Pacific Gas and Electric Company

Emerging Technologies Program

Application Assessment Report #0825

Occupancy-Based Guestroom Controls Study

Issued: 10 April 2010

Project Manager: Wayne Krill
Pacific Gas and Electric Company

Prepared By: Donald J. Frey, P.E.
John Arent
Doug Dougherty

Architectural Energy Corporation
2540 Frontier Avenue, Suite 201
Boulder, CO 80301
(303) 444-4149

Table of Contents

PREFACE .... **III**

ACKNOWLEDGEMENTS .... **III**

EXECUTIVE SUMMARY **1**

- FIELD STUDY 1
- COMPUTER MODELING 2
  - Simulation Results for On/Off Control 3
  - Simulation results for setback control 4
  - Maximum savings from on/off controls 4
- SAMPLE PAYBACK CALCULATION 5
- CONCLUSIONS 5
- HOTEL ROOM CONTROLS INCENTIVE CALCULATOR 6

PROJECT BACKGROUND **7**

FIELD STUDY **8**

- MONITORING APPROACH 8
  - Bin analysis 9
  - Hotel description 9
  - Hotel Fan-Coil Unit Monitoring 11
  - Lighting and Receptacle Monitoring 12
- MONITORED ENERGY USE 13
  - Observed energy usage 13
  - Occupancy patterns 15
  - Observed room temperatures and chiller energy 18
  - Bin analysis 18

COMPUTER MODELING **23**

- METHODOLOGY 23
  - Schedules 24
  - The computer model 24
  - Lighting and plug load schedules 25
  - HVAC system and central plant 26
  - Modeling guestroom controls 26
- SIMULATION RESULTS 27
  - Setback control 27
  - On/off control simulation results 31

COMPARISON WITH OTHER GUESTROOM CONTROL STUDIES **35**

- COMPARISON WITH EMERGING TECHNOLOGIES REPORT 35
- COMPARISON WITH CARD-KEY CONTROL 35
- COMPARISON WITH MONITORED DATA 36

SAMPLE PAYBACK CALCULATION **37**

HOTEL ROOM CONTROLS INCENTIVE CALCULATOR **39**

CONCLUSIONS **40**

APPENDIX A: EQUIPMENT USED TO MONITOR HOTELS **43**

- FAN-COIL AND ELECTRICAL CIRCUIT MONITORING EQUIPMENT 43
- GUESTROOM OCCUPANCY (OCCUPIED/UNOCCUPIED) 45

WEATHER STATION EQUIPMENT 48
ONE-TIME MEASUREMENTS.. 49

APPENDIX B: CALIFORNIA CLIMATE ZONES 51

APPENDIX C: MONTHLY SIMULATION RESULTS BY CLIMATE ZONE................................ 53

Preface

Architectural Energy Corporation (AEC), an energy and environmental research, development, and design consulting firm located in San Francisco, California conducted this research and prepared this document for Pacific Gas & Electric.

The AEC Project Manager was Mr. Donald Frey, PE. Mr. John Arent, PE and Mr. Asim Tahir, PE contributed to the research and this report. Doug Dougherty contributed as technical editor to the report. Mr. John Browne helped to develop monitoring plans, identify appropriate monitoring equipment, bench test equipment, and install data loggers and guestroom controls. 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 Ernie Campos, engineering director of the Westin St. Francis Hotel, to participate in the study. The assistance of his staff is most gratefully acknowledged.

Executive Summary

Occupancy-based guestroom energy management systems sense when a hotel room is occupied and adjust the energy systems — such as HVAC, lighting, and outlets — accordingly to save energy. They may turn systems completely off when a room is unoccupied or, in the case of HVAC, set back the thermostat. This report investigates the potential savings from control of room HVAC and lighting, as well as the cost-effectiveness of occupancy-based systems.

We first conducted a field study at the Westin St. Francis Hotel in downtown San Francisco, and then extended the results with a computer model. Computer modeling allowed us to estimate annual energy use in San Francisco and to expand the results to four other climates within Pacific Gas and Electric Company's service territory.

We compared the results with those of previous studies focused on card-key systems and the literature on such controls in general. And we prepared a sample payback calculation.

Based on the field measurements and computer modeling, we developed a Hotel Rooms Controls Incentive Calculator for estimating the annual energy savings and peak demand reduction potential of hotel guestroom controls.

Field Study

Our field monitoring focused on HVAC systems, lighting and equipment loads, and occupancy patterns. Temperatures, air flow rates, power, and current were measured in HVAC systems; electric current was measured on lighting equipment circuits; and occupancy was determined with recording passive infrared detectors.

Data were collected at four rooms in the hotel for a period of approximately 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 data were collected for an additional five weeks. Four weeks of data were analyzed for each room.

