Size (Days)
	480	6/1 - 11/2	NW	1	
	581	6/1 - 8/29 9/17 - 11/2	SE	2	
Baseline	680	6/1 - 7/15	NW	3	316
	683	6/1 - 7/15 8/21 - 9/8* 9/9 - 10/3	SE	3	
	479	6/2 - 7/15	SE	1	
	585	6/1 - 7/25*	SE	2	
	587	6/1 - 7/25	SE	2	
Occupancy Controls	672	6/1 - 7/25	NW	3	359
	674	6/1 - 7/25	NW	3	
	676	6/1 - 7/25	NW	3	
	677	6/2 - 7/15	SE	3	
	678	6/1 - 7/15	NW	3	
	479	8/21 - 8/29 8/30 - 9/8 9/9 - 10/3	NW	1	
	585	8/21 - 9/8* 9/23 - 9/30 10/1 - 10/3*	NW	2	
	587	8/4 - 8/28 9/23 - 10/19 10/27 - 11/2*	NW	2	
Occupancy Controls + EMS	672	8/4 - 8/27*	NW	3	277
	674	6/2 - 7/25	NW	3	
	676	8/4 - 8/29	NW	3	
	677	8/21 - 9/8* 9/9 - 10/3	NW	3	

Appendix B

2 Results

Fan Energy Consumption

Fan energy consumption per day showed no correlation with average daily outdoor air temperature (Figure 7). Analysis of all sampled days resulted in an average fan energy consumption of 1.33 kWh per day in the Baseline group, 1.22 kWh per day in the Occupancy Controls group, and 1.05 kWh per day in the Occupancy Controls + EMS group. However, calculation of the 95% confidence interval for these groups showed that the differences between groups were not statistically significant as shown in Figure 7 below.

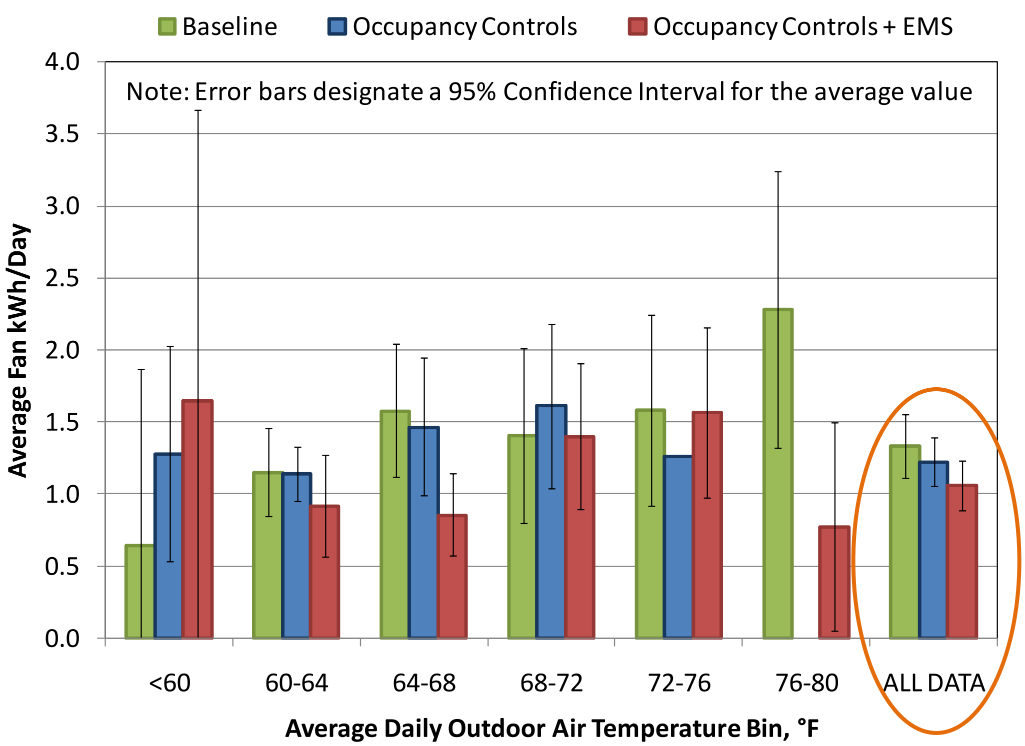

Figure 7: Graph of average fan energy consumption vs. average daily outdoor temperature

Cooling Energy Consumption

Cooling energy consumption generally correlates to outdoor air temperature because hotter daily temperatures increase the load on the building while decreasing air conditioner efficiency. However, occupant behavior is likely to be the driving force of energy consumption in hotel rooms, since occupants choose different setpoints, may or may not turn off the unit upon leaving, may open windows which change the building load, occupy rooms at different times throughout the day, etc. However, since this study evaluates the average result produced by varying occupant behavior, the only reasonable correlation that can be made for cooling energy consumption is with outdoor air temperature.

