Central Hotel Guest Room Energy Controls Final Report

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1 Executive Summary

Occupancy controls, which reduce energy use when spaces are unoccupied, have been gaining interest in the field of energy efficiency. These controls are common in lighting systems, but have not gained much ground in the HVAC industry. A potential challenge in implementing occupancy controls in the HVAC industry is the time delay in returning an unoccupied space to the desired temperature when occupancy resumes.

Recent strides by HVAC manufacturers have introduced more sophisticated controls that calculate setback and setup temperatures based on the amount of time the heating and cooling equipment needs to bring the space back to the user defined setpoint temperature. This method allows the building manager to adjust the allowable recovery time to bring the room back to the setpoint. Theoretically, a longer recovery time would result in greater energy savings but may be more noticeable to the occupant.

A similar method for reducing energy consumption, specifically in buildings with a central management system, is to provide the central management system with a tool that can further increase setback and setup temperatures based on their knowledge of occupancy. In hotels this means increasing recovery times for vacant rooms.

During the summer of 2010, occupancy controls and an energy management system (EMS) were installed at the Best Western Island Palms hotel in San Diego, CA. The study included 12 rooms that were instrumented with temperature and current loggers collecting data every 15 minutes. Four rooms were used as a base case with the occupancy and EMS controls turned off while the other eight rooms utilized the controls. The data was analyzed between three groups: Baseline, occupancy controls, and occupancy with EMS controls. The daily energy use was calculated for all groups and plotted against the daily average outdoor air temperature (Figure 1). The results suggest that cooling energy consumption was reduced for average daily outdoor air temperatures higher than 68°F by utilizing the occupancy controls and EMS system, while at average daily outdoor air temperatures lower than 68°F no energy savings from the technology was observed.

Extrapolating the linear regression to typical metrological year (TMY3) data for climate zone seven yields a savings estimate of 100kWh/Year per hotel guest room for the occupancy controls plus EMS technology compared to the baseline. The demand response event produced mixed results in which some of the thermostats did not receive the wireless load shed command. Because the sample size was small, it is unclear what percentage of the guest rooms in the hotel did not receive the signal. No complaints were received from guests. This study took place in a very temperate climate in San Diego, CA, while the energy savings potential of these technologies could be better realized in hotter climates. Future research should focus on a hotter climate to better correlate energy savings to outdoor air temperature.

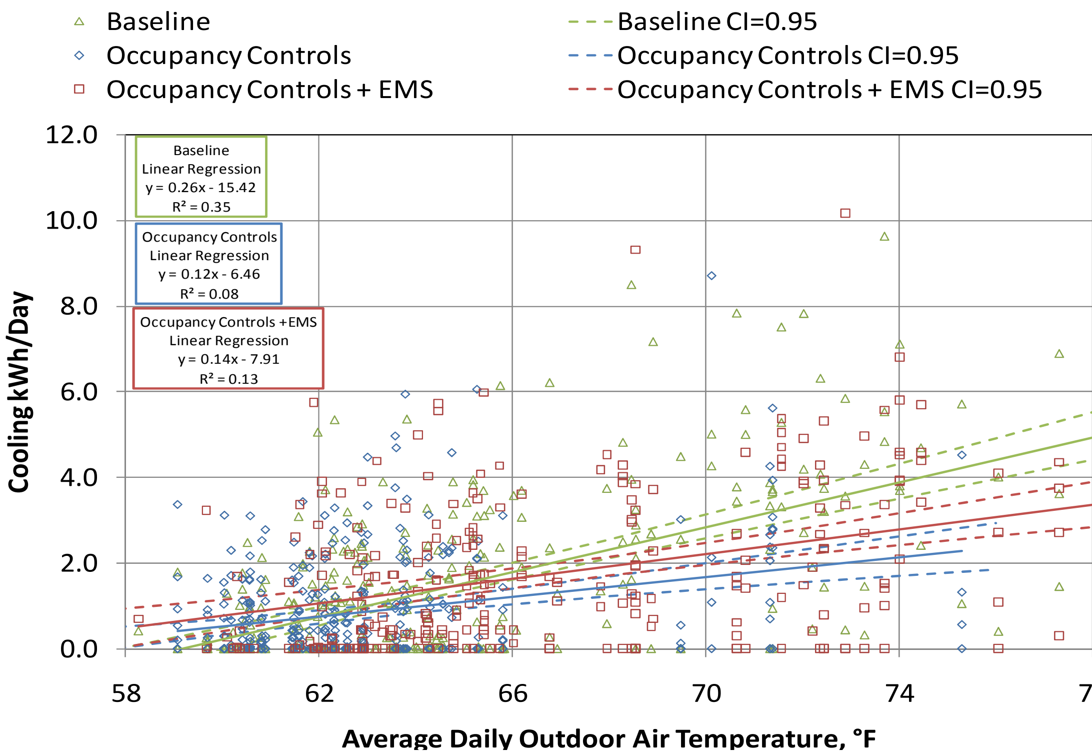

Figure 1 -- Linear regression and 95% confidence interval for cooling kWh/Day versus average daily outdoor temperature for each control group.

2 Background

A large fraction of hotel energy use and peak energy demand can be attributed to space conditioning loads in the summer. 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 setpoint temperatures in the summer, which results in a greater load on the cooling 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.

3 Objectives

The objective of the study is to evaluate the energy use from air conditioning in hotel guest rooms with three different control strategies:

1) Digital thermostat controlled by the guest
2) Digital thermostat with integral occupancy sensor and energy saving controls when the room is unoccupied.
3) Digital thermostat with integral occupancy sensor providing the same energy saving controls as group 2, in addition to an integrated energy management system (EMS). The EMS enables deeper temperature setbacks for unsold rooms and the ability to activate a load shed mode during demand response events.

