Pacific Gas and Electric Company

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Emerging Technologies Program

Application Assessment Report #0801

Card-Key Guestroom Controls Study

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Preface

Architectural Energy Corporation (AEC), an energy and environmental research, development, and design consulting firm with offices located in San Francisco, California and Boulder, Colorado conducted this research and prepared this document for Pacific Gas & Electric. The AEC Project Manager is Mr. Donald Frey, PE. Mr. John Arent, PE and Mr. Asim Tahir, PE contributed to the research work and this report. Mr. John Browne helped to develop monitoring plans, identify appropriate monitoring equipment, bench test equipment, and install data loggers. Mr. Brian Fowler participated in the development, review, and analysis of guestroom surveys.

Acknowledgements

This work would not have been possible without the willingness of Stefan Muhle, General Manager of the Orchard and Orchard Garden Hotels, to participate in the study. The assistance of his staff at the Orchard Garden and Orchard Hotels, including Aya Shida and Roy Dumandag, is most gratefully acknowledged and appreciated.

Executive Summary

In the hospitality industry in the United States, card keys are used almost universally to gain entry to guestrooms and other areas of hotels—such as swimming pools, exercise rooms, and laundry areas—but not as part of energy management systems. We studied the literature on potential energy and demand savings from card key control systems in *Application Assessment Report #0609*, *Marketable Technologies for the Hospitality Segment*[1]. The current report is derived from field observations as well as computer simulations based on those observations. In addition, we surveyed hotel guests for their perceptions of card key controls.

We monitored HVAC systems, lighting equipment, and occupancy patterns in four rooms in each of the two hotels. Because of the small sample and the ability of guests to override controls, we used computer simulations based on observed occupancy patterns to calculate annual results for San Francisco and to expand the results to four other climates within Pacific Gas and Electric Company's (PG&E's) service territory.

Field Study

The overall energy savings during the monitoring period across the rooms was 28% but that savings ranged from 54% to -39%. The variability was due to the significant influence guests could exercise over the energy used in a room. One of the hotels allowed guests to override the controls completely whereas the other hotel did not. We concluded that 1) expected energy savings would not be realized if guests can override the control system; and 2) the variability in the way rooms are used is so great that accurate estimates of savings cannot be developed using measured data from a small number of hotel rooms.

Computer Simulations

Computer simulations allowed us to extend the analysis to 60 virtual rooms and the five PG&E climate zones. The HVAC energy usage for each zone and the average across all zones are presented in Table 1. The annual savings calculated for San Francisco (Climate Zone 3) is about 32%; the average savings is nearly 27%. These percentages agree surprisingly well with the average savings of 28% calculated from the measured data.

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[1] *Application Assessment Report # 0609, Marketable Technologies for the Hospitality Industry*, Pacific Gas and Electric Company, Emerging Technologies Program September 2007.

Table 1: HVAC Energy Savings for a 60-Room Hotel, On/Off Control (300 ft^2 Rooms)

Climate Zone	HVAC Total, Inactive Control (kWh)	HVAC Total, Active Control (kWh)	HVAC Savings (kWh)	HVAC Savings
CZ3	52,623	35,659	16,964	32.2%
CZ4	61,979	45,184	16,795	27.1%
CZ5	54,550	37,754	16,796	30.8%
CZ12	65,343	48,752	16,591	25.4%
CZ13	74,098	59,206	14,892	20.1%
Average	61,719	45,311	16,408	26.6%

The annual savings of natural gas that supplies space heating were calculated for each of the five climate zones and are presented in Table 2. The use of natural gas is reduced by 7.6% in San Francisco. The average reduction in natural gas is 7.5%.

Table 2: Gas Savings for a 60-Room Hotel, On/Off Control, (300 ft^2 Rooms)

Climate zone	Gas Usage, Inactive Control (therms)	Gas Usage, Active Control (therms)	Gas Savings, (therms)	Gas Savings
CZ3	922	852	70	7.6%
CZ4	1,085	995	90	8.3%
CZ5	913.5	789	124.5	13.6%
CZ12	1,411	1336	75	5.3%
CZ13	1,352	1287	65	4.8%
Average	1,137	1,052	85	7.5%

The peak demands with on/off controls active and inactive are shown in Table 3. In San Francisco the peak demand is reduced by 36% when on/off controls were active. The average reduction in peak demand across the five climates is 27%. Peak demand occurs during the afternoon hours. Since guestroom occupancy is the lowest during this time, peak electrical demand is significantly reduced when on/off guestroom controls are used.

This finding implies that central cooling plant components (chillers, cooling towers, and pumps) in existing buildings could be run more efficiently if they were equipped with variable speed control. Moreover, central cooling plants in new buildings could conceivably be downsized, further decreasing energy consumption and demand. At a minimum, hotels that install guestroom controls should also consider installing variable frequency drives.

Table 3: Peak Demand Savings for a 60-Room Hotel Wing, On/Off Control (300 ft^2 Rooms)

Climate Zone	Peak Demand, Inactive Control (kW)	Peak Demand, Active Control (kW)	Peak Demand Reduction (kW)	Peak Demand Reduction
CZ3	23.5	15	8.5	36%
CZ4	26	19	7	27%
CZ5	23.5	17	6.5	28%
CZ12	28	20.5	7.5	27%
CZ13	27.5	22	5.5	20%
Average	25.7	18.7	7.0	27%

In addition, we found that, as the number of degrees by which a thermostat is increased (set back or set up), the savings from setback control can approach the savings from on/off control, but cannot exceed it. The savings from on/off are actually an upper limit to what can be saved when rooms are unoccupied.

The average savings from a 2° F setback (setup) is 3.5%. This is substantially smaller than the 26.6% average savings achieved with on/off control. The annual savings in natural gas for setback control are minimal in all climates.

The information in this report provides boundaries on possible energy savings. The lower limit of savings is achieved with a 2° F setback (setup). The upper limit is achieved with the on/off control. Savings that could be achieved with increased setback (setup) are between these two values.

Overall, our findings are summarized in the following table.

Attribute	Amount	Unit	Notes
Nationwide hotel construction estimate	80,000,000	ft^2 per year	CBECS database, table B9, 1990-2000[2]
California construction estimate	3,809,524	ft^2 per year	Assumes that PG&E territory per capita construction rate is the same as the national rate.
Guestroom construction estimate	2,857,142	ft^2 per year	Assumes that 75% of hotel floor space are guestrooms.
Guestroom size	300	ft^2	Size of hotel guestrooms monitored in this study.
Annual guestrooms added	9,524	rooms / yr	
Retrofit market	19,048	rooms / yr	Assumes that retrofit market is twice that of new construction.
Market penetration	10%		Assumption.
Incentive program length	2	Years	Assumption.
10% market penetration	5,715	rooms	Calculated.

2 U.S. Energy Information Administration, 1999 Commercial Buildings Energy Consumption Survey: Detailed Tables, table B9.

Attribute	Amount	Unit	Notes
Per room savings	337	kWh	Based on average energy savings in this study.
Per room demand savings	117	W	Based on average demand savings in this study.
Annual PG&E energy savings	1,926	MWh/yr	Anticipated energy savings which can be achieved if 10% market penetration is achieved.
Annual PG&E demand savings	669	kW/yr	Anticipated demand reduction which can be achieved if 10% market penetration is achieved

Comparison to Previous Report

In comparison with the literature review conducted in *Application Assessment Report #0609*, *Marketable Technologies for the Hospitality Segment*, the actual savings found in this report were approximately 66% less. The peak demand reduction reported in the literature is approximately 200 W per room, whereas the savings calculated in this research project ranged from 92 W to 142 W per room; the average across all climate zones was 117 W per room. This is roughly 60% of what is commonly reported.

Guest Surveys

Survey questionnaires were given to all the guests in Hotel #1 and to the guests staying in the monitored rooms in Hotel #2. Although about 80% of respondents found their room to be comfortable when they first arrived, more of the guests with access to active controls used the controls to change conditions in their rooms.

The main conclusions drawn from the responses of guests are:

1. Guests' responses to the survey questions were almost identical, whether they were in rooms with active or inactive controls. Turning the HVAC system and lighting off while they were away made very little difference in how they perceived the comfort of their rooms.

2. The majority of guests support the hotels' activities to be environmentally responsible and are willing to tolerate minor inconveniences to participate in these efforts.

3. The risk to hotel owners and managers of guest complaints resulting from card-key guestroom controls is very low in climates like San Francisco.

Project Background

Card keys have become almost universal in the hospitality industry in the United States. They are used to gain entry to guest rooms and other areas of the hotel, such as swimming pools and exercise rooms. In card-key based guestroom energy management systems, which have not yet gained market acceptance in the U.S., the presence of a card key in a holder just inside the front door is an indicator that the room is occupied. The holder acts as a master switch that controls the HVAC system and some of the hardwired lights and electrical outlets. A guest entering the room uses the key to unlock the door and then places it into the holder. As the guest leaves the room s/he removes the card key from the holder; and the controlled lights, controlled outlets, and HVAC unit go into unoccupied mode.

In some cases the HVAC unit is completely shut off. In other cases, the thermostat is set back, but the HVAC is not turned off. Not all lights and outlets are controlled, since some need to remain on to power clocks, telephones, and devices plugged in by guests. In general, the number of controlled lights and outlets in a room range from zero to about 50%. As a result, the percentage energy savings for lights and plug loads is generally less than the percentage HVAC savings.

Previous Study

The market for guestroom controls is dominated by occupancy-based systems that use passive infrared detectors to determine when a room is occupied. Card-key systems are widely used in Europe and Asia but are relatively new to the United States. Little independent information is available about the energy and demand savings that these systems can produce.

Emerging Technologies Program *Application Assessment Report #0609*, *Marketable Technologies for the Hospitality Segment*, produced by Pacific Gas & Electric Company (PG&E) contains a compilation of information derived from publicly available sources regarding card-key hotel guestroom controls. It includes an overview of: the technology, and discussions of market opportunity, benefits, and cost effectiveness; design considerations; and energy savings opportunity in PG&E's territory. The contractor that prepared the report for PG&E, Architectural Energy Corporation (AEC), conducted a literature search. AEC also contacted manufacturers to locate field studies verifying the savings potential of these devices. They found that most performance assessments had been conducted by manufacturers of guestroom controls.

The annual energy savings for this technology when applied to a typical hotel room was estimated in the *Application Assessment Report #0609* to be 1,000 kWh/yr, and the demand savings, 200 W. Across PG&E's service territory, the energy savings were estimated to be 2,540 MWh/yr, and the demand savings 508 kW/yr. These numbers assumed a 10%

penetration rate that would install this technology in a total of 2,540 new and existing hotel guestrooms annually.

Since the assessment report showed significant opportunity for these controls to save energy and reduce peak electrical demand, PG&E contracted with AEC to conduct a field study to further investigate the potential savings and cost effectiveness of these controls. Because the technology can be installed in both new and existing guestrooms, two hotels in San Francisco were studied. The card-key system in one was installed during construction. The card-key system in the other was retrofit in a small number of rooms for this project.

The potential for energy savings and demand reduction results from the fact that guests tend to keep some lights on and rarely turn off the HVAC when leaving the room. This project was designed to investigate the way that guests occupy hotel rooms and use HVAC and lighting equipment. The potential for energy savings is totally dependent on these two factors.

Computer modeling, based on data from monitoring the hotels, was used to expand the results from San Francisco to other climates in PG&E's service territory. A survey to determine how hotel guests perceived this technology was also conducted. This report presents the results of the three studies.

Related Empirical Studies

Southern California Edison (SCE) studied passive infrared guestroom controls in a hotel in Palm Springs. The heating and cooling in that hotel were provided by packaged terminal air conditioning units (PTACs). PTACs are self-contained through-the-wall air conditioning units. Each unit has its own electrical connection and thermostat. The SCE study found that the PTACs tended to over-cool the rooms in the summer and over-heat them in the winter. It also found that the electricity for HVAC purposes could be reduced by as much as 44% if the rooms were conditioned only when they were occupied.

San Diego Gas & Electric (SDG&E) was in the process of evaluating occupancy-based guestroom controls at four hotels in the San Diego area at the same time that this study for PG&E was being conducted. The research teams working on the SDG&E and PG&E projects collaborated on analysis methods and monitoring equipment.

Potential Other Applications

This research project was conducted in full-service hotels. However, the card-key and occupancy-based control systems are also applicable to other types of hotels and motels, as well as other types of living units, such as assisted living facilities and college dormitories. In the case of assisted living facilities, it may be necessary to keep the HVAC temperature close to the set point because older people have less tolerance to temperature swings. Dorms may be a good application, since students spend many hours away from their rooms and can tolerate temperature swings. They are also generally supportive of the need to conserve energy and willing to participate in energy-savings activities. The hotel results will not be directly applicable to these other types of living units, since the savings depend on how often rooms are occupied; occupancy schedules will be different for different types of living units. Additional monitoring and analysis is necessary to quantify the savings in these other types of living units.

Project Hypothesis / Objectives

The hypothesis investigated in this study is that card-key guestroom control systems can deliver significant energy savings by preventing the considerable waste of energy in unoccupied hotel rooms.

The primary objectives of this project were:

- to estimate energy demand and cost savings
- to determine the cost-effectiveness of card key controls
- and to assess the acceptance of such controls by hotel guests.

To achieve these objectives, we conducted three studies: a field study of actual energy use in hotel rooms, computer simulations based on guest behavior, and a survey of guests' impressions.

Field Study

Four rooms were monitored in each of two San Francisco hotels for a period of eight to ten weeks. We collected data using battery-powered monitoring equipment in each of the guestrooms. The monitoring was done to determine HVAC energy used, lighting energy used, and occupancy schedules. Data was collected for a five-week period when the HVAC and lighting equipment were not controlled (the “inactive” period) and a second five-week period when the equipment was controlled (the “active” period).