The entire sample is broken down into bins by average daily outdoor temperature to illustrate that distribution of the sample with regard to average daily outdoor air temperature was significantly different between groups

(Figure 8). The weather was cooler during data collection for the Occupancy Controls group, which occurred during the first half of the summer, and warmer during data collection for the Occupancy Controls + EMS group, which occurred during the last half of the summer. The Baseline group data, for which collection occurred over the entire summer, has a distribution that falls in between the other two groups. Because these distributions are so different, it is imperative to complete the analysis by correlating the data to outdoor air temperature.

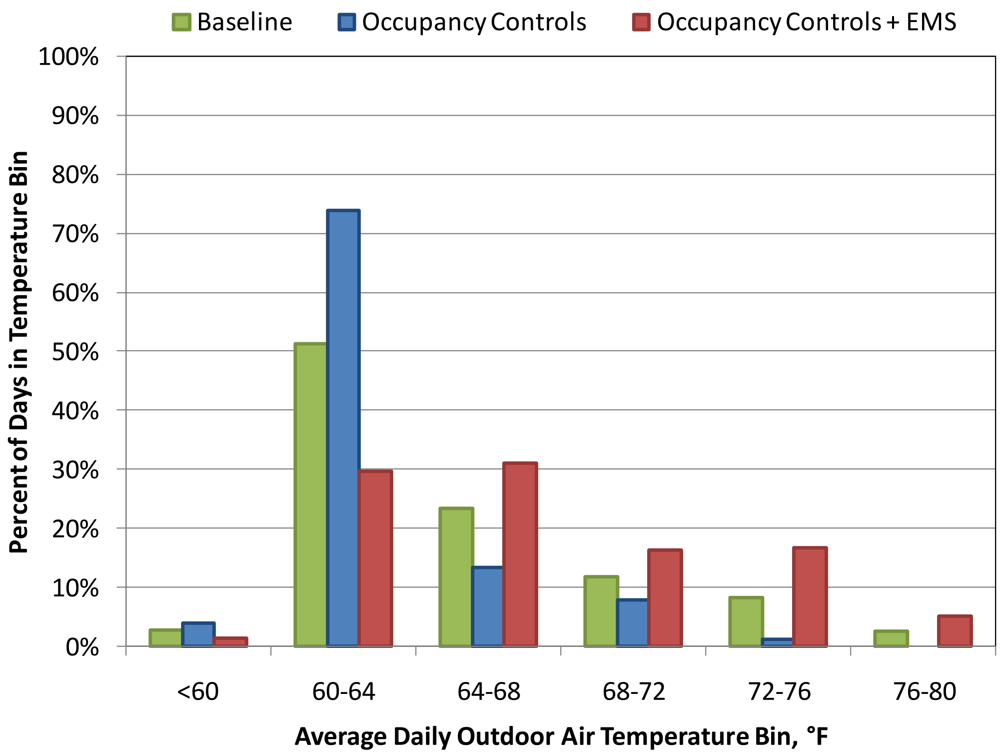

Figure 8: The sample from each group varies significantly with regard to the percentage of days sampled vs. average daily outdoor air temperature

Plotting the entire data set of cooling kWh per day vs. average daily outdoor temperature for each group illustrates the distribution of the collected data (Figure 9). The least squares regression lines have a weak correlation, indicating that factors other than average daily outdoor air temperature are driving cooling energy consumption. However, the 95% confidence intervals of these regression lines indicate that energy consumption by group is differentiated when the average daily outdoor air temperature exceeds approximately 68°F. In the Baseline group, 22% of the sample days are above 68°F daily outdoor temperature, followed by 9% of the Occupancy Controls group sample and 38% of the Occupancy Controls + EMS group sample. The very low number of sample days above 68°F for the Occupancy Controls group suggests that the sample size of that group is too small to reliably interpret cooling energy consumption.

Further examination of the data requires consideration of other variables that may affect cooling energy consumption. In this study, two variables that may be relevant are the orientation of guest rooms (which either face SE or NW) and the floor that the guest room is on (1st, 2nd, or 3rd). SE rooms generally have more morning sun exposure while NW rooms generally have more afternoon sun exposure. In this particular hotel, all guest rooms have patios with overhangs so that significant direct sun is not expected. Third floor guest rooms are expected to have higher cooling loads than the lower floors because the upper floors insulate the lower floors.