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 deep setback which changes the recovery time to 15 minutes with a setback of no more than 10°F.

The integrated energy management system (EMS) is another energy saving tool that aims to reduce heating and cooling costs in hotel rooms. When a guest checks out of a room, the cooling setpoint is changed to 74 degrees and the range of allowable setpoint temperatures is narrowed from 68-80 to 70-75. All of the occupancy controls work the same as in sold rooms.

4 Project Approach

4.1 Methodology

The study is being conducted at the Best Western Island Palms on the coast in San Diego, CA. The Casa Marina building has 48 rooms facing southeast or northwest on three floors (Figure 2). The building was constructed in 2009.

All rooms have an energy management system installed. This system has occupancy sensing thermostats in each room and energy management controls.

Each room 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.

Twelve rooms were used in the study. Four rooms were assigned to the baseline group (group 1) and eight rooms were assigned to the test group (groups 2 and 3). Data was collected for the baseline rooms (group 1) for the entire summer. Data was collected for occupancy controls (group 2) for the first half of the summer. Data was collected for the occupancy controls plus EMS (group 3) for the second half of the summer. This strategy was chosen because the EMS was not functional until August 1st, 2010.

Figure 2 – Best Western Island Palms, Casa Marina

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 each day was then binned by average daily outdoor air temperature and compared between groups to determine energy savings.

The groups were chosen to, as much as possible, be matching in room orientation and floor number (**Error! Reference source not found.**). All rooms have a patio door switch that disables the air conditioning and heating when the patio door is open. The groups are:

1) Rooms 683, 680, 581, 480
    a. Baseline test 6/1/10 – 11/2/10
2) Rooms 678, 677, 676, 585, 674, 672, 587, 479
    a. Occupancy controls 6/1/10 - 8/1/10
    b. Occupancy controls + EMS 8/2/10 - 11/2/10

The occupancy sensor was disabled in the rooms for the baseline test so that the thermostats function like a manually controlled digital thermostat.

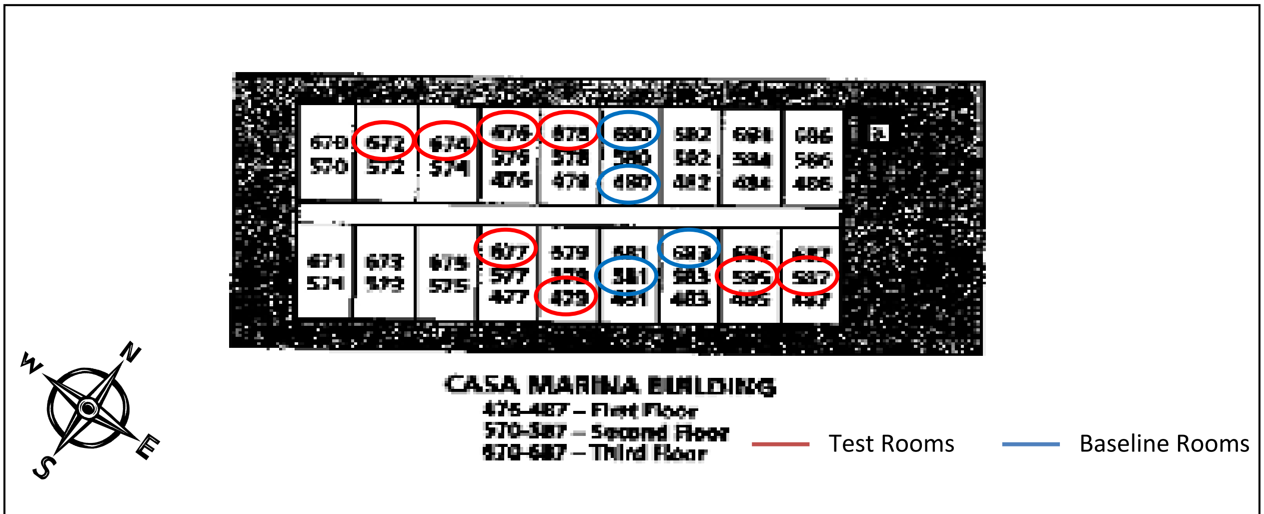

Figure 3 – Schematic showing room orientation

4.2 Instrumentation

Weather data was obtained from a local weather station at the airport (approximately 3 miles away). Each room has the following monitoring equipment installed (Figure 4):

1. 0-20 Amp current transducer and logger installed on the heat pump power source.
2. Temperature transducer and logger in the supply air vent.
3. Temperature transducer and logger to monitor room temperature.
4. Room occupancy sensor with door switch, recorded by a state data logger.

The accuracy of instrumentation used is summarized in Table 1.