For the first half of the monitoring period, the controls were disabled to obtain a baseline energy use. This is referred to as the “inactive” period. The controls were then enabled and the energy use was monitored for the same rooms. This is referred to as the “active” period. The specific dates covered by the two periods is shown in Table 4.

Table 4: Dates of Data Used in the Analysis

	Inactive Period Dates	Active Period Dates
Hotel #1 – All Rooms	8/9/08 through 9/6/08	9/27/08 through 10/27/08
Hotel #2 – Rooms 506 & 507	8/9/08 through 9/9/08	9/19/08 through 10/19/08
Hotel #2 – Rooms 703 & 708	8/9/08 through 9/9/08	10/17/08 through 11/16/08

The energy savings for the monitoring periods were determined by comparing the total energy during the active period with the energy use during the inactive period. Weather data (outside air temperature and humidity) was collected to establish relationships between energy use and weather; this was used to estimate annual energy use.

Monitoring Approach

Two possible monitoring approaches were considered for this project. One involved collecting data in a room with the guestroom controls inactive, then turning the controls on and continuing monitoring in the same room. This is referred to as an “on/off” approach. The other approach considered was to monitor two groups of rooms at the same time. The guestroom controls would be active in one group and inactive in the other. This is referred to as a “parallel” approach.

There are pros and cons to each approach. The biggest potential drawback of the on/off approach is whether or not the weather conditions are similar during the two monitoring periods. The biggest potential drawback of the parallel approach is whether or not the groups of rooms are similar. It was determined that the analysis methodology could adjust for slightly different weather conditions, so the on/off approach was viable. It was also determined that the differences in the physical characteristics of the rooms were so slight compared to the differences in the way guests use the rooms that the parallel approach was also viable.

The decision to use an “on/off” approach to monitor the guestrooms was based on two factors. One was to keep the costs to purchase and install monitoring equipment within budget. The other concerned access to guest rooms and disruption to the hotel. Finding time for busy staff to do anything extra in hotel rooms is difficult. The fewer the number of rooms monitored at each hotel, the easier it was for each hotel to participate in the program. Keeping the hotel owners and managers happy was important for the success of this project and for any future projects PG&E might want to do in hotels.

Four rooms per hotel were instrumented. Data were collected that show how rooms operated in the absence of guestroom control (the inactive period) and with guestroom control (the active period). Each room was run for six weeks in the inactive mode, and then run for six weeks in the active mode. Since the logging equipment was out of sight of the guests, it was left in place while the data were being analyzed.

Test Sites

Two hotels were selected as test sites for the card-key control system. The guestroom control system was installed in one during construction and was retrofit to the other. The hotel in which the card-key system was installed during construction is referred to as Hotel #1. The one in which the systems were retrofit is referred to as Hotel #2.

Hotel #1 Description

Hotel #1 is a LEED-certified® building that has a card-key guestroom control system as one of its energy-saving features. The exterior of this 86-room hotel is shown in Figure 1. The HVAC unit, bathroom lights, and bedside lights are controlled by the card-key system installed during construction. The electrical outlets, including the TV and DVD player, are not controlled. When the card key is removed from a holder next to the door (see Figure 2), the hardwired lights and HVAC equipment are turned off. The TV and anything (including table and floor lamps) plugged into the electrical outlets will stay on. It is important to emphasize that the HVAC in this hotel is turned off, not just set back. The thermostat is shown in Figure 3. The default thermostat set point is 72^{o} F.

Figure 1: Exterior of Hotel #1

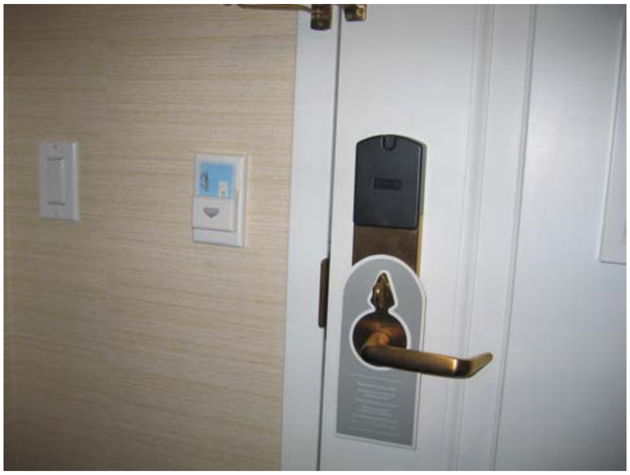

Figure 2: Hotel #1 Guestroom Key Holder with Key Inserted

Figure 3: Hotel #1 Guestroom Thermostat

The HVAC and lighting monitoring plans implemented at Hotel #1 are described in the sections below.

Data were collected at four rooms in Hotel #1 for a period of five weeks with the guestroom controls inactive. This initial period served as the control or baseline for the study. The guestroom controls were then made active and the rooms were monitored for an additional five weeks.

Hotel #1 Fan-Coil Unit Monitoring

The methodology used in this project to determine the energy delivered to the guestrooms by the fan-coil units was discussed with personnel at the Western Cooling Efficiency Center at the University of California at Davis and with personnel at the PG&E Energy Center. All agreed that it is difficult, invasive, and expensive to accurately measure water flow rates and water temperatures in fan-coil units. It is impractical in a field assessment project such as this to make these measurements. The practical approach is to take measurements on the air side of the fan coil to estimate the energy delivered to the room. The air-side measurement approach was taken in this project. Table 5 contains a listing of the time-series measurements that were taken in the Hotel #1 rooms and the monitoring devices that were used to take them. Additional information about each monitoring device is presented in Appendix A. Table 6 contains a description of the one-time measurements that were made in guestrooms at Hotel #1 at the time the monitoring equipment was installed.

Table 5: HVAC Time-Series Measurements in Hotel #1

Measurement	Measurement Device
Fan Status (on/off) – Measured at the HVAC Unit.	Onset Energy Pro Logger with Watt Transducer and 5 Amp CT
Supply Air Temperature	Onset Energy Pro Logger with Smart Sensor for Temperature
Return air Temperature	Onset Energy Pro Logger with Smart Sensor for Temperature
Supply Air Humidity	Onset Energy Pro Logger with Smart Sensor for Temperature
Return Air Humidity	Onset Energy Pro Logger with Smart Sensor for Temperature

Table 6: HVAC One-Time Measurements in Hotel #1

Measurement	Measurement Device
Air Flow Rate through the coil (cfm) – Fan has two speeds. Two flow rates were measured.	Alnor flow hood

The measurements at the fan-coil unit were taken in the plenum space accessed through the door in the ceiling, which is shown in Figure 4. The fan-coil unit, where the water and air temperature measurements were taken, is shown in Figure 5. One-time measurements of the supply air flow were taken at the supply air grill. Measurements were taken for all fan speeds. The supply air grill is shown on the right and the return air grill is on the left in Figure 6. The room air temperature was assumed to be equal to the return air temperature. No temperature sensors were placed in the room because of concerns that they would be tampered with or removed by guests.

Figure 4: Hotel #1 Fan-Coil Unit Ceiling Access Door

Figure 5: Hotel #1 Fan-Coil Unit

Figure 6: Hotel #1 Guestroom Supply Air and Return Air Grills

Hotel #1 Lighting and Receptacle Monitoring

The measurements of electrical power used by lights and electrical receptacles were taken in the electrical panels. Electrical panels serving three floors of the buildings are shown in Figure 7. Circuits for each floor are in a separate panel. Figure 8 shows the Circuit Directory that identifies the circuits in one of the panels. The circuits are laid out similarly in the other two panels. Each guestroom is served by three electrical circuits. The circuits are labeled “GFCI Receptacle,” “Lighting, Fan Coil,” and “Room Receptacle.” All three circuits for each of the four rooms were monitored. Tests were done at the time the monitoring equipment was installed to determine which lights are on each circuit and to measure the load of the fan and pumps in the fan coil unit.

Table 7: Lighting and Receptacle Time-Series Measurements in Hotel #1

Measurement	Measurement Device
GFCI Receptacle Circuit Energy (kWh)	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT
Lighting, Fan Coil Circuit Power (kWh)	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT
Room Receptacle Circuit Power (kWh)	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT

Table 8: Lighting One-Time Measurements in Hotel #1

Measurement	Measurement Device
Bathroom Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Bedside Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Desk Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Overhead Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp

Figure 7: Electrical Panels in Hotel #1

Figure 8: Hotel #1 Electrical Circuit Directory

Hotel #2 Description

Hotel #2 is a boutique hotel similar to Hotel #1. Both hotels are owned, managed, and operated by the same organizations and individuals. The two hotels are located two blocks apart in downtown San Francisco. Hotel #2 is relatively new, though not as new as Hotel #1. The exterior of the hotel is shown in Figure 9. This hotel recently gained LEED-EB® certification. A wireless card-key guestroom control system manufactured by Entergize was selected for this hotel for two reasons: 1) the system was easy to retrofit into the guestrooms, since no wires had to be run and only switches and outlets had to be replaced; and 2) the system is similar to the one used at Hotel #1 and therefore provides a similar guest experience. This system was installed in four rooms for the purpose of testing in this project.

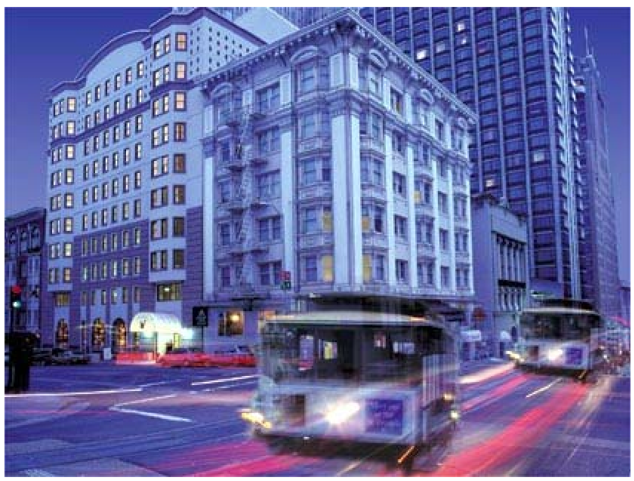

Figure 9: Exterior of Hotel #2

The main light switch located just inside the entry door is shown in Figure 10. This switch was replaced with an Entergize "Master Switch." The Master Switch has a slot into which the room key is placed to energize the other light switches and electrical outlets. The room thermostat is shown in Figure 11. The thermostat was replaced and a circuit board that is a radio-frequency receiver was placed in the electrical box behind the thermostat. The bathroom light switches are shown in Figure 12. Both were replaced with Entergize switches to turn off the bathroom lights when the room is unoccupied. Each room has four electrical outlets similar to the one shown in Figure 13. One of the outlets is controlled to turn off the light, and the other one remains active so that the telephone, clock radio, and any devices brought into the room are continuously powered. A four-gang outlet behind the TV and DVD cabinet are also controlled. The mini-bar light switch shown in Figure 14 is controlled. The electrical outlet remains powered.

Figure 10: Main Light Switch in Hotel #2

Figure 11: Room Thermostat in Hotel #2

Figure 12: Bathroom Light Switches in Hotel #2

Figure 13: Electrical Outlets in Hotel #2

Figure 14: Light Switch and Electrical Outlet at the Mini Bar in Hotel #2

The HVAC and lighting monitoring plans that were implemented at Hotel #2 are described in the sections below.

Hotel #2 Fan-Coil Unit Monitoring

For the same reasons discussed above for Hotel #1, measurements in Hotel #2 were taken on the air side of the fan coil to estimate the energy delivered to the rooms.

Table 9: HVAC time-Series Measurements in Hotel #2

Measurement	Measurement Device
Fan Status (on/off) – Measured at the electrical panel on the circuit labeled “heater.”	Onset Energy Pro Logger with Watt Transducer and 5 Amp CT
Supply Air Temperature	Onset Energy Pro Logger with Smart Sensor for Temperature
Return Air Temperature	Onset Energy Pro Logger with Smart Sensor for Temperature
Supply Air Humidity	Onset Energy Pro Logger with Smart Sensor for Temperature
Return Air Humidity	Onset Energy Pro Logger with Smart Sensor for Temperature

Table 10: HVAC One-Time Measurements in Hotel #2

Air Flow Rate through the coil (cfm) – Fan has two speeds. Two flow rates were measured.	Alnor flow hood

The measurements at the fan-coil unit were taken in the plenum space accessed through the door in the ceiling. The fan-coil unit where the air temperature measurements were taken is shown in Figure 15. One-time measurements of the supply air flow were taken at the supply air grill. Measurements were taken for all fan speeds. The supply air grill is shown in Figure 16. The return air grill is located in the closet (see Figure 17). The closet door has louvers to allow the air to move from the room, through the closet, and up into the return grill. The room air temperature was assumed to be equal to the return air temperature.

Figure 15: Hotel #2 Fan Coil Unit

Figure 16: Hotel #2 Supply Air Grill

Figure 17: Hotel #2 Return Air Grill

Hotel #2 Lighting Monitoring

The energy used by the lighting was monitored at the electrical breaker panel. Three circuits serve each room, as shown on the Circuit Directory in Figure 18. Two circuits are labeled as outlets and the third is labeled as a “heater.” The heater circuit actually serves the fan coil unit. The bathroom lighting is served by the circuit labeled “Bathroom Outlets.”