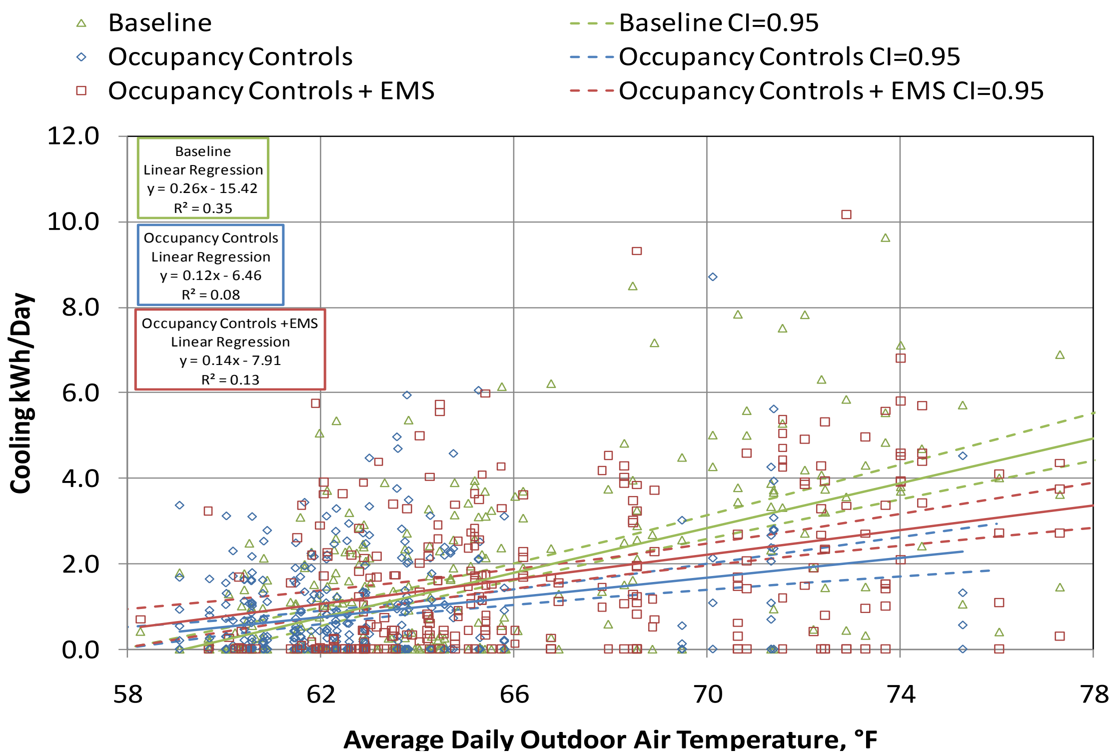

Figure 9: Linear regression and 95% confidence interval for cooling vs. average daily outdoor temperature for each control group

The Baseline group results are plotted with division of the dataset into two subgroups based on room orientation (Figure 10). Calculation of the linear regression and confidence interval for the linear regression show that no statistically significant difference in cooling energy consumption is expected due to room orientation. The Baseline group results are plotted again with division of the dataset into three subgroups based on the floor the room is on (Figure 11). Calculation of the linear regression and confidence interval for the linear regression show suggests a statistically significant increase in energy consumption for third floor rooms. Analysis of the sample distribution by floor (Table 7) shows that the Baseline group actually had the lowest percentage of room days sampled from the 3rd floor (41%) and that the percentage sampled from the Occupancy Controls and Occupancy Controls + EMS groups was higher at 70% and 57% respectively. Therefore, the average cooling energy consumption of the Occupancy Controls and Occupancy Controls + EMS groups may be slightly inflated in comparison to the Baseline group, but there is not enough data to attempt a correction. However, it is clear that room floor distribution did not “help” the cooling energy consumption of the technology under test compared to the baseline.