The savings were calculated by comparing the energy used when the controls were inactive with the energy used when the controls were active. The overall energy savings during the monitoring period across four rooms was 25%, but the savings varied widely from 85% to -47%.

Computer Modeling

The wide variation in savings was due to the significant influence guests retained over how much energy was used in a room. They could raise or lower the thermostat set point temperature, turn the HVAC system completely off, or override the guestroom control system altogether.

To generalize control performance based on such widely varying parameters, computer simulations with inputs from monitored data were used to calculate savings, with the most important input being the room occupancy schedule.

The average number of minutes per hour that the guestrooms were occupied is shown in Figure 1. Since the baseline monitoring period was almost six weeks, the occupancy patterns of at least 150 different occupants are reflected in this schedule, assuming an average stay of two days. The influences of days when rooms are not sold (hence unoccupied) are included in the average minutes of occupancy. As expected, the rooms are occupied more at night and the early morning hours than during midday.

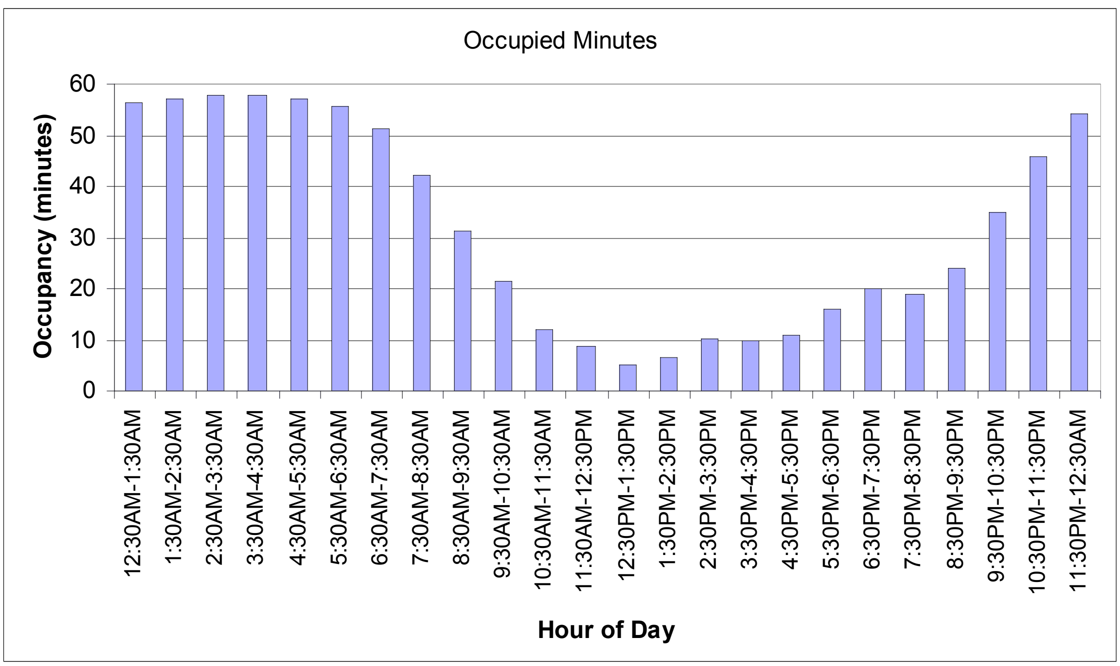


Figure 1: Average Room Occupancy (minutes per hour)

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, we developed a computer model consisting of 60 rooms. The number of rooms assumed to be occupied in each hour followed the schedule in Figure 1. Each guestroom has a floor area of 300 ft^2 to match the monitored room sizes at the St.

Francis Hotel. The computer model was driven with weather data for San Francisco – Oakland and the four other climate zones shown in Table 1.

Table 1: Climate Zones, Representative Cities, and Degree Days

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

Simulation Results for On/Off Control

The HVAC electrical and natural gas energy usage were simulated for the baseline and for on/off control in all five climate zones. The savings for each climate zone and the average savings across all climate zones were calculated.

The annual total electrical energy savings calculated for Climate Zone 3 is 19%. The average electrical savings across all climate zones is 15% of the total room electric energy. These percentages are lower than the reported savings for the card-key system, because for the occupancy based system it was assumed that neither the lights nor the plugs were controlled. The savings for individual rooms ranged from 213 kWh/year (CZ13) to 294 kWh/year (CZ3) with an average across all climate zones of 249 kWh/year. This average savings represents 25.4% of the energy expended by the HVAC system alone (i.e., not counting the lights or plug loads).