Table 11: Lighting and Receptacle Time-Series Measurements in Hotel #2

Measurement	Measurement Device
Bathroom Outlets Circuit Power	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT
Guestroom Outlets Circuit Power	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT

Table 12: Lighting and Receptacle One-Time Measurements in Hotel #2

Measurement	Measurement Device
Bathroom Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Bedside Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Desk Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Overhead Light Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp
Floor Lamp Power (kW)	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp

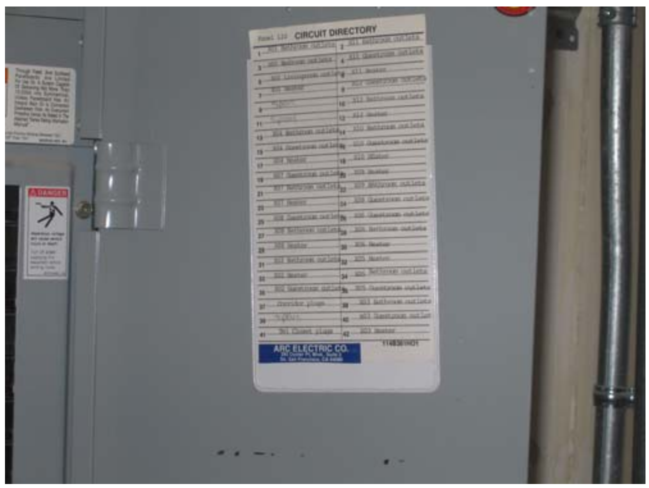

Figure 18: Hotel #2 Electrical Circuit Directory

Measured Data Results for Hotel #1

This section provides performance monitoring results of the card-key guestroom control systems at the two hotels.

HVAC Results for Hotel #1

The total amount of energy used in each of the rooms during the two monitoring periods is shown in Table 13. Room 410 is a larger room than the other three rooms. It has two full beds; the other rooms have one bed. More energy was used in this room than the other rooms during the period when the controls were inactive, but it did not use the most during the period when the controls were active. Guests in the room during the active period had different habits than the ones in the previous period.

Differences in the way guests use rooms have a very strong effect on how much energy is used. A good example of this is illustrated in Figure 19, in which the electrical energy use on a daily basis for Room 207 is plotted versus average daily room temperature. This data was collected during the time period when the controls were active. The energy increases substantially as the room temperature decreases. The correlation coefficient is 0.582, which is substantial enough to observe the trend that energy consumption increases as room temperature decreases.

It supports the observation that energy use is strongly influenced by occupants' room temperature preferences.

Table 13: Hotel #1 HVAC Energy Use

Room Number	Inactive Chiller (kWh)	Inactive Fan (kWh)	Inactive HVAC (kWh)	Inactive (therms)	Active Chiller (kWh)	Active Fan (kWh)	Active HVAC (kWh)	Active (therms)	HVAC Savings
201	27.48	38.09	65.57	1.390	18.47	11.90	30.37	2.624	53.7%
204	16.72	10.23	26.95	0.956	13.28	7.27	20.55	0.520	23.7%
207	27.56	23.38	50.94	0.362	29.15	18.47	47.62	0.906	6.5%
410	56.63	41.49	98.12	0.848	23.22	10.05	33.27	0.337	66.1%
Total	128.39	113.19	241.58	3.556	84.12	47.69	131.81	4.387	45.4%

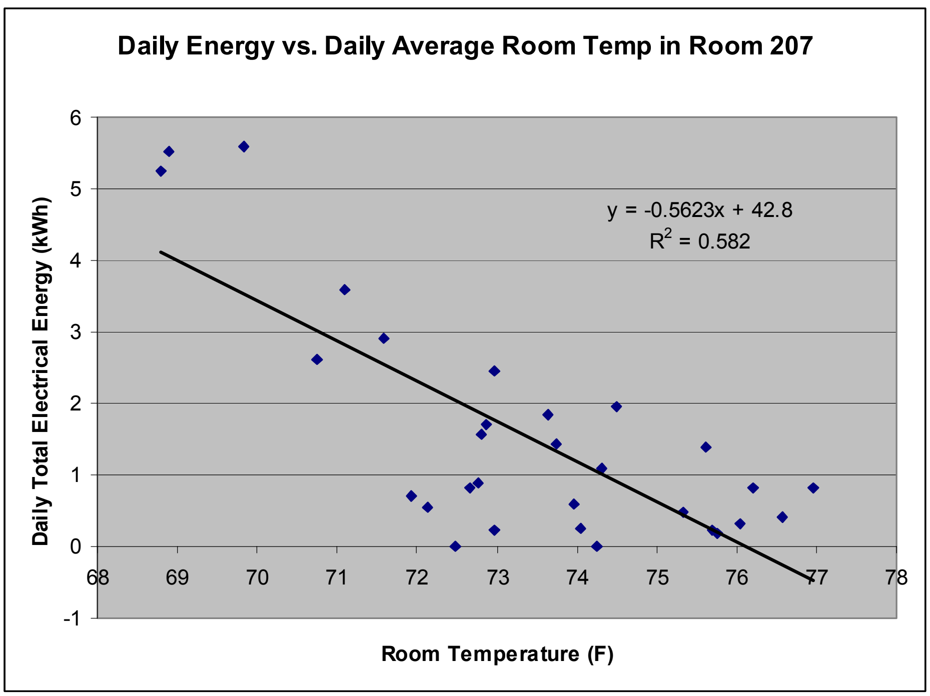

Figure 19: Daily Electrical Energy Use vs. Daily Average Room Temperature – Room 207

The numbers in Table 13**Error! Reference source not found.** show that energy use decreases in all four rooms when the controls are active. The percentage savings ranged from about 7 to 66%, with an average of approximately 45%. Since the savings varied by a factor of 10, no definite conclusions about the magnitude of typical percentage savings can be drawn from these results. This variation indicates that many more hotel rooms would need to be monitored over a longer period of time to develop representative savings values with measured data. The computer simulations thus provide a more representative value of savings.

It became clear during research that energy use in hotel rooms is dependent upon the way guests use them. Nevertheless, researchers adhered to the original plan and used the data to develop correlations between outside air temperature and HVAC energy usage. Researchers also used bin data of outside air temperature for an entire year to predict energy use and savings.

To improve the accuracy of the correlations, the data was divided into four groups. The active and inactive periods were kept separate. Then the data in each of these groups was separated according to whether the room was occupied or unoccupied. Since occupancy was tracked down to the minute, the room was considered occupied if it was occupied at least 80% of the hour and considered unoccupied if it was occupied less than 10% of the hour. Correlations were developed between daily average outside air temperature and daily HVAC energy use. The four resulting plots are shown in Figure 20 through Figure 23.

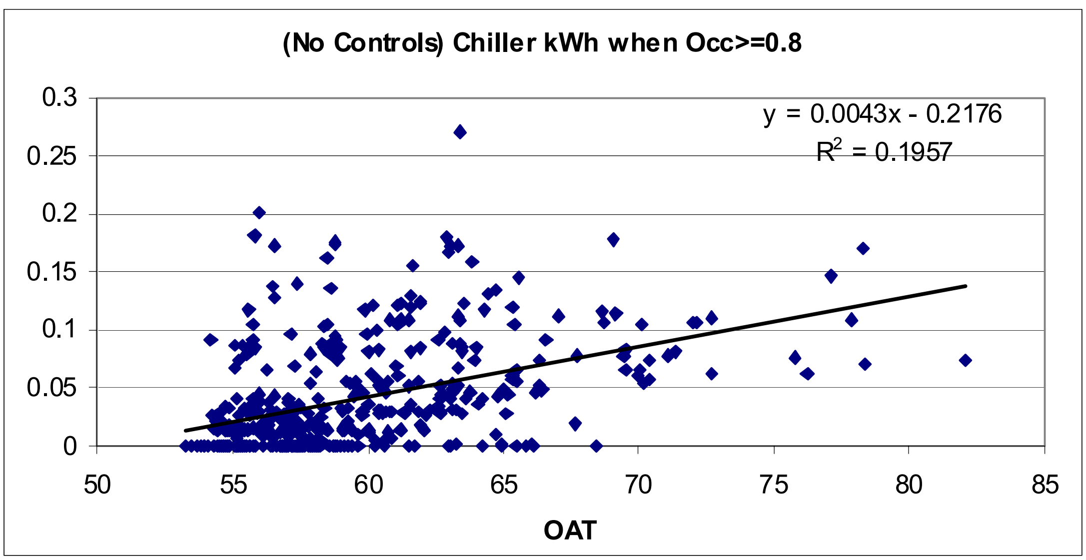

Figure 20: Daily HVAC Electrical Energy Use vs. Daily Average Outside Air Temperature – Inactive, Occupied

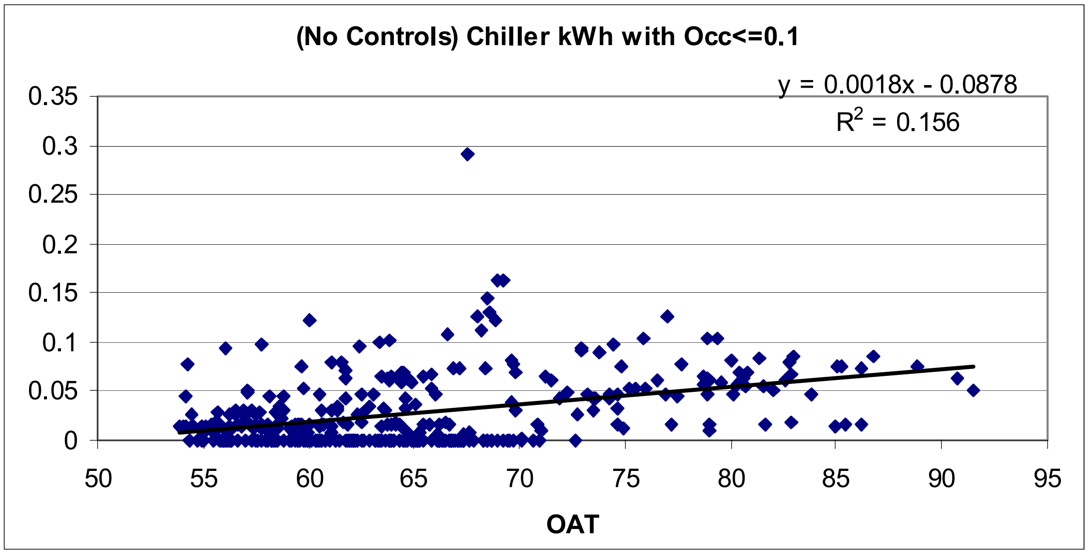

Figure 21: Daily HVAC Electrical Energy Use vs. Daily Average Outside Air Temperature – Inactive, Unoccupied

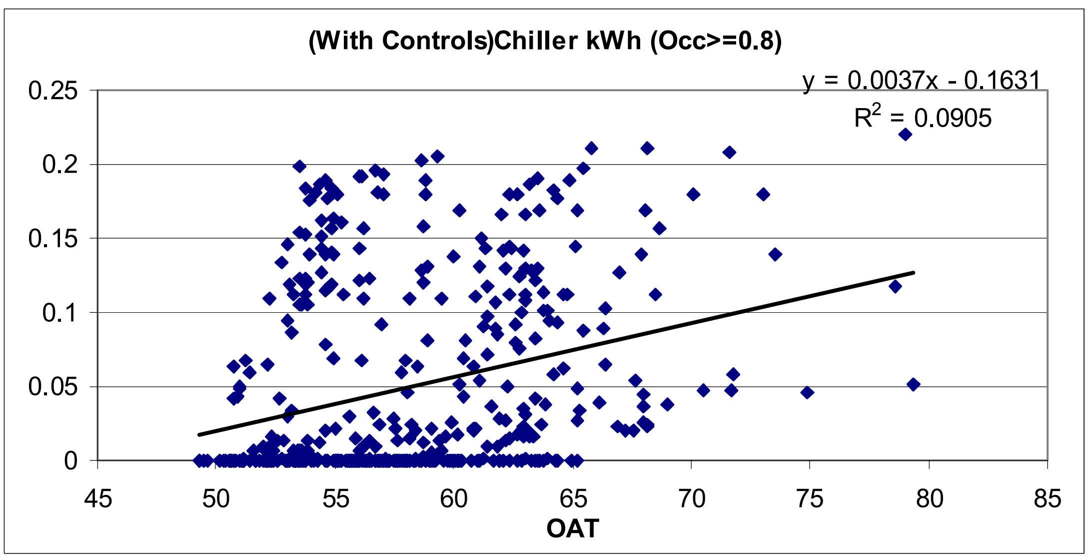

Figure 22: Daily HVAC Electrical Energy Use vs. Daily Average Outside Air Temperature – Active, Occupied

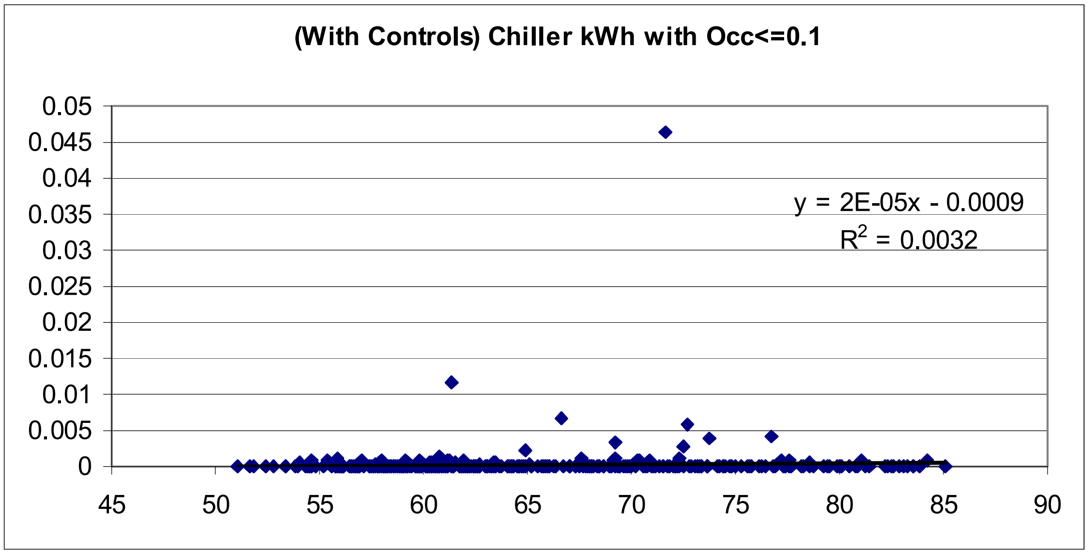

Figure 23: Daily HVAC Electrical Energy Use vs. Daily Average Outside Air Temperature – Active, Unoccupied

Four estimates of annual energy consumption were made; outside air temperature bin data for San Francisco was applied to each of the equations resulting from the correlations shown in the figures above. The results were then multiplied for the occupied and unoccupied periods by the percentage of time rooms are occupied and unoccupied. These were then added together to derive estimates of the annual energy consumption with the controls inactive and active.