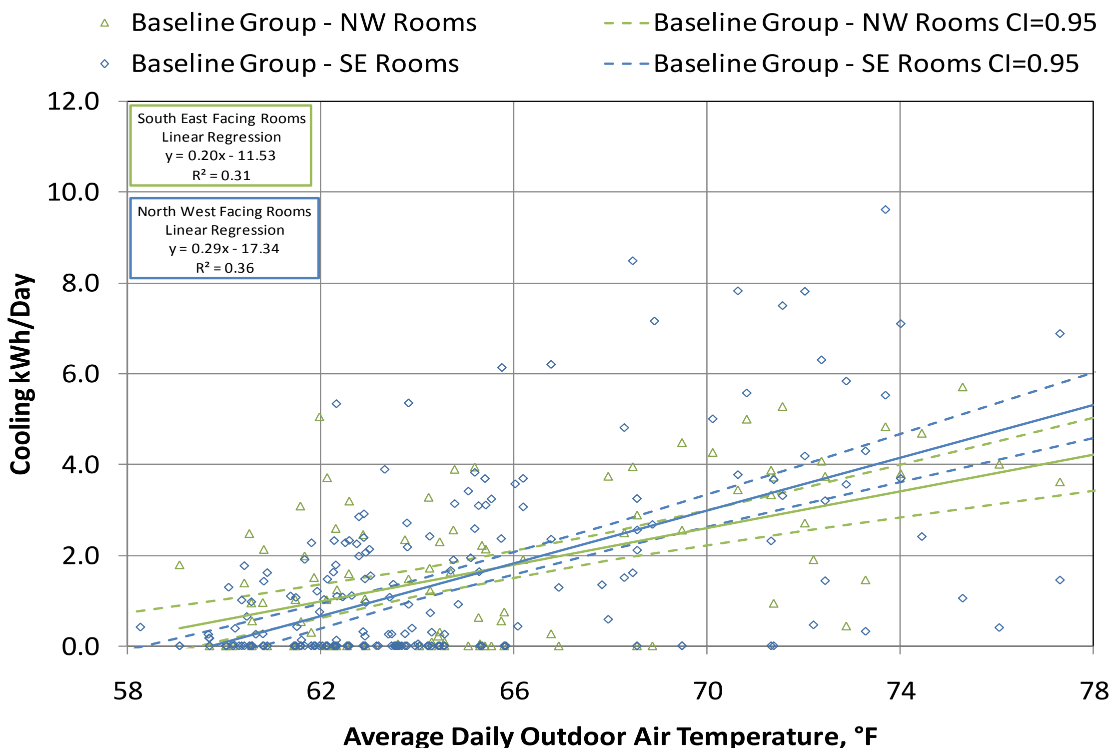

Figure 10: Linear regression and 95% confidence interval for cooling vs. average daily outdoor temperature for the baseline group, divided into subgroups of NW and SE facing rooms

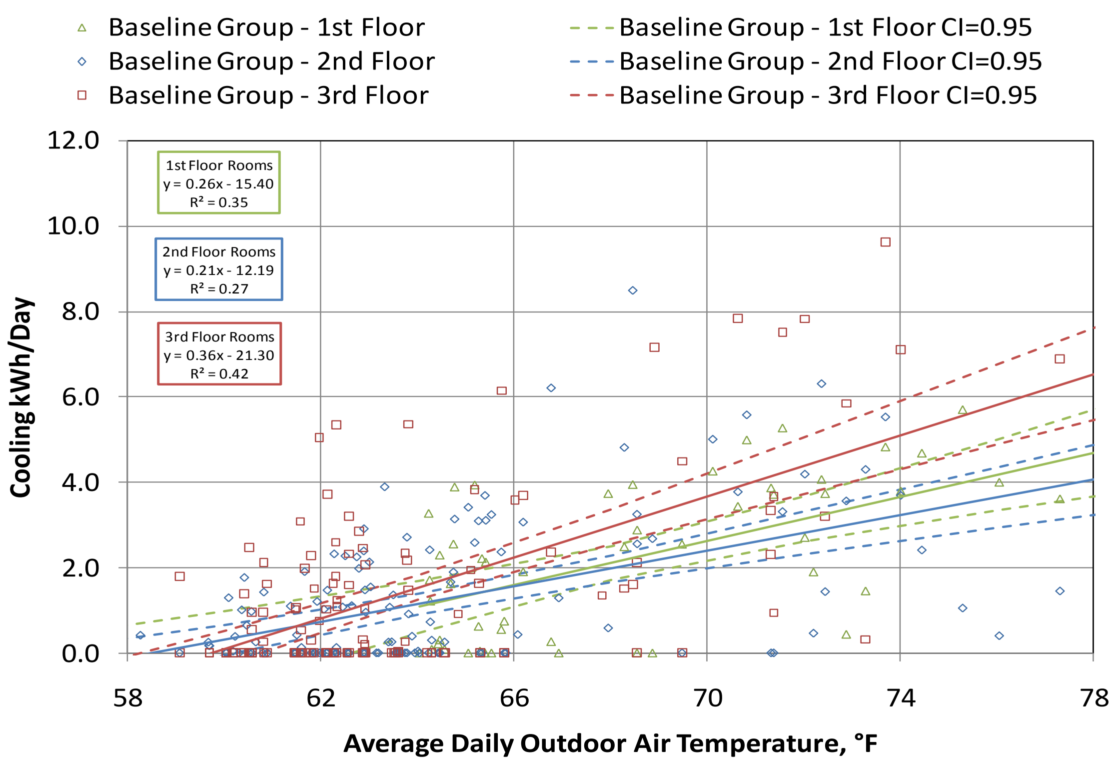

Figure 11: Linear regression and 95% confidence interval for cooling vs. average daily outdoor temperature for the baseline group, divided into subgroups of 1st, 2nd, and 3rd floor rooms