The annual natural gas savings (room space heating only) calculated for CZ3 is 17.5%. The average reduction in natural gas consumption across all five climate zones is also 16.9%, though the range is 10.5% (CZ13) to 23.7% (CZ5). The average natural gas savings for individual rooms is 3 therm/year.

The annual peak demand reduction calculated for CZ3 is 32%. The average reduction in peak demand across the five climates is 21%. Peak demand reduction on a per room basis ranged from 67 Watts (CZ13) to 133 Watts (CZ3), with an average of 91 Watts. 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. The implication of this finding is that central cooling plant components (chillers, cooling towers, and pumps) in existing buildings could be run more efficiently if they are equipped with variable speed control; and central cooling plants in new buildings could conceivably be downsized, further decreasing energy consumption and demand. As a minimum, hotels that install guestroom controls should also consider installing variable frequency drives for pumps and cooling tower fans.

Simulation results for setback control

At the St. Francis Hotel, the guestroom controls set back the thermostats of the HVAC equipment when the rooms were unoccupied. The simulation results for the 300 ft^2 rooms with setback control are presented below. The assumption is that the thermostat is set back (or up) by 2 °F when the room is unoccupied.

The annual HVAC only electrical energy savings calculated for CZ3 is 3%. The average electrical savings across all climate zones is 4.7%. The savings for individual rooms ranged from 23 kWh/year (CZ5) to 112 kWh/year (CZ12) with an average across all climate zones of 62 kWh/year.

The annual natural gas savings (room space heating only) calculated for all climate zones is small.

The annual peak demand reduction calculated San Francisco - Oakland is 6.7%. The average reduction in peak demand across the five climates is 10.7%. Peak demand reduction ranged from 28 Watts (CZ3) to 100 Watts (CZ12), with an average of 48 Watts.

In addition to the results for a hotel with 300 ft^2 rooms, this report also contains results for a hotel with larger, 450 ft^2 rooms with on/off control, and results for both 300 ft^2 rooms and 450 ft^2 rooms with setback control. For the larger room size, on average, electric energy savings and gas savings increase, but demand savings decrease.

Maximum savings from on/off controls

In all cases, the energy savings from setback control is far less than it is for on/off control. In fact, as the number of degrees by which the thermostat is set back (or set up) increases, 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.

Even though the on/off control strategy produces more savings than the setback control, the extent to which this strategy will be accepted by guests in hot climates such as Fresno, is unknown. Guest surveys show that it is acceptable in San Francisco. The best strategy in the hot climates may be to determine the greatest amount of setback (setup) that guests will tolerate without major complaints. The information in this report provides boundaries on the possible 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.

Sample Payback Calculation

The equipment cost of an occupancy-based guestroom control system, without centralized control, is approximately $270 per room. Labor costs brings the installed cost for the retrofit system to approximately $530 per room.

Using the average savings listed above for electric energy, demand and gas; typical utility rates as shown below; and the above installation cost for the controls leads to the following:

Table 2: Sample Simple Payback Calculation

Per Room	Electric Savings	On-Peak Demand Reduction	Natural Gas Savings
Annual Savings	249 kWh / yr	0.092 kW	3.0 therms / yr
Utility Cost	$ 0.13 / kWh	$ 10.00 / kW-month	$ 0.80 / therm
# months Demand savings		6	
Annual Cost Savings	$32.33	$5.52	$2.38
Total Annual Cost Savings	$40.23		
Estimated Installation Cost	$530		
Simple Payback	13.2 Years		

Conclusions

The finding of savings in the amount of approximately 250 kWh/yr/room is a significant change from previous studies, where savings in the neighborhood of 1,000 kWh/yr/room were cited. While the fraction of energy saved by room controls is comparable to previous studies, the absolute magnitude of the energy savings is smaller. The smaller savings values lead to significantly longer payback periods than previously expected.

- The monitored data is based on a small sampling of hotel rooms. Occupant behavior can have a large influence on achieved savings.
- The estimated installation cost of $530 per guestroom includes two hours of labor that might be reduced on a per-room basis in a large installation. As guestroom control technology becomes more widespread, hardware prices may be expected to decrease.

- Utility rates will vary from the typical rates used above, and will most likely increase in the future. Any finding of higher baseline energy consumption or cost, or reduced installation cost, will decrease the payback period from the results shown in this report.

Hotel Room Controls Incentive Calculator

In parallel with this report, we developed a simple electronic calculator capable of estimating the electrical and gas energy savings and peak demand reduction achievable by installing hotel guestroom controls. The savings are based on the simulation results presented in this study and in the Card-Key Guestroom Controls Study referenced earlier.