Annual savings were derived by subtracting the predicted energy use with the controls active from the predicted energy use with the controls inactive. These calculations are shown in Table 14. The result is an estimated annual savings of 16.7 kWh/yr or 9%. The calculated energy savings was greater for hotel rooms in climates other than San Francisco, with cooling energy savings ranging from 18 to 31%.

Table 14: Calculated Annual Cooling Energy Savings Using Regressions

	CZ3 (San Francisco)	**CZ4 (San Jose)**	**CZ5 (San Luis Obispo)**	**CZ12 (Sacramento)**	**CZ13 (Fresno)**
Baseline (inactive controls)	181.2 kWh	219.9 kWh	188.5 kWh	238.7 kWh	350.7 kWh
Active Controls	164.5 kWh	165.5 kWh	154.8 kWh	164.9 kWh	241.9 kWh
Savings	9.2%	24.7%	17.9%	31.1%	31%

The bin analysis predicts smaller savings than were observed in the data for the monitored rooms. The regressions of cooling energy use to outside air temperature do not show a very strong correlation. Moreover, since only the cooling season was monitored there is little data when outside air temperatures are cool (less than 55° F). This makes it difficult to extrapolate the results to lower outside air temperatures. With an outside air temperature less than 50° F, there should be little or no cooling use. When outside air temperatures are low, the regression for the case with active controls predicts slightly higher energy use than the regression for the baseline case with inactive controls.

Furthermore, the data was collected in a hotel in San Francisco and may not be robust enough to predict the energy consumption of hotels in other climate zones. There are five climate zones within PG&E's service territory as shown in Table 15.

Table 15: Climate Zones, Representative Cities, and Degree Days

Climate Zone	Representative City	Heating Degree Days	Cooling Degree Days
CZ3	San Francisco	2,863	142
CZ4	Sunnyvale	2,387	594
CZ5	San Luis Obispo	2,361	312
CZ12	Sacramento	2,666	1,248
CZ13	Fresno	2,433	1,991

The results in Table 16 show the energy savings that result—assuming that there is no compressor-based cooling required when the outside air temperature is below 53° F. With this assumption, the bin analysis results in a 26% chiller energy savings for buildings in the San Francisco climate zone. Higher savings are calculated for the San Jose and San Luis Obispo climate zones.

Table 16: Calculated Annual Cooling Energy Savings Using Regressions (assumes no cooling needed when OAT<53F)

	CZ3 (San Francisco)	CZ4 (San Jose)	CZ5 (San Luis Obispo)	CZ12 (Sacramento)	CZ13 (Fresno)
Baseline (inactive controls)	176.4 kWh	190.7	159.4	205.7	314.6
Active Controls	130.6 kWh	112.1	98.8	105.7	187.1
Savings	26%	41%	38.0%	48.6%	41%

Annual chiller energy estimates from bin analysis. This is a linear correlation with outside air temperature; the chiller energy was set to 0 if OAT < 53F.

If similar savings occurred in 100 rooms of a hotel, the hotel would save between 3,664 and 10,200 kWh in cooling energy—or approximately $500 to $1,500 annually. Based on monitored data, the fan energy savings would be 69% of the chiller energy savings. This would place the annual HVAC energy savings from $845 (San Francisco) to $2,535 (Fresno).

The study considered a multi-variable regression approach to predict energy consumption, involving room air temperature, outside air temperature, and occupancy. The correlations using this approach were no better than the correlations obtained using the method employed above. There was significant scatter in the data and no clear dependence on guestroom occupancy levels. As seen throughout this section, using analytical methods to find patterns or correlations between energy use and outside air temperature yield very poor correlations with the hotel guestroom data.

Monitored data was reviewed to understand how frequently guests overrode the card key control system by leaving a card in the slot or by switching the fan on (Hotel #2 only) when they were out of the room. This was done by looking at how often the fan coil units ran when the rooms were unoccupied. Results are shown in Table 17 for two rooms in each of the hotels that represent the fan use in all the rooms.

Table 17: Calculated Effects of Occupant Override of Cardkey Control System

Hotel and Room Number	Fan kWh	Fan kWh While Occupied
Hotel #1, Rm 201	11.90	0.22
Hotel #1, Rm 410	10.05	1.04
Hotel #2, Rm 507	10.92	2.36
Hotel #2, Rm 708	9.18	2.35

The guestroom control system was overridden only occasionally in Hotel #1. However, in Hotel #2, the guestroom control system was often overridden. While the rooms were unoccupied in Hotel #2, the fan energy was nearly 25% of that when the rooms were occupied. This pattern of overriding the guestroom controls reduces the energy savings at Hotel #2. This may be partially explained by the fact that the hotel staff and cleaning staff may not have been sufficiently trained on the operation of the system. Moreover, for the system installed at Hotel #2, it is possible to manually override the guestroom control by selecting the fan button at the thermostat. It is not possible to override the fan at the thermostat in Hotel #1.

Lighting and Plug Load Results for Hotel #1

Lighting and plug loads were measured at one-minute intervals during the monitored period at Hotel #1. The lighting energy use was reduced by an average of 22% over the four rooms. When adding in plug loads, energy use for lighting and plug loads was reduced by just 7.4%. This low reduction was because few of the receptacles were controlled. Room receptacle loads were slightly higher during the active period than during the inactive period. While this is contrary to expected results, it is another indication that energy savings strongly depend on the way the rooms are used.

Table 18: Hotel #1 Lighting and Plug Loads

Room Number	Inactive GFCI (kWh)	Inactive Lighting (kWh)	Inactive Room Rec (kWh)	Inactive Total	Active GFCI (kWh)	Active Lighting (kWh)	Active Room Rec (kWh)	Active Total (kWh)
201	0.13	15.16	16.08	31.36	0.16	12.38	16.35	28.89
204	0.12	8.39	17.37	25.88	0.08	8.18	18.86	27.11
207	0.18	12.60	17.33	30.12	0.08	11.57	18.75	30.40
410	0.39	10.69	17.62	28.70	0.18	4.27	16.66	21.11
Total	0.82	46.84	68.4	116.06	0.5	36.4	70.62	107.51

Measured Data Results for Hotel #2

HVAC Results for Hotel #2

The inactive monitoring period for Hotel #2 was August 8th through September 6th. The post monitoring period was October 10th through November 7th. The card-key controls system in Hotel #2 was not installed during construction, but was retrofit to the rooms. The guestroom control system in Hotel #2 was similar, but not identical to the one in Hotel #1. Two major differences are: 1) the fan can be switched to "on" in Hotel #2 to run continuously, even when the card key is removed from the slot; and 2) the bathroom lights can be turned on (and left on) when no card key is in the slot. The monitoring results show that the energy savings in two rooms in Hotel #2 were negative and were minimal in another room. Savings are not available for the fourth room because the monitoring device was removed by a guest. The fan energy during unoccupied periods (as shown in Table 19 was nearly 25% as large as fan energy use during occupied periods.

Table 19: Hotel #2 HVAC Energy Use

Room Number	Inactive Chiller kWh	Inactive Fan kWh	Inactive HVAC kWh	Inactive (therms)	Active Chiller kWh	Active Fan kWh	Active HVAC kWh	Active therms	HVAC Savings
506	31.70	13.99	45.69	0.323	30.75	8.75	39.50	0.177	13.5%
507	18.27	12.20	30.48	0.172	31.32	10.92	42.24	0.342	-38.6%
703*	14.11	5.21	19.32	0.007	n/a				
708**	32.28	10.39	42.67	0.049	36.27	9.18	45.45	0.074	-6.52%
Total+	82.25	36.58	118.84	0.544	98.34	28.85	127.19	0.593	-0.39

** Monitoring period 8/14-9/8 ** Monitoring period 10/17-11/16 + Does not include room 703*

Lighting and Plug Load Results for Hotel #2

The lighting and plug load energy savings results from Hotel #2 are shown in Table 20 Energy use increased in two rooms and decreased in two others. There is not a clear savings pattern for two reasons. The first is that each guest uses his/her room differently; the second is that each guest could override the bathroom lighting switch, thus negating any savings.

Table 20: Hotel #2 Lighting and Plug Loads

Room Number	Inactive Guestroom Outlet kWh	Inactive Bathroom Outlet kWh	Inactive Total	Active Guestroom Outlet kWh	Active Bathroom Outlet kWh	Active Total (kWh)	Savings
506	13.36	1.50	14.86	12.56	1.40	13.96	6.1%
507	9.39	1.48	10.87	9.85	1.19	11.04	-1.6%
703	11.96	1.22	13.18	11.43	1.43	12.86	2.4%
708	8.78	0.94	9.72	12.62	1.46	14.08	-44.9%
Total	43.49	5.14	48.63	46.46	5.48	51.94	-6.8%

The most important results from the monitoring at Hotel #2 are that savings are reduced when the guestroom controls can be easily overridden. The monitored data shows long periods when the fans in some rooms ran continuously—even when the rooms were unoccupied. Bathroom lighting was also on when rooms were unoccupied. These patterns were not seen in the data for Hotel #1 because these override options were not available.

Computer Simulations

The amount of energy used in a hotel guestroom depends on many variables that are neither consistent nor predictable. The way any individual room is used changes each time a new guest moves in. Variables include: whether the room is sold or unsold, whether it is occupied or unoccupied, the temperature the guest prefers, the number of lights the guest turns on, and whether or not lights are turned off when the guest leaves the room. The empirical measurements taken in this project provide a great deal of value to understanding how the rooms are used and any features of the guestroom controls that influence the potential for savings.

However, because of the small sample size, small number of rooms monitored, and relatively short monitoring periods, the empirically-derived savings are not the best predictors of average annual savings. They are useful for understanding the rough magnitude of the potential savings, but should not be used to predict the annual savings that wide application of these controls could produce.

A better way to predict annual savings is to use the information about: occupancy patterns, lighting use patterns, average room temperature, and the frequency with which controls are defeated by occupants as the inputs to computer models. The models can simulate the energy use of a hotel with no guestroom controls and the energy use of the same hotel with guestroom controls. The difference is the savings in energy and electrical demand attributable to the controls. In addition, simulations can predict savings produced by completely turning off HVAC equipment when rooms are unoccupied and the savings that would result from setting thermostats up (or down, depending on the season) when the rooms are unoccupied.

The data from the guestrooms with and without active card-key controls were analyzed to derive typical occupancy and thermostat set points; these were used as inputs to the DOE-2.1E computer simulation. The models were run with weather data for San Francisco, San Jose, San Luis Obispo, Sacramento, and Fresno. Demand and energy savings values were calculated for each location. The guestrooms monitored in this project were smaller (300 ft^2) than what was found to be typical in the *Application Assessment Report* (450 ft^2). A second set of models was developed for the larger rooms, and the simulations and analysis were repeated.

The Computer Model

The computer simulation of the typical hotel was developed using Visual DOE, which uses the DOE-2.1E simulation engine. To account for the diversity of occupancy schedules, a wing with 60 hotel rooms was modeled. Each room had a slightly different occupancy schedule; on average, the occupancy schedules had the same occupancy rate as the monitored data. The rooms were seldom occupied (less than 10-15%) during the afternoon hours and were occupied approximately 95% during the early morning hours. The building envelope was modeled as compliant with 2005 Title 24 envelope criteria. The window-wall ratio (WWR) was set at approximately 43% for the entire building.

The front of the modeled hotel was oriented north; each floor consisted of 20 rooms with ten rooms facing north and ten facing south. Fenestration was double-paned clear glass with a U-factor of 0.483 Btu/h-ft^2-F and a SHGC of 0.698. The building window-wall ratio was 35.4%. The building was assumed to have exterior shading from adjacent buildings along the east and south façade and buildings across the street to the north and west. Average guestroom size was assumed to be 300 ft^2, to be consistent with the average room size of the hotels studied. No other hotel areas such as a lobby or restaurant were modeled since the principal area of concern was the energy savings potential for guestrooms.

Schedules

Occupancy data for all guests staying in all eight guestrooms during the period when the controls were inactive (the baseline) was analyzed to develop the room occupancy schedule for the average day. Occupancy was tracked in each of the rooms with the Energy Eye occupancy sensor and wireless transceiver. Occupancy data was compiled into one-hour average bins to determine typical guest occupant patterns. The average number of minutes per hour that all guestrooms were occupied is shown in Figure 24.