Sensor	Accuracy
Current Transducer	± 0.9 Amps
Temperature Transducer	± 0.4 °F

Table 1 – Accuracy of instrumentation used in the study

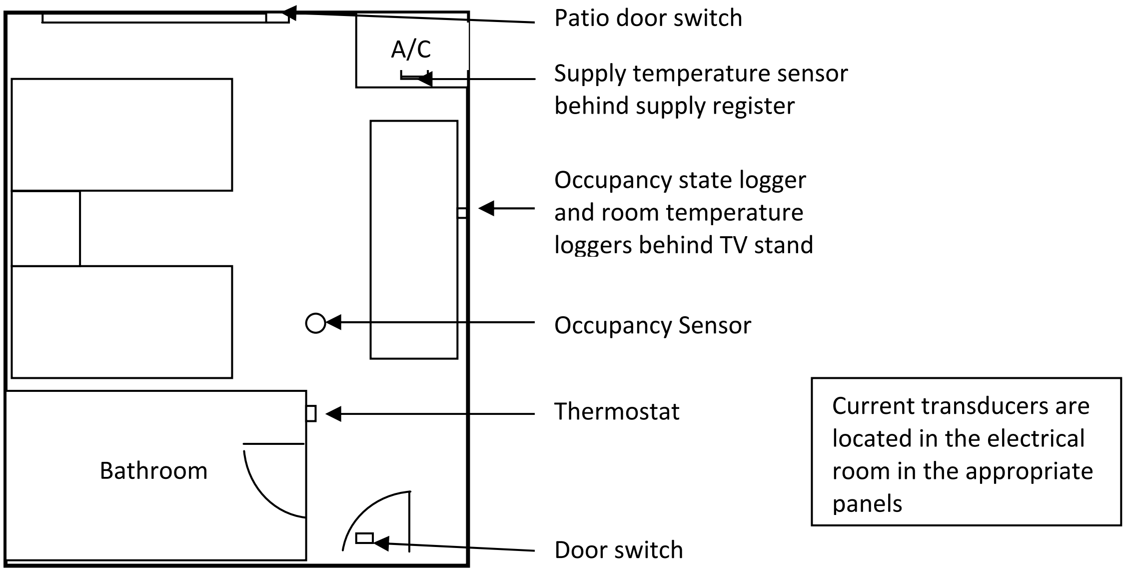

Figure 4 - Room layout showing instrumentation

4.3 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 63-71°F (Table 2). 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

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

Table 2 - Energy efficiency ratio for each PTHP in cooling mode

4.4 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, and the logic is described in Table 3. 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.

Loss of data was caused by the following events:

1. Loss of loggers (presumably by occupant theft)
2. Battery failure (even though battery life was checked at install)
3. Incorrect launching of the logger during setup
4. 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:

1. 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.
2. 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 amp. 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 were discarded.

Additionally, two other events required excluding data from the study. Enabling the energy management system, 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 + EMS controls group.

Estimating Energy Consumption

Power consumption in fan mode was measured during the basic test of each unit, with the result being 0.27-0.28kW. 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 0.275kW 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 (205V) and power factor (0.98) measured during the basic test of each unit. The power consumption versus 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, with the relationship shown in Equation 1.

When the unit was in air conditioning mode, the power was determined from Equation 1 and 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.

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. The 95% confidence interval for the average was calculated from Equation 2.

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. For each group (baseline, occupancy controls, occupancy + EMS controls), the total cooling energy consumption per day was plotted versus the average daily outdoor air temperature for that day. A linear trendline was plotted using the least squares method. The 95% confidence interval for the predicted y-value, Y_k, for a given independent variable, X_k, was determined from Equation 3 and Equation 4[1,2].

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

1. Baseline (n=316)
2. Occupancy Controls (n=359)
3. Occupancy Controls + EMS (n=317)

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

Mode	Current Logic	Temperature Logic	Alternate Logic if Absolute Value (Supply-Room) < 5°F
Off	Current < 0.10 A	N/A	
Fan On	0.10 < Current < 1.00 A	N/A	
Cooling On	Current > 1.00 A	Supply-Room < -5°F	Supply temperature decreasing with time
Heating On	Current > 1.00 A	Supply-Room > 5°F	Supply temperature increasing with time
Heating w/Resistance Heat	Current >8.00 A		

Table 3 - Logic to determine status of package unit

Group	Room numbers and dates	Room Orientation and Floor	Sample Size (Days)
Baseline	480 – [6/1 to 11/2] [*]	NW, 1st Floor	316
	581– [6/1 to 8/29] [9/17-11/2]	SE, 2nd Floor	
	680 – [6/1 to 7/15]	NW, 3rd Floor	
	683 – [6/1 to 7/15] [8/21-9/8] [*] [9/9-10/3]	SE, 3rd Floor	
Occupancy Controls	479 – [6/2 to 7/15]	SE, 1st Floor	359
	585 – [6/1 to 7/25] [*]	SE, 2nd Floor	
	587 – [6/1 to 7/25]	SE, 2nd Floor	
	672 – [6/1 to 7/25]	NW, 3rd Floor	
	674 – [6/2 to 7/25]	NW, 3rd Floor	
	676 – [6/1 to 7/25]	NW, 3rd Floor	
	677 – [6/2 to 7/15]	SE, 3rd Floor	
	678 – [6/1 to 7/15]	NW, 3rd Floor	
Occupancy Controls + EMS	479 – [8/21 to 8/29] [8/30 to 9/8] [*] [9/9 to 10/3]	NW, 1st Floor	277
	585 – [8/21 to 9/8] [*] [9/23 to 9/30] [10/1 to 10/3] [*]	NW, 2nd Floor	
	587 – [8/4 to 8/28] [9/23 to 10/19] [10/27 to 11/2] [*]	NW, 2nd Floor	
	672 – [8/4 to 8/27] [*]	NW, 3rd Floor	
	674 – [8/4 to 8/29]	NW, 3rd Floor	
	676 – [8/4 to 8/29]	NW, 3rd Floor	
	677 – [8/21 to 9/8] [*] [9/9 to 10/3]	NW, 3rd Floor	

Table 4 - Data set analyzed after accounting for lost data

[*] Only days in the period where the average daily temperature exceeded 64°F were included