Table 7: Analysis of Room Orientation and Floor by Group

Group	Room Orientation Days		Room Orientation %		Floor Days			Floor %		
	SE	NW	SE	NW	1	2	3	1	2	3
Baseline	220	96	70	30	51	137	128	16	43	41
Occupancy Controls	150	209	42	58	44	62	253	12	17	70
Occupancy Controls + EMS	158	119	57	43	40	80	157	14	29	57

Annual Energy Consumption

The linear regression for each group can be extrapolated to typical metrological year (TMY3) data for climate zone 7 (Figure 12) to estimate annual cooling energy consumption per hotel guest room. The results should be interpreted with caution because of the weak correlation of the regression line and the rather large magnitude of the confidence interval. A larger sample size is needed to have further confidence in the annual energy consumption.

With this note of caution under consideration, the regression equation is applied to the TMY3 data for climate zone 7 and the total cooling energy cooling consumption is calculated for each group. When the average daily temperature is less than 60°F, the cooling energy consumption is negligible and assumed to be zero. The result is that the Baseline group uses approximately 400 kWh per room per year, the Occupancy Controls group uses approximately 330 kWh per room per year, and the Occupancy Controls + EMS group uses approximately 300 kWh per room per year. Because the climate zone in which this study was conducted is one of the mildest in California, it is not reasonable to extrapolate the results to other California climate zones.

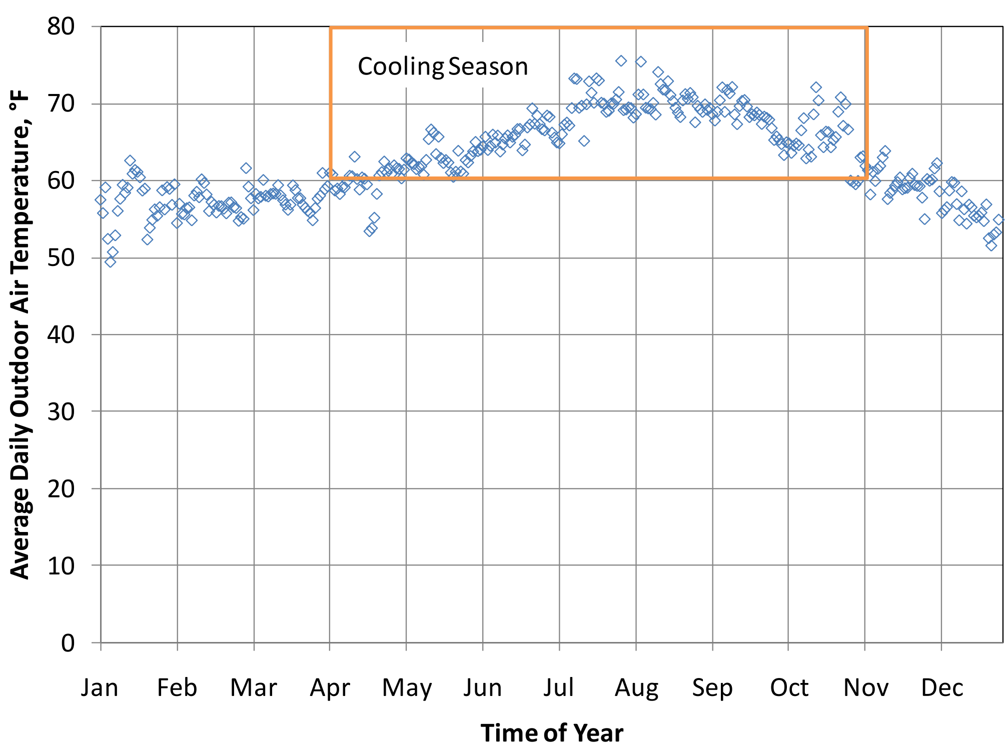

Figure 12: Typical meteorological year data for climate zone 7

Hotel Feedback

The hotel management would not consider purchasing the technology without rebates or incentives from the utility. To consider installing a new technology their standard return on investment strategy is to payback within 3 years meaning that the purchase price of the thermostats and related equipment must be less. There were no reports of guests or hotel employees complaining or noticing the equipment controlling the thermostats.