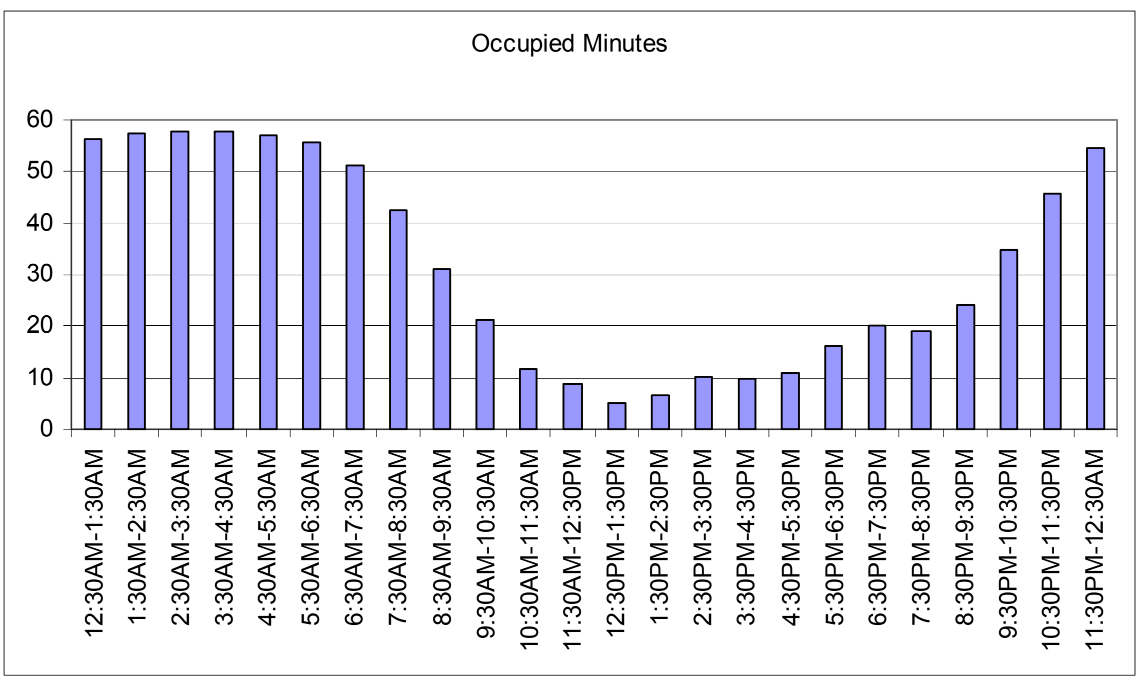

Figure 24: Average Hourly Occupancy (minutes/hour), Baseline Period

Since the baseline monitoring period was approximately six weeks, the occupancy patterns of at least 150 different occupants are reflected in this schedule, assuming the average stay is two days.

The schedule is expressed as the number of minutes in each hour that the average room is occupied. Since most computer simulations have a computational time step of one hour, it is not possible to model a single room with occupancy for a fraction of an hour. To compensate for this limitation, a computer model consisting of 60 rooms was developed. The number of rooms assumed to be occupied in each hour of the day used the measured percentage in Figure 24. As expected, the rooms are occupied more at night and in the early morning hours. Midday occupancy is low.

The average occupancy during a given hour was translated to schedules by assigning a unique schedule to each of the 60 rooms. For example, if for a given hour the average occupancy rate was 54 minutes out of the hour, 54 of the 60 rooms were modeled as occupied for the entire hour and six of the rooms were modeled as unoccupied for the entire hour. Some variability was applied to the schedules so that the average daily occupancy per room varies from 10 hours to 16 hours per day, while the overall averages match the monitored data. The occupancy schedules for each of the 60 rooms are presented in Figure 24. The schedules were inputs to the computer simulations.

Lighting and plug load schedules were derived from hourly average data over the eight rooms monitored at the hotels. Lighting and plug load peak demands were taken from hourly averages of monitored data, which were 75 W and 60 W, respectively.

Lighting and Plug Load Schedules

Schedules for both lighting and plug loads were developed using four weeks of average hourly demand in two of the monitored rooms at Hotel #1. The maximum hourly loads observed during this period were approximately 75 W for lighting and 60 W for plugs. The average lighting load for each hour of the day was compared to the 75 W maximum to develop hourly schedules for input to the computer simulations, as shown below in Table 21.

Since lighting was controlled by the card-key system, two schedules were developed from the data. One schedule shows the lighting energy used during the baseline period (inactive controls); and a second schedule shows the lighting energy use when the guestroom controls were active. The schedules for both periods are presented in Figure 25. It is clear that guestroom controls create the largest reduction in lighting energy use in afternoon hours—when the rooms are least occupied.

Table 21: Hourly Average Lighting Loads from Monitored Data

Hour	201 Hourly Lighting Load (Watts)	204 Hourly Lighting Load (Watts)	Average (Watts)	Fraction (Schedule)
0	26.18	11.42	18.80	0.25
1	22.77	10.36	16.56	0.22
2	23.63	9.15	16.39	0.22
3	20.04	8.76	14.40	0.19
4	18.37	7.78	13.07	0.17
5	16.33	10.66	13.50	0.18
6	17.55	15.37	16.46	0.22
7	20.86	14.35	17.60	0.23
8	18.28	10.08	14.18	0.19
9	17.12	14.02	15.57	0.21
10	12.24	11.37	11.80	0.16
11	18.05	10.59	14.32	0.19
12	13.03	6.36	9.70	0.13
13	7.66	6.46	7.06	0.09
14	8.41	9.71	9.06	0.12
15	7.20	7.63	7.41	0.10
16	7.31	13.79	10.55	0.14
17	11.25	11.27	11.26	0.15
18	11.55	11.02	11.28	0.15
19	14.01	12.81	13.41	0.18
20	17.57	11.96	14.76	0.20
21	21.07	13.78	17.42	0.23
22	23.69	17.55	20.62	0.27
23	25.27	9.64	17.46	0.23
Max	80.15	71.12	75.63	

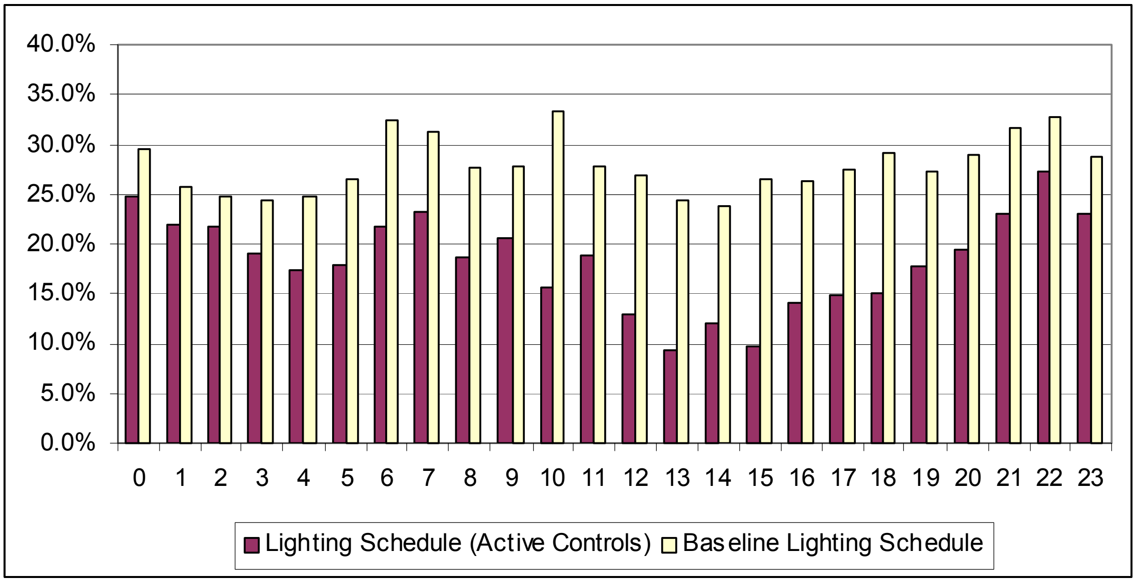

Figure 25: Comparison of Lighting Schedules for Baseline (Inactive) and Active Guestroom Controls

HVAC System and Central Plant

The HVAC system was modeled as a four-pipe fan-coil system with a separate system for each room. The water temperature for the cooling and heating coils was set at 55° F and 120° F, respectively. The fans for the fan-coil units were modeled as constant volume fans with a fan power of 0.00046 bhp/cfm. The fan size (cfm) was selected using an iterative approach. The fan design airflow was chosen to be the smallest discrete size that would prevent significant under-cooling (less than 50 hours annually). The discrete sizes of 200, 400, 600, and 800 cfm were chosen as representative of fan coil units on the market.

The central plant was modeled as a water-cooled chiller with medium efficiency (0.7 kW/ton nominal) and a central boiler with 80% thermal efficiency. The cooling tower uses a two-speed fan and the system has a waterside economizer for compressor-free cooling when conditions allow.

Modeling Guestroom Controls and Fans

The default fan schedules for the baseline system (without guestroom controls) were modeled to be continuously "on." In practice, this is never the case since fans are set to cycle with the call for cooling or heating, and only run until the set point temperature is reached. For the guestroom control case, the fan operating schedule for each room was set to coincide with the occupancy schedule—when the room was occupied the fan was on, and when the room was unoccupied the fan was off. The building envelope, schedules, and HVAC systems were assumed to be identical regardless of the assumptions about how the room was controlled. Three important observations were made about fans during the course of the analysis.

First, monitored data shows that fan operation during unoccupied hours in rooms with active controls adds 5.7% to the fan energy total. This results from guests “tricking” the control system into thinking that unoccupied rooms are occupied when they aren’t. This was modeled in the simulations by adding an hour of fan operation to the fan schedule when the rooms were unoccupied. Assuming an average occupancy of 60% (within a 24 hour day), daily fan operation was approximately 0.82 hours (60% x 24 hrs x 5.7%). For the 60-room hotel, this was simulated by adding one hour of fan operation to 49 of the 60 rooms (49/60 = 0.82) each day when they were unoccupied. This assumption produced slightly lower fan and chiller energy savings than would be derived without this correction.

Second, fan energy as a percentage of the chiller energy in the simulation results was significantly greater than it is in the monitored data. The simulations have a limitation in the way that the fans are modeled. The DOE-2 simulation program only allows four-pipe fan-coil systems to have continuous fan operation. In reality, however, the fans in the plenums above the rooms cycle on and off with the loads to maintain the room temperature at the thermostat setting. The model thus over-predicts the fan energy use and dilutes the HVAC energy savings.

From the monitored data, the average fan energy use was 69% of the cooling energy use. The simulation—which uses a fan schedule that is always on when the room is occupied—estimated fan energy use as being approximately 20% larger than the cooling energy use. A more accurate energy savings prediction was developed by calculating the fan energy use to be the same fraction of cooling energy use as seen in the monitored data. Adjustments were made to the fan energy after the simulations were run to derive a more realistic estimate of HVAC and total energy savings.

Third, an opportunity exists to significantly downsize chillers in hotels with guestroom controls. This is a result of most rooms being unoccupied during the afternoon hours with their HVAC and lighting systems turned off. The HVAC equipment was modeled just as it is in the hotels, and was not downsized.

Simulation Results

Hotels with three sets of assumptions were simulated in each of five climate zones. The first set of assumptions involved the size of the guestrooms. The rooms in the hotels studied in this project were approximately 300 ft^2. The average hotel room size in California, according to the *Application Assessment Report #0609, Marketable Technologies for the Hospitality Segment*, is 450 ft^2. A simulation with rooms having 450 ft^2 was developed to create savings that can be compared to the savings predicted in the *Application Assessment Report*. The second set of assumptions involved whether the guestroom controls were active or inactive. The third and final set of assumptions was whether the thermostats were turned off completely when the rooms were unoccupied (as was the case in the monitored hotels) or whether the thermostats were merely set back (as is the case with guestroom controls in many hotels).

Simulating both of these control strategies demonstrates the magnitude of savings produced by each strategy and how sensitive the potential savings are to this decision. The setback strategy assumed that the thermostat set points were adjusted 2° F from the seasonal default settings of 72° F for cooling and 70° F for heating. The setback thermostat settings, therefore, were 74° F for cooling and 68° F for heating. The five climate zones for which all models were run were CZ3 (San Francisco), CZ4 (San Jose), CZ5 (San Luis Obispo), CZ12 (Sacramento), and CZ13 (Fresno). These climates zones were selected because they represent the range of annual weather conditions where large numbers of hotels are built in PG&E's service territory.

Simulation Results: On/Off Control

The energy savings predicted for a guestroom control system that turns off the controlled loads (HVAC fan coil unit, and some lighting and plug loads) when the room is unoccupied are presented in the following tables. The annual electrical energy by end-use is presented in Table 22, the 300 ft^2-room hotel, and Table 25 for the 450 ft^2-room hotel. The fan energy in these two tables was calculated as 69% of the cooling energy, as described previously. The results in these two tables are representative of the energy consumption savings that will be achieved in actual hotels.

The annual lighting savings are 2,800 kWh per year for 60 rooms—approximately 47 kWh per room. Since all hotel room lighting was energy efficient (compact fluorescents), this represents an approximately 15% reduction in lighting energy use. Receptacles are not controlled, so their energy use does not change. All other end uses are controlled and discussed below.