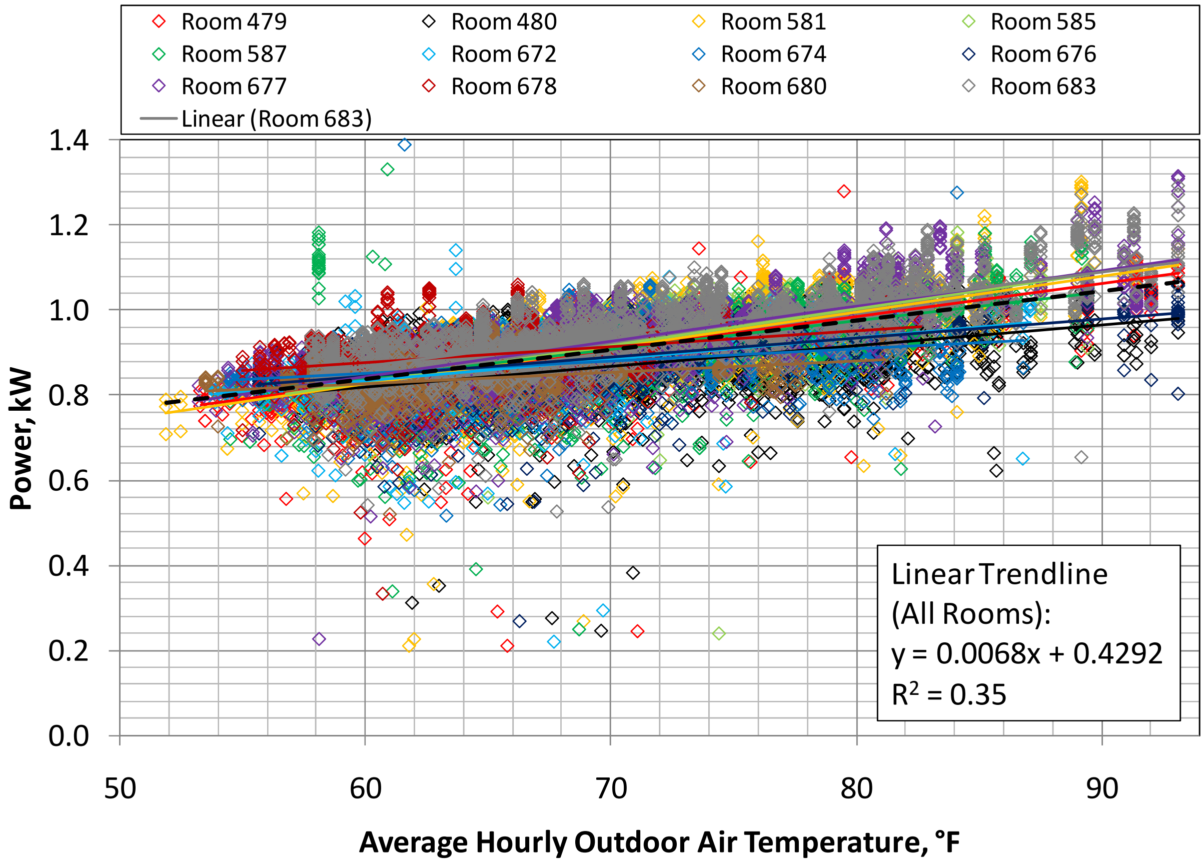

Figure 6 – Relationship between average hourly outdoor air temperature and power consumption in air conditioning mode for each unit and the linear trendline calculation for all data in the sample.

5 Results

Occupancy

Analysis of room occupancy showed very similar occupancy patterns across the test groups (Table 5). The rooms were sold, meaning that they were rented to a customer overnight, between 77-79% of the sampled days. This resulted in an average occupancy, meaning that an occupant was actually in the room, between 56-57% of the time. Therefore, no difference in average energy consumption between test groups due to occupancy is expected.

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/Day in the baseline group, 1.22 kWh/Day in the occupancy controls group, and 1.05 kWh/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 (Figure 7).

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.

Plotting the entire data set of cooling kWh/Day versus 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° daily outdoor temperature, followed by 9% of the occupancy controls group sample and 38% of the occupancy + 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 southeast (SE) or northwest (NW)) and the floor that the guest room is on (1^{st}, 2^{nd}, or 3^{rd}). Southeast rooms generally have more morning sun exposure while northwest 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.

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 6) shows that the baseline group actually had the lowest percentage of room days sampled from the 3^{rd} 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.

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.

Simple Payback

The incremental cost of the occupancy control + EMS system is $426.52 per room. Once installed there is no expected maintenance costs or operational costs. Using an electricity rate of $0.16 per kWh and an estimated yearly energy savings of 100kWh per room, the estimated payback period in climate zone 7 is 27 years. The relatively long payback period is partly due to the already low baseline cooling energy use in climate zone 7. 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 climate zone 7 within its lifetime.

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.

Demand Response

Although a significant difference in cooling energy consumption was not seen between the occupancy controls group and the occupancy controls + EMS group, the other potential benefit of the EMS is the ability to issue load shed commands. This can potentially help the utility manage load when electricity is scarce on hot days. On September 27th, 2010 when the outdoor air temperature peaked above 90^{o}F, a test demand response event was issued to all 48 rooms at the hotel, with the exception of the 4 rooms that were in the baseline group. At that time, five of the 44 rooms were being monitored to record the response (Figure 13). The demand response event issued a command to the thermostats to shut of the unit for 30 minutes (regardless of whether cooling, heating, or fan was on) and let the temperature drift outside of the programmed setback. Occupants in the room were allowed to override the command. The command was issued at 12pm, 1pm, 2pm, and 3pm.

The results show that the 12pm command 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 command. The logs from the EMS system show that the thermostats in rooms 676 and 677 temporarily lost connection to the EMS and so did not receive the command. Because the backbone of the system is wireless the connection between the thermostats and the EMS can be lost at times, delaying the receipt of load shed signals. 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 thermostats and central system is critical to ensure receipt of demand response signals. The hotel staff did not receive any complaints during the load shed.