Table 22: Energy Use for a 60-Room Hotel, On/Off Control (300 ft^2 Rooms, with Fan Correction)

Control Strategy	Lights (kWh)	Receptacles (kWh)	Cooling (kWh)	Tower/Heat Rejection (kWh)	Pumps/Aux. (kWh)	Fans (kWh)	Total (kWh)
CZ3 No Control	12,531	11,366	25,999	3,570	5,115	17,939	76,520
CZ3 On/Off Control	8,737	11,366	18,234	1,908	2,936	12,581	55,762
CZ4 No Control	12,531	11,366	31,095	3,813	5,615	21,456	85,876
CZ4 On/Off Control	8,737	11,366	23,065	2,448	3,756	15,915	65,286
CZ5 No Control	12,531	11,366	27,111	3,591	5,141	18,707	78,446
CZ5 On/Off Control	8,737	11,366	19,350	2,014	3,038	13,352	57,857
CZ12 No Control	12,531	11,366	32,912	3,904	5,818	22,709	89,240
CZ12 On/Off Control	8,737	11,366	24,937	2,591	4,017	17,207	68,854
CZ13 No Control	12,531	11,366	38,030	3,981	5,846	26,241	97,994
CZ13 On/Off Control	8,737	11,366	30,604	2,974	4,511	21,117	79,308
Average for all Climate Zones, Inactive Control	12,531	11,366	31.029	3,772	5,507	21,410	85,616
Average for all Climate Zones, Active Control	8,737	11,366	23238	2387	3651.6	16,034	65,414

The energy consumption and savings from HVAC alone are shown in Table 23 for the 300 ft^2-room hotel and in Table 26 for the 450 ft^2-room hotel. Depending on climate, predicted annual HVAC energy savings range from 20 to 32% for the 300 ft^2 rooms and 19 to 22% for the 450 ft^2 rooms. The magnitude of the energy savings in warmer climates was nearly the same as in cooler climates; however, the savings was a smaller percentage of the total HVAC energy use in hotter climates. On a percentage basis, the coastal climate with a relatively long cooling season (San Luis Obispo) offered the greatest potential energy savings.

Table 23: HVAC Energy Savings for a 60-Room Hotel, On/Off Control (300 ft^2 Rooms, with Fan Correction)

Climate Zone	HVAC Total, Inactive Control (kWh)	HVAC Total, Active Control (kWh)	HVAC Savings (kWh)	HVAC Savings
CZ3	52,623	35,659	16,964	32.2%
CZ4	61,979	45,184	16,795	27.1%
CZ5	54,550	37,754	16,796	30.8%
CZ12	65,343	48,752	16,591	25.4%
CZ13	74,098	59,206	14,892	20.1%
Average	61,719	45,311	16,408	26.6%

Gas energy savings are shown in Table 24 for the 300 ft^2-room hotel and Table 27 for the 450 ft^2-room hotel. The gas usage figures include space heating and do not include hot water heating, commercial cooking, or any other gas uses. The gas savings ranged from 5 to 14% for the 300 ft^2-room hotel and from 7 to 34% for the 450 ft^2-room hotel.

Table 24: Gas Savings for a 60-Room Hotel, On/Off Control, (300 ft^2 Rooms)

Climate Zone	Gas Usage, Inactive Control (therms)	Gas Usage, Active Control (therms)	Gas Savings, (therms)	Gas Savings
CZ3	922	852	70	7.6%
CZ4	1,085	995	90	8.3%
CZ5	913.5	789	124.5	13.6%
CZ12	1,411	1336	75	5.3%
CZ13	1,352	1287	65	4.8%
Average	1,137	1,052	85	7.5%

Table 25: Energy Use for a 60-Room Hotel, On/Off Control (450 ft^2 Rooms, with Fan Correction)

Climate Zone and Control Strategy	Lights (kWh)	Receptacles (kWh)	Cooling (kWh)	Tower/Heat Rejection (kWh)	Pumps/Aux. (kWh)	Fans (kWh)	Total (kWh)
CZ3 No Control	16,210	14,236	32,265	4,577	6,286	22,263	95,837
CZ3 On-Off Control	11,406	14,236	25,409	3,060	4,732	17,532	76,375
CZ4 No Control	16,210	14,236	36,939	4,680	6,864	25,488	104,417
CZ4 On-Off Control	11,406	14,236	29,551	3,179	5,108	20,390	83,870
CZ5 No Control	16,210	14,236	32,958	4,973	7,055	22,741	98,173
CZ5 On-Off Control	11,406	14,236	27,572	3,300	5,096	19,025	80,635
CZ12 No Control	16,210	14,236	39,982	4,787	7,075	27,588	109,878
CZ12 On-Off Control	11,406	14,236	32,404	3,317	5,331	22,359	89,053
CZ13 No Control	16,210	14,236	50,560	5,374	7,541	34,886	128,807
CZ13 On-Off Control	11,406	14,236	41,346	3,760	5,763	28,529	105,040
Average for all Climate Zones, Inactive Control	16,210	14,236	38,541	4,878	6,964	26,593	107,422
Average for all Climate Zones, Active Control	11,406	14,236	31,256	3,323	5,206	21,567	86,995

Table 26: HVAC Energy Savings for a 60-Room Hotel, On/Off Control (450 ft^2 Rooms, with Fan Correction)

Climate Zone	HVAC Total, Inactive Control (kWh)	HVAC Total, Active Control (kWh)	HVAC Savings (kWh)	HVAC Savings
CZ3	65,391	50,733	14,658	22.4%
CZ4	73,971	58,228	15,743	21.3%
CZ5	67,727	54,993	12,734	18.8%
CZ12	79,432	63,411	16,021	20.2%
CZ13	98,361	79,398	18,963	19.3%
Average	76,976	61,353	15,624	20.3%

Table 27: Gas Savings for a 60-Room Hotel, On/Off Control, (450 ft^2 Rooms)

Climate Zone	Gas Usage, Inactive Control (therms)	Gas Usage, Active Control (therms)	Gas Savings, (therms)	Gas Savings
CZ3	881	819	62	7.0%
CZ4	1,653	1,141	512	31.0%
CZ5	1,398	926	472	33.8%
CZ12	2,098	1482	616	29.4%
CZ13	1,673	1176	497	29.7%
Average	1,541	1,109	432	28.0%

Peak demand is reduced when guestroom controls with on/off control are used. Table 28 shows that peak demand in the hotel with 300 ft^2 rooms was reduced by 20 to 36%. Peak demand in the hotel with 450 ft^2 rooms was reduced by 15 to 27%, as shown in The peak demand reduction was highest in the mild climates. Guestroom occupancy is typically lowest during the afternoon hours, when building peak demand normally occurs. Since guestroom controls that turn off HVAC when rooms are unoccupied significantly reduce peak demand, central cooling plants in new and existing buildings could be run more efficiently with variable speed control.

Table 28: Peak Demand Savings for a 60-Room Hotel, On/Off Control (300 ft^2 Rooms)

Climate Zone	Peak Demand, Inactive Control (kW)	Peak Demand, Active Control (kW)	Peak Demand Reduction (kW)	Peak Demand Reduction
CZ3	23.5	15	8.5	36%
CZ4	26	19	7	27%
CZ5	23.5	17	6.5	28%
CZ12	28	20.5	7.5	27%
CZ13	27.5	22	5.5	20%
Average	25.7	18.7	7.0	27.2%

Table 29: Peak Demand Savings for a 60-Room Hotel, On/Off Control (450 ft^2 Rooms)

Climate Zone	Peak Demand, Inactive Control (kW)	Peak Demand, Active Control (kW)	Peak Demand Reduction (kW)	Peak Demand Reduction
CZ3	24.5	18.0	6.5	27%
CZ4	27.5	21.0	6.5	24%
CZ5	24.5	18.0	6.5	27%
CZ12	30.5	26.0	4.5	15%
CZ13	33.5	28.5	5.0	15%
Average	28.1	22.3	5.8	20.6%

Simulation Results: Setback Control

The following tables and figures show simulation results when the guestroom control system adjusts the thermostat setting when the room is unoccupied. The thermostat setting is set up 2° F in the summer and set back 2° F in the winter. This strategy is defined as “setback control.” The annual electrical energy by end use is presented in Table 30 for the 300 ft^2-room hotel and in Table 33 for the 450 ft^2-room hotel. The fan energy in these two tables was also calculated as 69% of the cooling energy, as described previously. Assumptions about lighting and receptacles were the same for setback control as they were for on/off control; thus, the energy use for buildings with no control was the same as those with on/off control (Table 22 and Table 25). The difference between the hotels with setback and on/off control was in the HVAC energy use. The hotels with setback control used more energy than the hotels with on/off control.

Table 30: Energy Results for 60 Room Hotel, Setback Control (300 ft^2 Rooms, with Fan Correction)

Control Strategy	Lights (kWh)	Receptacles (kWh)	Cooling (kWh)	Tower/Heat Rejection (kWh)	Pumps/Aux. (kWh)	Fans (kWh)	Total (kWh)
CZ3 No Control	12,531	11,366	25,999	3,570	5,115	17,939	76,520
CZ3 Setback Control	8,737	11,366	25,726	3,547	5,054	17,751	72,181
CZ4 No Control	12,531	11,366	31,095	3,813	5,615	21,456	85,876
CZ4 Setback Control	8,737	11,366	30,487	3,766	5,541	21,036	80,933
CZ5 No Control	12,531	11,366	27,111	3,591	5,141	18,707	78,447
CZ5 Setback Control	8,737	11,366	25,979	3,301	4,761	17,926	72,070
CZ12 No Control	12,531	11,366	32,912	3,904	5,818	22,709	89,240
CZ12 Setback Control	8,737	11,366	30,951	3,460	5,238	21,356	81,108
CZ13 No Control	12,531	11,366	38,030	3,981	5,846	26,241	97,995
CZ13 Setback Control	8,737	11,366	36,930	3,824	5,634	25,482	91,973
Average for all Climate Zones, Inactive Control	12,531	11,366	31,029	3,772	5,507	21,410	85,615
Average for all Climate Zones, Active Control	8,737	11,366	30,015	3,580	5,246	20,710	79,653

The HVAC electricity savings for a guestroom setback control are shown in Table 31 for the 300 ft^2-room hotel and Table 34 for the 450 ft^2-room hotel. The energy savings for setback control was approximately 1 to 7% for the 300 ft^2-room hotel and 8 to 12% for the 450 ft^2-room hotel. These savings, while significant, were smaller than the savings for the same hotel with on/off controls.

Table 31: HVAC Energy Savings for 60 Room Hotel, Setback Control (300 ft^2 Rooms, without Fan Correction)

Climate Zone	HVAC Total, Inactive Control (kWh)	HVAC total, Active Control (kWh)	HVAC Savings (kWh)	HVAC Savings
CZ3	52,623	52,078	545	1.0%
CZ4	61,979	60,830	1,149	1.9%
CZ5	54,550	51,967	2,583	4.7%
CZ12	65,343	61,005	4,338	6.6%
CZ13	74,098	71,870	2,228	3.0%
Average	61,719	59,550	2,169	3.5%

Gas energy savings are shown in Table 32 for the 300 ft^2-room hotel and Table 35 for the 450 ft^2-room hotel. The gas energy savings—which only include guestroom space heating—were less than 1% for the hotel with 300 ft^2 rooms and no more than 7% for the hotel with 450 ft^2 rooms. The gas savings for the setback control were also much smaller than the savings achieved with the on/off control.

Table 32: Gas Savings for a 60-Room Hotel, Setback Control, (300 ft^2 Rooms)

Climate Zone	Gas Usage, inactive control (therms)	Gas Usage, Active Control (therms)	Gas Savings (therms)	Gas Savings
CZ3	922	921.5	0.5	0.05%
CZ4	1,085	1089	(4)	(0.3%)
CZ5	913.5	912.5	1	0.11%
CZ12	1,411	1406	5	0.35%
CZ13	1,352	1346	6	0.44%
Average	1,137	1,135	1.7	0.15%

Table 33: Energy Use for a 60 Room Hotel, Setback Control (450 ft^2 Rooms, without Fan Correction)

Control Strategy	Lights (kWh)	Equipment (kWh)	Cooling	Tower/Heat rejection (kWh)	Pumps/Aux. (kWh)	Fans (kWh)	Total (kWh)
CZ3 No Control	16,210	14,236	32,265	4,577	6,286	22,263	95,837
CZ3 Setback Control	11,406	14,236	28,119	4,049	5,774	19,402	82,986
CZ4 No Control	16,210	14,236	36,939	4,680	6,864	25,488	104,417
CZ4 Setback Control	11,406	14,236	33,487	4,212	6,209	23,106	92,656
CZ5 No Control	16,210	14,236	32,958	4,973	7,055	22,741	98,173
CZ5 Setback Control	11,406	14,236	29,945	4,440	6,396	20,662	87,085
CZ12 No Control	16,210	14,236	39,982	4,787	7,075	27,588	109,878
CZ12 Setback Control	11,406	14,236	36,557	4,318	6,461	25,224	98,202
CZ13 No Control	16,210	14,236	50,560	5,374	7,541	34,886	128,807
CZ13 Setback Control	11,406	14,236	46,699	4,869	6,916	32,222	116,348
Average for all Climate Zones, Inactive Control	16,210	14,236	38,541	4,878	6,964	26,593	107,422
Average for all Climate Zones, Active Control	11,406	14,236	34,961	4,378	6,351	24,123	95,456

Table 34: HVAC Energy Savings for a 60-Room Hotel, Setback Control (450 ft^2 Rooms, without Fan Correction)

Climate Zone	HVAC Total, Inactive Control (kWh)	HVAC Total, Active Control (kWh)	HVAC Savings (kWh)	HVAC Savings
CZ3	65,391	57,344	8,047	12.3%
CZ4	73,971	67,014	6,957	9.4%
CZ5	67,727	61,443	6,284	9.3%
CZ12	79,432	72,560	6,871	8.7%
CZ13	98,361	90,706	7,655	7.8%
Average	76,976	69,813	7,163	9.3%

Table 35: Gas Savings for a 60-Room Hotel, Setback Control (450 ft^2 Rooms)

Climate Zone	Gas Usage, Inactive Control (therms)	Gas Usage, Active Control (therms)	Gas Savings (therms)	Gas Savings
CZ3	881	876	5	0.6%
CZ4	1653	1578	75	4.5%
CZ5	1398	1300	98	7.0%
CZ12	2098	2012	86	4.1%
CZ13	1673	1610	63	3.8%
Average	1,541	1,475	65.4	4.3%

The following tables show there was a demand reduction with setback control, but the reduction was less than that of the on/off control. Peak demand was reduced 6 to 15% for the hotel with 300 ft^2 rooms; and reduced 13 to 18% for the hotel with 450 ft^2 rooms.