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

Table 5 - Analysis of room sold percentage and occupancy percentage by group

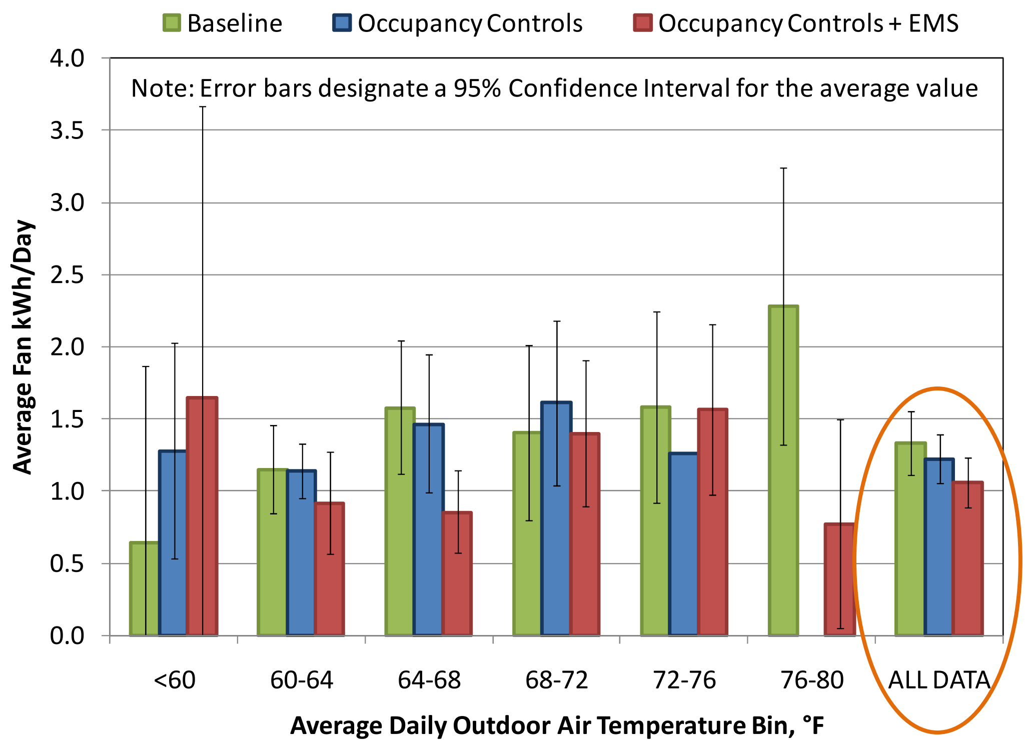

Figure 7 – Fan energy consumption in kWh/Day does not have a correlation to outdoor temperature. An analysis of all data combined does not show a statistically significant savings due to the control technology.

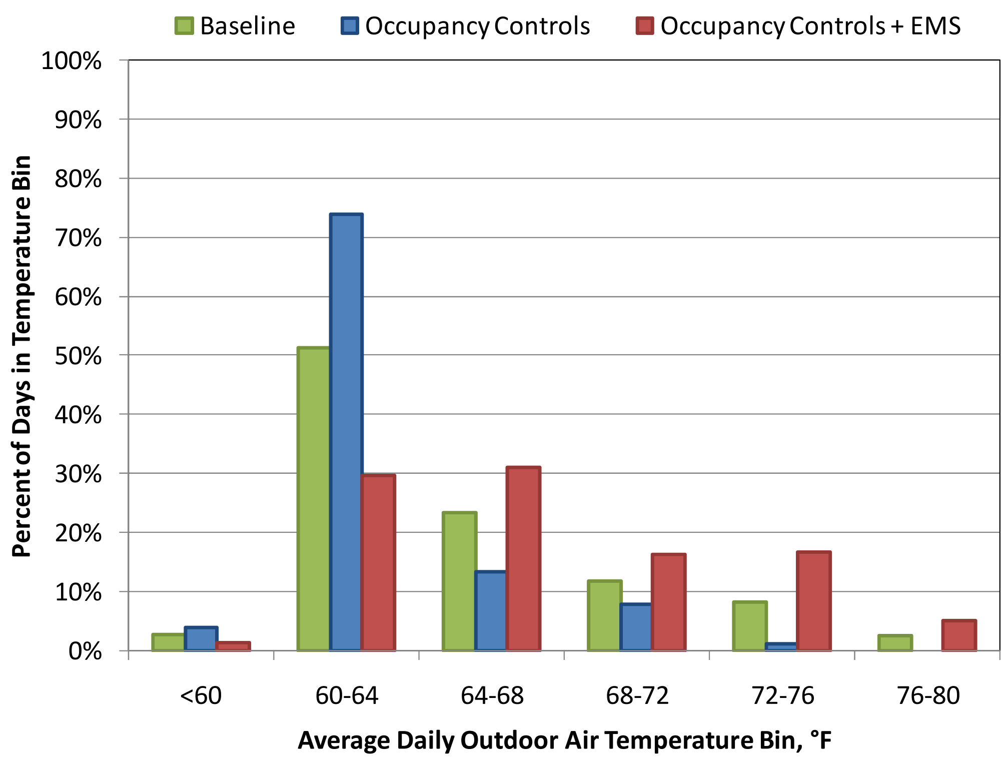

Figure 8 – The sample from each group varies significantly with regard to the percentage of days sampled versus average daily outdoor air temperature.

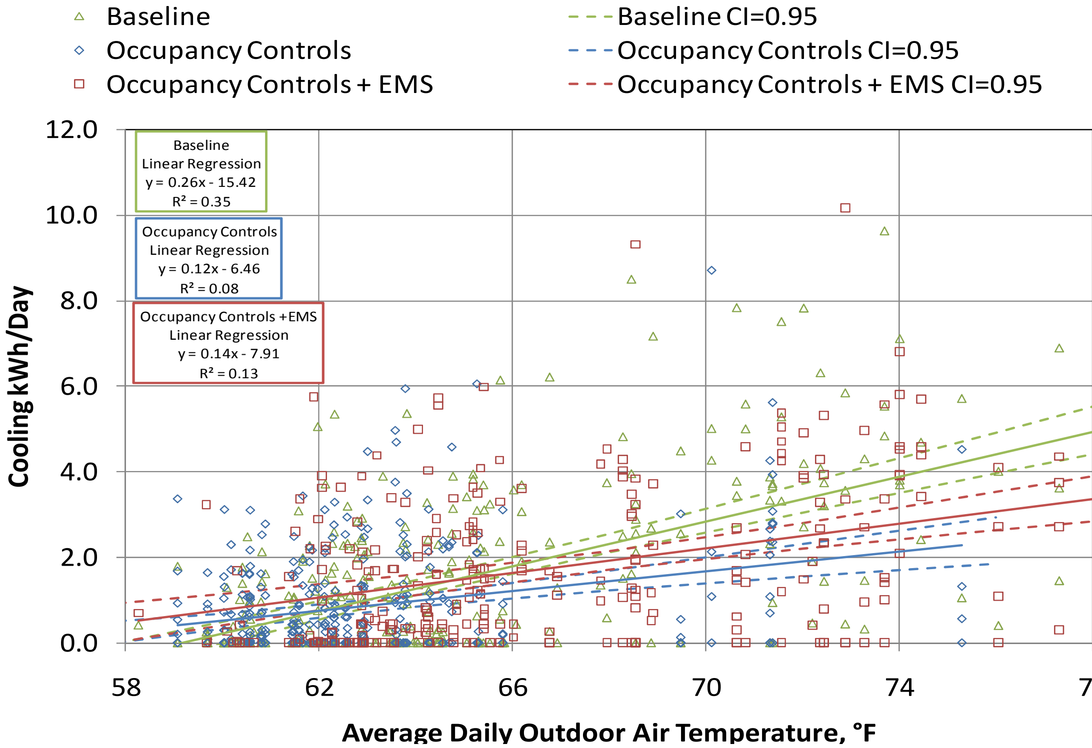

Figure 9 – Linear regression and 95% confidence interval for cooling kWh/Day versus average daily outdoor temperature for each control group.

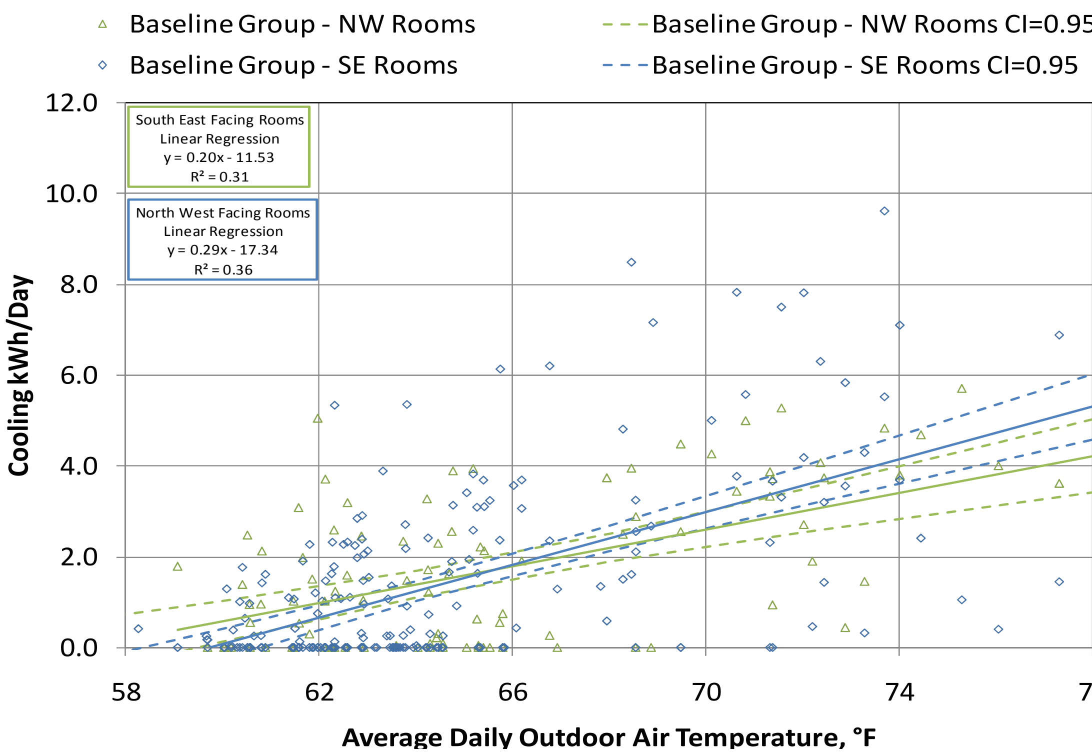

Figure 10 – Linear regression and 95% confidence interval for cooling kWh/Day versus average daily outdoor temperature for the baseline group, divided into subgroups of northwest and southeast facing rooms.