Table 36: Peak Demand Savings for a 60-Room Hotel, Setback Control (300 ft^2 Rooms)

Climate Zone	Peak Demand, Inactive Control (kW)	Peak Demand, Active Control (kW)	Peak Demand Reduction (kW)	Peak Demand Reduction
CZ3	23.5	22	1.5	6%
CZ4	26	23.5	2.5	10%
CZ5	23.5	20	3.5	15%
CZ12	28	24	4.0	14%
CZ13	27.5	24.5	3.0	11%
Average	25.7	22.8	2.9	11%

Table 37: Peak Demand Savings for a 60-room Hotel, Setback Control (450 ft^2 Rooms)

Climate zone	Peak demand, inactive control (kW)	Peak demand, active control (kW)	Peak demand reduction (kW)	Peak demand reduction (%)
CZ3	24.5	21.0	3.5	14%
CZ4	27.5	24.0	3.5	13%
CZ5	24.5	20.0	4.5	18%
CZ12	30.5	26.5	4.0	13%
CZ13	33.5	29.0	4.5	13%
Average	28.1	24.1	4.0	14%

With only a 2° F setback, the electricity and gas energy savings were much lower with setback control than with on/off control. The savings from setback control increase as the amount of the setback increases. However, the on/off control results represent the maximum savings that a guestroom control strategy can produce.

Monthly Energy Consumption Simulations

Appendix C compares the monthly energy consumption for: base buildings (no control), buildings with on/off control, and buildings with setback control. For each climate zone, two graphs were developed for the 300 ft^2 hotel rooms and two were developed for the 450 ft^2 hotel rooms. These graphs show the monthly electricity consumption (Figure 26) and the monthly gas consumption (Figure 27). The figures illustrate the typical increase in electricity consumption and decrease in gas consumption in the summer months. They also highlight the following: baseline buildings (ones without guestroom controls) use the most energy; buildings with setback control use less energy than the baseline; and buildings with on/off control use the least amount of energy.

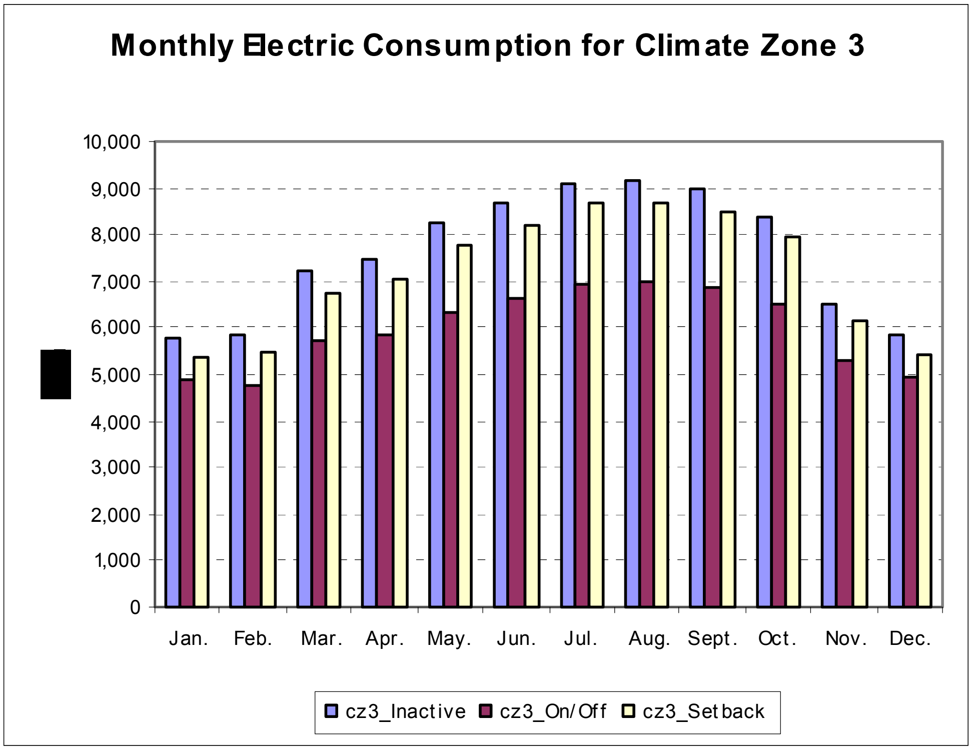

Figure 26: Monthly Electricity Consumption for CZ3, Hotel Wing with 300 ft^2 Rooms

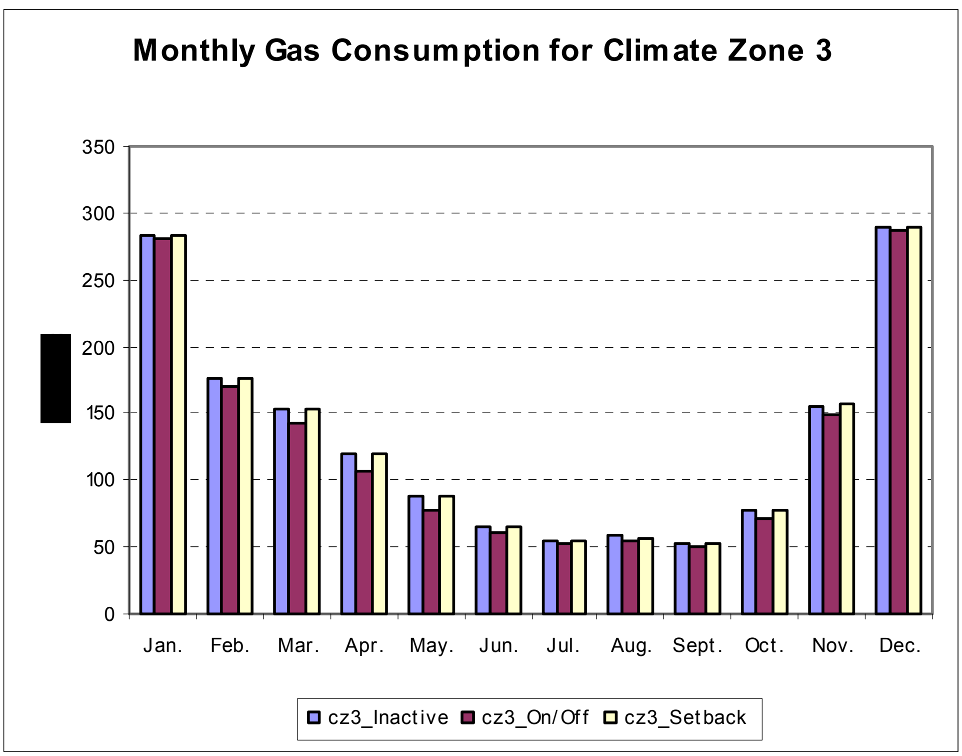

Figure 27: Monthly Gas Consumption for CZ3, Hotel Wing with 300 ft^2 Rooms

Hotel Guest Surveys

Hotel guests were surveyed to obtain information about their satisfaction with the comfort of their rooms and the operation of their room controls. Guests staying in the monitored rooms at each of the hotels were asked to complete a brief questionnaire to assess their satisfaction with the controls in the room. The survey was given to the guests during check-in as an insert in the folder containing their room keys. Guests were asked to complete the questionnaires and return them to the front desk at check out.

Since all of the rooms in Hotel #1 have guestroom controls, management was asked to give surveys to all guests—not just the guests staying in the monitored rooms. Guests were asked to record the dates they checked in and out and their room number. This would identify if the guests stayed in one of the monitored rooms and whether the controls in the monitored room were active during their stay.

Survey Background

Few hotels in the United States have card-key control systems. It is important to know how guests felt about their stay in the two hotels with card-key systems to determine if these systems are viable options for a large number of hotels. Hotel owners and managers will not install card-key systems if they think guests will disapprove of them.

Guestroom controls based on passive infrared technology (occupancy sensors) are common. Guests are accustomed to seeing occupancy sensors on the thermostat and have virtually no interaction with this type of control system; they may not even know it is present in their rooms. However, guests know when they are staying in a room with a card-key control system since they have to insert their room key in the holder next to the front door to activate the lights and the heating and cooling system.

The guests were surveyed in both hotels to learn how they perceived the controls and felt about their experience staying in the hotel. Since the heating and cooling equipment in these guestrooms was turned completely off when the rooms were unoccupied, they represent the worst-case conditions. Rooms in which the thermostat is set up (or back) when guests are away will likely be closer to the set point temperature when they return than rooms in which the heating and cooling is turned off. Guests that are accepting of the on/off controls in the monitored hotels, are very highly likely to be accepting of controls that set back the temperature by a few degrees.

Survey Sample Size and Sources

A total of 184 surveys were returned, as shown in Table 38. All of the rooms in Hotel #1 had guestroom controls, so all guests staying in that hotel were asked to complete surveys. Only four rooms had guestroom controls in Hotel #2. Only the guests staying in the four rooms with controls were asked to complete surveys. For these reasons, more surveys were completed and returned for Hotel #1 than for Hotel #2.

Table 38: Number of Survey Responses

	Rooms with Active Guestroom Controls	**Rooms with Inactive Guestroom Controls**
Hotel #1	119	12
Hotel #2	30	23
TOTAL	149	35

Survey Responses

We review the responses to the guest surveys in this section by question, discussing the purpose of each question first.

Question 1: Please describe your primary purpose of staying at this hotel.

Business:
Leisure:
Other:

The purpose for this first question was to obtain information about why people stayed at the hotels. This information was gathered because it would be useful to better understand the observed occupancy patterns, since guests on leisure travel would likely spend more time in their room than guests traveling on business. The results are shown in Table 39.

Table 39: Survey Question #1

	Hotel #1	**Hotel #2**	**Both Hotels**
Business	40%	37%	39%
Leisure	57%	62%	59%
Other	3%	1%	2%

More leisure travelers than business travelers stayed in these hotels—nearly 60%. The percentage of guests in each of these three categories was similar for both hotels.

Question 2: When you first arrived, was the temperature in your room:

Too hot?
Too cool?
Just right?

The purpose for this second question was two-fold. First, it was to determine if guests perceived the temperature of rooms with active controls to be acceptable when they first arrived. Second, it was to evaluate if guests perceived a difference in arrival temperature between rooms with active controls and rooms without them. The assumption is that the HVAC systems in rooms with active controls will have been turned off for some period of time prior to a guest's arrival; the possibility of perceived discomfort is greater than it would be in rooms where the HVAC is not controlled. The results are shown in Table 40.

Table 40: Satisfaction with Arrival Temperature

	Rooms with Active Guestroom Controls	**Rooms with Inactive Guestroom Controls**	**Difference (Active – Inactive)**
Too hot	8%	13%	-5%
Too cool	8%	5%	3%
Just right	84%	82%	2%

A high percentage of guests arriving at their rooms thought the temperature was just right, regardless of whether the room had active or inactive guestroom controls. Whether the room was controlled or not made little difference in how guests perceived the temperature upon their arrival. In all cases, the differences were small. These results were somewhat unexpected, since the rooms with inactive guestroom controls should have been closer to the thermostat set point temperature than ones with active guestroom controls.

Question 3: During your stay, was the room temperature:

Too hot?
Too cool?
Just right?

The purpose for this third question was to determine if guests perceived the temperature of rooms to be acceptable during their stay, and if guests perceived a difference in temperature during their stay between rooms with active controls and rooms without them. The assumption was that the HVAC systems in all of the rooms should maintain the set point temperature and it shouldn't matter if the guestroom controls were active or not, since all systems operate the same when the rooms are occupied. The results are shown in Table 41.

Table 41: Satisfaction with Room Temperature During the Stay

	Rooms with Active Guestroom Controls	**Rooms with Inactive Guestroom Controls**	**Difference (Active – Inactive)**
Too hot	4%	3%	1%
Too cool	0%	7%	-7%
Just right	96%	90%	6%

Overall, the guests thought the temperature in their rooms was just right during their stays regardless of whether the guestroom controls were active. The surprising finding was that a higher percentage of guests in the rooms with active controls reported the temperature to be just right as compared to guests' responses in the rooms with inactive controls. One possible reason was that the thermostat set point in rooms with active controls always reset to 72° F when a guest returned to the room. The thermostats in the other rooms maintained whatever set point had been dialed in by the current guest or a previous guest.

Question 4: During your stay, did you adjust the thermostat?

Yes:
Yes, several times:
No:

The purpose for this fourth question was to see if guests took action if they were not satisfied with the room temperature. The assumption was that guests in rooms with active guestroom controls would adjust the thermostat more often than guests in rooms with inactive controls, if they were not satisfied with the room temperature when they returned. The results are shown in Table 42.

Table 42: Frequency of Thermostat Adjustments

	Rooms with Active Guestroom Controls	Rooms with Inactive Guestroom Controls
Yes	48%	58%
Yes, several times	36%	19%
No	16%	23%

A higher percentage of guests staying in rooms with active guestroom controls adjusted the thermostat than guests staying in the rooms with inactive controls. Only 16% of the guests in the rooms with active controls did not adjust the thermostat, compared to 23% in the rooms with active controls. Guests in rooms with active controls also adjusted the thermostat more often than guests in rooms with inactive controls. The biggest factor influencing this behavior was probably that the thermostat set point in the rooms with inactive controls never changed. Once a guest was satisfied with the temperature they did not have to make changes. Thermostat set points in the rooms with active controls were reset to 72° F every time the guest re-entered the room. Even though guests in rooms with active controls changed the thermostat setting more often, they also reported that they are more comfortable, as the answers to Question 3 indicate.