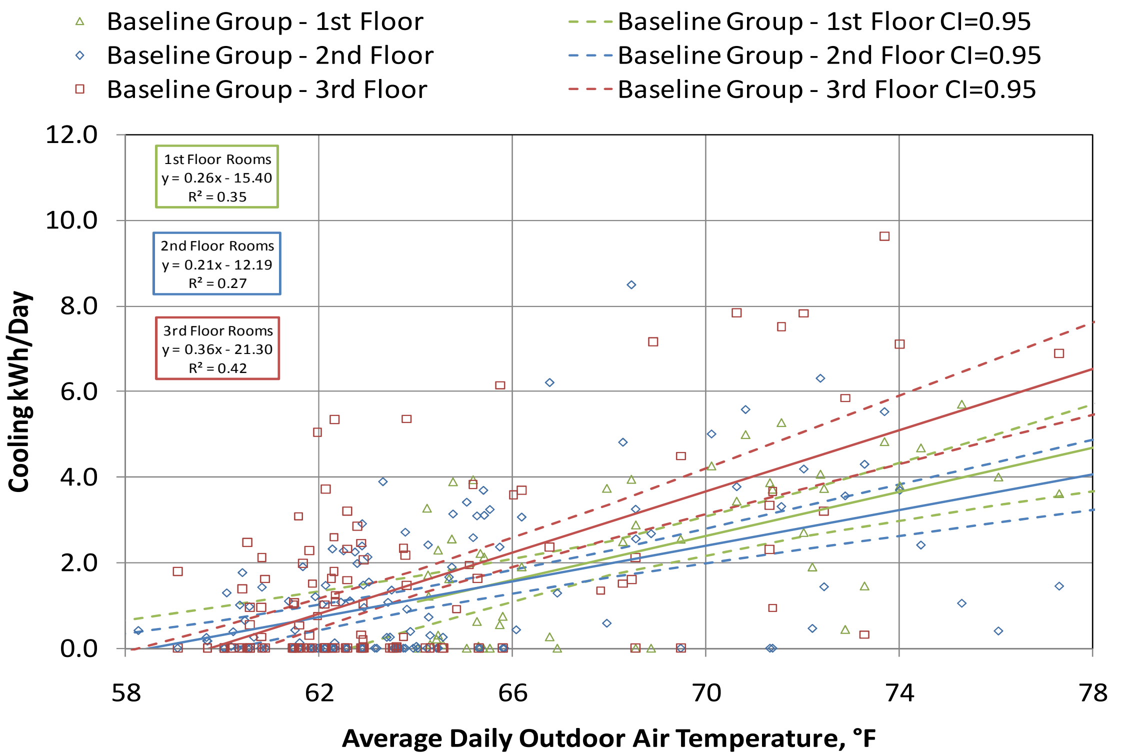

Figure 11 – Linear regression and 95% confidence interval for cooling kWh/Day versus average daily outdoor temperature for the baseline group, divided into subgroups of 1st, 2nd, and 3rd floor rooms.

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%

Table 6 - Analysis of room orientation and floor by group

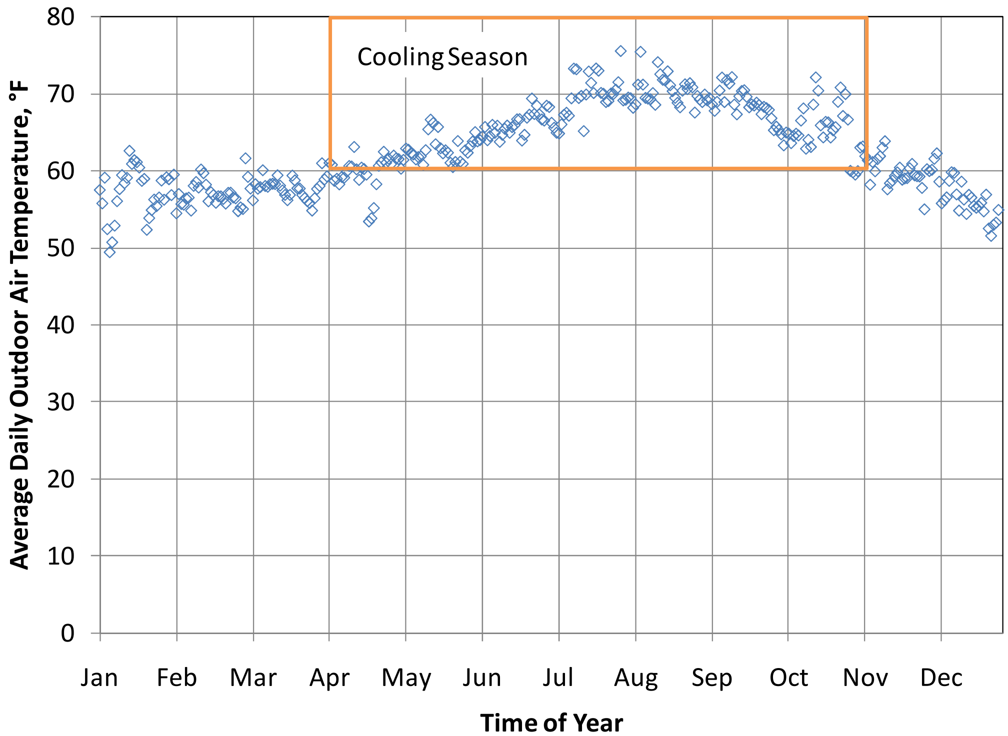

Figure 12 - Typical meteorological year data for climate zone 7. The hotel guest rooms studied generally consumed energy for cooling when the average daily outdoor air temperature exceeded 60°F.

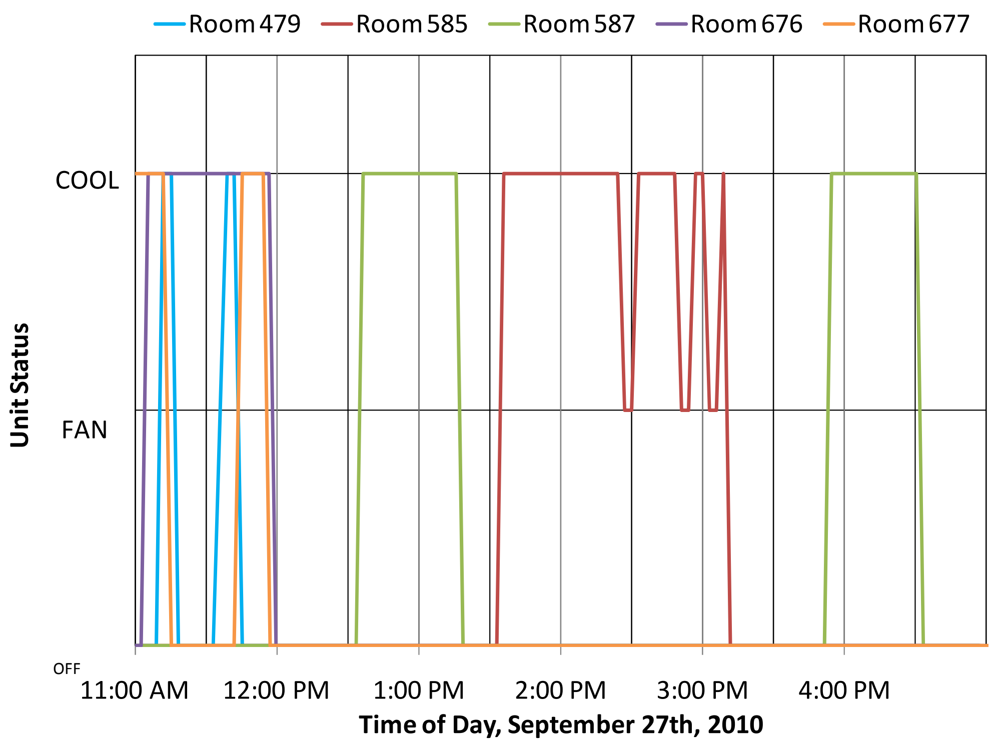

Figure 13 – Unit response in five rooms to demand response signal that attempted to shut the unit off at 12pm, 1pm, 2pm and 3pm.

6 Conclusion

While a large data set was gathered for each group, it is difficult to make conclusions because of the relatively mild climate on the coast of San Diego and the relatively low magnitude of energy consumption for cooling. A test in a more extreme climate zone would be better for assessing the impacts of the thermostat technology. For this study, the analysis shows a statistically significant difference in the linear regression correlation between average daily outdoor air temperature and cooling energy consumption for the baseline group versus the two test groups when the average daily outdoor air temperature exceeds 68°F. Extrapolating the linear regression to typical metrological year (TMY3) data for climate zone seven yields a savings estimate of 100kWh/Year per hotel guest room for the occupancy controls plus EMS technology compared to the baseline. This result satisfies the objective which was to evaluate the energy savings potential of using occupancy and EMS controls to adjust thermostat setpoints in hotel rooms. The demand response event produced mixed results in which some of the thermostats did not receive the wireless load shed command. Because the sample size was small, it is unclear what percentage of the guest rooms in the hotel did not receive the signal. No complaints were received from guests.

7 Further Research

A larger sample size is required to generate further confidence in the results. After analyzing the data from the study, it became clear that heating use was negligible when the average daily outdoor air temperature exceeded 64°F. This suggests that the study could be accomplished by monitoring with a current transducer on the air conditioner and that the supply and room temperature sensors are not required. In addition, the occupancy sensor and logger verified that there was no bias in room occupancy, but this is also discernable by analyzing room sold data provided by hotel management. Reducing the data collection instrumentation to one current logger would significantly reduce cost per room monitored so that more rooms could be monitored for the available budget. In addition, if access to the air conditioner circuit is available outside of the guest room, the study could be completed without disturbing the hotel operation.

8 Acknowledgements

The WCEC would like to acknowledge and thank Best Western Island Palms hotel and staff for their support in this project.

9 Disclaimer

This report was prepared as a result of work sponsored by the San Diego Gas and Electric (SDG&E) Emerging Technologies Program and the University of California (UC). It does not necessarily represent the views of SDG&E, UC, their employees, or the State of California. SDG&E, the State of California, its employees, and UC make no warranty, expressed or implied, and assume no legal liability for the information in this report; nor does any party represent that the use of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by SDG&E or UC, nor has SDG&E or UC, nor has SDG&E or UC passed upon the accuracy or adequacy of the information in this report.

10 References

[1] Regression Analysis - Confidence Interval of the Line of Best, http://people.stfx.ca/bliengme/ExcelTips/RegressionAnalysisConfidence2.htm

[2]Draper, N. R., and H. Smith. *Applied Regression Analysis*. New York: John Wiley & Sons, 1966. Print.

Appendix

List of Equations

$$P = 0.0068 \times T + 0.4292 \qquad \text{Equation 1}$$

where T is the outdoor air temperature in °F and P is the air conditioner power consumption in kW

$$95\%\ Condifence\ Interval = \pm 1.96\ \times \frac{\sigma}{\sqrt{n}} \qquad \text{Equation 2}$$

where σ is the standard deviation of the sample and n is the sample size.

$$95\%\ Condifence\ Interval = \pm 2.069\ \times\ S_{yx}\sqrt{\left(\frac{1}{n} + \frac{(X_k - \bar{X})^2}{\sum(X_i - \bar{X})^2}\right)} \qquad \text{Equation 3}$$

where $\bar{X}$ is the average x-value, X_i is each individual x-value from the sample, n is the sample size, and S_{yx} is the standard error of the estimate calculated from the equation:

$$S_{yx} = \sqrt{\left(\frac{1}{n-2}\left[\sum(Y_i - \bar{Y})^2 - \frac{[\sum(X_i - \bar{X})\,(Y_i - \bar{Y})^2]}{\sum(X_i - \bar{X})^2}\right]\right)} \qquad \text{Equation 4}$$

where $\bar{X}$ is the average x-value, X_i is each individual x-value from the sample, $\bar{Y}$ is the average y-value, Y_i is each individual y-value from the sample, and n is the sample size.