Question 5: If you answered "Yes" to question 4, how did you adjust the thermostat?

Raised the setting to be warmer:
Raised and lowered the setting:
Lowered the setting to be cooler:

The purpose for this fifth question was to understand how the guests changed the thermostat setting. This helped evaluate the default thermostat setting of 72° F in rooms with active guestroom controls. If guests adjusted it upward most often, then it was set too low. If guests more frequently adjusted it downward, then it was too high. The results are shown in Table 43.

Table 43: Direction of Thermostat Adjustments

	Rooms with <u>Active</u> Guestroom Controls	**Rooms with <u>Inactive</u> Guestroom Controls**
Raised the setting to be warmer	29%	35%
Raised and lowered the setting	5%	3%
Lowered the setting to be cooler	66%	62%

Guests lowered their thermostat settings more often than they raised them. Very few guests raised and lowered their thermostat settings. The percentage of guests who lowered thermostat settings in the rooms with active guestroom controls was only slightly greater than the percentage of guests staying in rooms with inactive guestroom controls. Fewer guests would change the thermostat setting in the rooms with active control, if the default set point was lowered a degree or two. This is desirable because guests who do not have to adjust the thermostat will more likely perceive a better guest experience. The impact on energy consumption would be small, since the HVAC is off when no one is in the room, guests lower the set point most often themselves, and the people who want to be warmer will still adjust the thermostat to be comfortable.

Question 6: When you returned to the room from being out, was the temperature:

Too hot?
Too cool?
Just right?

The purpose for the sixth question was to determine if guests noticed a change in the temperature of their room when they returned to their room, compared to how it was when they left. (Presumably it was comfortable when they left.) The assumption is that the rooms with inactive controls should be the same temperature when guests return as they were when they left. The temperature in the rooms with active guestroom controls could change, since the HVAC would be turned off while they were out. The results are presented in Table 44.

Table 44: Room Temperature When Returning from Being Out

	Rooms with <u>Active</u> Guestroom Controls	**Rooms with <u>Inactive</u> Guestroom Controls**	**Difference (Active – Inactive)**
Too hot	22%	19%	3%
Too cool	9%	3%	6%
Just right	70%	78%	-8%

The differences in the perception of temperature upon returning to the room between the two groups of rooms were not great—in fact, they were very similar. The highest percentages of respondents in both groups said their room was just right when they returned from being out. Eight percent were more satisfied in the rooms with inactive controls. (This is logical, since the temperature in these rooms should not have changed while the guests were out; it may have changed in the rooms with active control.)

The next highest group reported the room to be too hot, followed by the group that reported it was too cold. The temperature in the rooms with inactive controls presumably did not change while the guests were out, yet some occupants perceived that the room was no longer comfortable upon their return. One reason is that most guests had been exposed to outside temperatures just before returning to their rooms. The contrast between the temperature of their environment just before entering the room and the room temperature likely influences how they perceive the room temperature. Responses from guests staying in the rooms with active controls are similar to responses from guests staying in rooms with inactive controls. This indicates that turning the HVAC system off while they were out had little impact on their perception of the temperature in the room upon their return.

Question 7: Did you notice any difference in the heating or air conditioning system from your room when you returned from being out?

No:
Not sure/don't know:
Yes:

The purpose for the seventh question was to determine if guests would perceive that the HVAC system had been changed while they were away from their room. The assumption is that the HVAC systems in the rooms with inactive controls should be the same when guests return as they were when they left, therefore they should perceive no change. However, the HVAC systems in the rooms with active guestroom controls were changed (i.e. turned off) while the guests were out, so it would not be unusual for them to report noticing a change. The results are presented in Table 45.

Table 45: HVAC System Change When Returning from Being Out

	Rooms with Active Guestroom Controls	Rooms with Inactive Guestroom Controls	Difference (Active – Inactive)
Yes	35%	29%	6%
Not sure/don't know	20%	20%	0%
No	45%	51%	-6%

The perceptions of whether or not the HVAC systems had been changed between the two groups of rooms were very similar. The highest percentages of respondents in both groups stated they didn't notice any change to their HVAC system. The next highest percentage said that they did notice a change to the system—though a higher percentage of guests in the rooms with active controls noticed a change. The same percentage in each group weren't sure if a change had been made.

Since responses from guests in rooms with active controls were similar to those from the guests in rooms with inactive controls, turning the HVAC system off while guests were out had little impact on their perceptions of whether a change had been made while they were out. The fact that nearly half the guests in the rooms with inactive controls perceived a change—even though none occurred—indicates that guests' sensitivity to change are complicated. The factors that enter into the perception of a change seemed to more strongly influence results than whether or not the system had actually changed. This factor is probably why the distribution of results is so similar for each of the hotels.

Question 7a: Was the difference:

> **Acceptable?**
> **Inconvenient?**

This follow-up question to Question 7 was written assuming some number of people would report noticing a change. This question was to better understand if they thought the change was acceptable and probably not a problem, or inconvenient and likely perceived as a problem. The results from are presented in Table 46.

Table 46: HVAC System Change Acceptability

	All Rooms
Acceptable	87%
Inconvenient	13%

The vast majority of guests reported that the change to the HVAC system as it affects the temperature in the room was acceptable.

Question 8: Which of the following would best describe your acceptance of a guestroom which has such temperature control systems (and environmental benefits):

> **Inconvenient and not acceptable:**
> **Inconvenient, but acceptable:**
> **Fully acceptable:**

The purpose for this question was to understand guest attitudes about having the temperature in their rooms automatically controlled to create environmental benefits. This question was only asked of guests staying in Hotel #2. The results are presented in Table 47.

Table 47: Acceptance of Guestroom Controls

	Rooms with Active Guestroom Controls	Rooms with Inactive Guestroom Controls	Difference (Active – Inactive)
Inconvenient and not acceptable	4%	5%	-1%
Inconvenient, but acceptable	12%	14%	-2%
Fully acceptable	83%	81%	2%

Again, the responses from guests were similar, whether or not they were staying in a room with guestroom controls. More than 80% of guests replied that the controls were acceptable. Only 12 to 14% of guests stated that controls were inconvenient, but acceptable. The smallest number of guests, 5% or less, responded that the controls were inconvenient and unacceptable. More than 95% of guests stated that the controls were acceptable. While guests may have perceived a change in the temperature of the room, they did not perceive it as unacceptable.

Question 9: Please provide comments about this hotel's efforts to reduce greenhouse gas emissions and be more environmentally-friendly.

The majority of the comments received were positive, as reflected in the following sample of the 50 positive comments from guests staying at Hotel #1.

> "We were gladly surprised with the commitment of the hotel with the environment. It was a great stay."
>
> "We both thought the hotel's efforts were excellent!"
>
> "Loved the "green" effort. Extremely clean and good service."
>
> "Enjoyed my stay. Doing a wonderful job with being green.
>
> "You are already dead right on it. Thanks."
>
> "Right on!"
>
> "I appreciate the energy savings and do not mind the inconvenience of adjusting the room to suit my needs. Thank you."
>
> "Keep up the great work. Thank you."
>
> "It's a very good idea for hotels to care for the environment."
>
> "We really appreciate the environmentally-friendly aspects."

“We were gladly surprised with the commitment of the hotel with the environment. It was a great "stay."

Only four comments were received that were not positive or supportive of the hotels' efforts to be environmentally sensitive. They are presented below.

“Label thermostat to have an "OFF" setting vs. "Economy." Very confusing.”

“Perhaps ceiling fans would be helpful!”

“At night while sleeping, room sometimes felt hot. Room was fine most of the time with the temp I set. However, at night it seemed to get too warm.”

“All efforts are welcome, but to be honest it seems a bit superficial. Most hotels don't wash towels each day, etc., and running a hotel must use an awful lot of energy no matter how you do it - other than generating your own solar power.”

Fewer surveys were returned for Hotel #2. Here are the comments that were received from guests staying at this hotel.

“Needs to be done; we have no choice.”

“Great stay.”

“Thanks for all the good and friendly service.”

“Poor explanation upon arrival! Didn't know it worked the DVD too.

“Yes.”

“It adjusted quickly.”

“Well done.”

“Nice hotel.”

“I appreciate the effort but each guest should be able to regulate temperature for their own comfort.”

“Good luck.”

Conclusions and Recommendations

1. The potential for energy saving and demand reduction is summarized in Table 48.

Table 48: Potential Market Impact of On/Off Guestroom Control

Attribute	Amount	Unit of Measure	Notes
Nationwide hotel construction estimate	80,000,000	ft^2 per year	CBECS database, table B9, 1990-2000[3]
California construction estimate	3,809,524	ft^2 per year	Assumes that PG&E territory per capita construction rate is the same as the national rate.
Guestroom construction estimate	2,857,142	ft^2 per year	Assumes that 75% of hotel floor space are guestrooms.
Guestroom size	300	ft^2	Size of hotel guestrooms monitored in this study.
Annual guestrooms added	9,524	rooms / yr	
Retrofit market	19,048	rooms / yr	Assumes that retrofit market is twice that of new construction.
Market penetration	10%		Assumption.
Incentive program length	2	Years	Assumption.
10% market penetration	5,715	rooms	Calculated.
Per room savings	337	kWh	Based on average energy savings in this study.
Per room demand savings	117	W	Based on average demand savings in this study.
Annual PG&E energy savings	1,926	MWh/yr	Anticipated energy savings which can be achieved if 10% market penetration is achieved.
Annual PG&E demand savings	669	kW/yr	Anticipated demand reduction which can be achieved if 10% market penetration is achieved

2. The monitored energy use in this project provides a basis for modeling energy savings in the use of room controls in a range of hotels that have central HVAC systems. Monitored data from the hotels with on/off controls show savings ranging widely, from –38 to 53%. Differences in how various occupants used the rooms, particularly where they set the termostat, account for this large variation in energy savings. This study identified the large impact these variables have on energy use.

3 U.S. Energy Information Administration, 1999 Commercial Buildings Energy Consumption Survey: Detailed Tables, table B9.

3. The average HVAC energy savings from the monitored data in hotels with on/off controls agreed with the savings predicted by the simulations; this validated the design of the simulations. Average HVAC energy savings were 28% over the course of the monitoring period. When considering the five climate zones used in this study, the simulation's predicted HVAC energy savings for on/off control averaged 26%.

4. On/off control produces significantly greater energy savings than temperature setback control. Simulation results for five climate zones show annual HVAC savings produced by on/off control. In 300 ft^2 rooms, savings range from 20 to 32%, with an average of about 26%. HVAC energy savings from setback control for the same size rooms ranged from 1 to 7%, with an average of 3.5%.

5. Simulation results show that total annual electricity savings for a single 300 ft^2 room with on/off control range from 311 to 346 kWh, with an average savings of 337 kWh. The savings for a similar size room with 2° F setback control ranged from 72 to 135 kWh, with an average savings of 99 kWh. The amount of savings produced by setback control is greater for larger temperature setbacks.

6. Demand savings—as a percentage of baseline demand—are higher for on/off control than for setback control. Peak demand reduction in 300 ft^2 rooms with on/off control ranged from 20 to 36%, with an average of 27%. The peak demand for the same room with setback control ranged from 6 to 14%, with an average of 11%.

7. Demand savings with on/off control are greater than demand savings produced by setback control. Simulation results show peak demand savings for a 300 ft^2 room with on/off control to range from 92 to 141 W, with an average of 117 W. Simulation results show peak demand savings for a 300 ft^2 room with setback control to range from 25 to 67 W; an average of 48 W on/off control will produce the most demand reduction.

8. The cost of a guestroom card-key control system for a new hotel is less than the cost of one for an existing hotel. In this study, the cost of the system for the new hotel was $390 per room. The cost of the system retrofit to the existing hotel was $650 per room.

9. Variable speed drives on chillers will save money in hotels with on/off guestroom controls. This results from the fact that guestroom occupancy is the lowest during the afternoon hours when peak loads occur. The effect of reduced occupancy is reduced peak demand. Utility incentive programs for guestroom controls should also promote variable speed drives on chillers.

10. Guest surveys show that guestroom control systems with on/off control are widely accepted. The surveys demonstrate that guests modified the thermostat settings slightly

more frequently when the guestroom control system was active than when it was inactive. Of the people that noticed a change in temperature upon returning to their room, the majority of survey respondents said that the change was acceptable.

11. Guestroom control systems that can be easily overridden will produce fewer savings than systems that cannot be overridden. The retrofit card-key system tested did not produce significant energy savings. This is partly attributed to the fact that the HVAC system operation and bathroom light switch operation can be overridden. Utility incentive programs should not apply to guestroom control systems that can be overridden by guests.

12. Guestroom controls are a mature market. They are available from many manufacturers. However, card-key type control systems have no significant market penetration in the United States. A utility-administered rebate/incentive program could be implemented quickly.

13. The challenge to any program will be to encourage hotel owners/managers to implement on/off control in hotter climates, or to encourage them to implement setbacks large enough to capture the full energy and demand savings potentials of these devices. Future study should determine whether or not on/off control is practical in all climates and, if not, determine the greatest amount of setback that is practical. Practicality would be determined by surveying guests' satisfaction with room temperatures when they return from being out of their rooms, similar to the survey used in this report.

APPENDICES

Appendix A – Equipment Used to Monitor Hotels

Appendix B – Simulation Results without Fan Correction

Appendix C – Monthly Energy Consumption Graphs

The appendices are separate reports linked to this one on the ETCC Web site.