The “Hotel Room Controls Incentive Calculator” also determines the annual energy cost savings and, if an installation cost is input, the corresponding simple payback period. Finally, it estimates the incentives PG&E will offer hotel customers to install either card-key or occupancy-based guestroom controls. The energy cost and incentive rates are stored within the calculator and may be updated from time to time by PG&E as necessary.

The calculator will support efforts to market room controls to hotel customers, and enable PG&E to calculate energy savings for processing incentive applications.

Project Background

Emerging Technologies Program *Application Assessment Report #0609*, *Marketable Technologies for the Hospitality Segment*, produced by Pacific Gas & Electric Company (PG&E) (September 2007) 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. Architectural Energy Corporation (AEC) conducted a literature search and contacted manufacturers to locate field studies to verify the savings potential of these devices. We found that most performance assessments had been conducted by the manufacturers of the guestroom controls.

Since the assessment report showed significant opportunity for these controls to save energy and reduce peak electrical demand, PG&E contracted with Architectural Energy Corporation to conduct a field study of the potential savings and cost-effectiveness of both card-key and occupancy-based controls in hotels in San Francisco.

Three hotels were investigated in the card-key study. They had central chillers and boilers and four-pipe fan-coil units in each room to deliver cooling and heating. Computer modeling, based on data from monitoring of the hotels, was used to expand the results from San Francisco to other climates around PG&E's service territory. A survey to determine how hotel guests perceived this technology was also conducted.

The current report presents the results for occupancy-based controls based on a field study at a San Francisco hotel and computer modeling. Occupancy-sensor controls provide a means to control HVAC equipment, lighting, and receptacle loads. When the guest enters the room, a door switch signals the controls to determine room occupancy. When the guest presence is detected, the HVAC system is enabled. When the guest leaves the room, the controls search for occupants; when no occupants are detected, the HVAC system is either shut off, or the thermostat is set back.

Occupancy sensor guestroom controls have been available for many years, and are applicable to different HVAC system types including fan coil and packaged terminal air conditioning (PTAC) units. Both wired and wireless versions are available. A prior technology review study conducted by Architectural Energy Corporation found annual savings values of up to 1083 kWh, using information found in other literature available at the time. With an installation cost of approximately $530 per guestroom the systems have an estimated payback of just over four years.

Field Study

Our general methodology was to collect data using battery-powered monitoring equipment in four guestrooms at the Westin St. Francis Hotel in downtown San Francisco. The monitoring was done to determine HVAC energy used, lighting energy used, plug load energy and occupancy schedules. Data was collected for an approximately five-week “inactive” period when the HVAC and lighting equipment were not controlled, and a second five-week “active” period when the equipment was controlled.

Monitoring approach

Two 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 guest use the rooms that the parallel approach was also viable.

A decision was made to use an “on/off” approach to monitor the guestrooms. This was mainly 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 were instrumented. Data was collected that shows how rooms operated in the absence of guestroom control (the inactive period) and with guestroom control (the active period). Each room was run for approximately five weeks in the inactive mode, and then run for an additional five weeks in the active mode. Since the logging equipment was out of sight of the guests, it was left in place while the data was being analyzed.

Bin analysis

Since the inactive and active monitoring periods occurred at different times of the year, differences in weather could have affected energy use. We accounted for this potential impact by developing a correlation between cooling energy use and outdoor air temperature. Separate linear regressions were developed during periods when the guestroom was occupied and when the guestroom was unoccupied, since occupancy also affects energy use. The correlations were then used with hourly weather data to estimate annual cooling energy use for occupied and unoccupied periods.

A bin analysis was performed for five different climate zones that represent the range of weather conditions in PG&E's service territory. These climates zones were selected because they represent the range of annual weather conditions where large numbers of hotels are located in PG&E's service territory.

- Climate Zone 3 (CZ3): Oakland
- Climate Zone 4 (CZ4): Sunnyvale
- Climate Zone 5 (CZ5): Santa Maria
- Climate Zone 12 (CZ12): Sacramento
- Climate Zone 13 (CZ13): Fresno.

For further climate zone information and a state map, see Appendix B.

Hotel description

The Westin St. Francis Hotel is a full-service hotel in downtown San Francisco with over 1,000 rooms. The occupancy-based guestroom control system we tested controlled the fan coil units. When guests are present, the fan coil unit is enabled and runs to maintain the setpoint temperature, which defaults to 72°F but can be adjusted by the guest. When the guest leaves the room and the system detects the absence, the thermostat heating and cooling setpoints are set back by 2°F. The system features a programmable setback and a programmable time-out delay before the system goes into setback mode.

Figure 2: Exterior of the Westin St. Francis Hotel

Shown here is the occupancy-based guestroom control thermostat installed in the monitored hotel rooms, the **e^4** Smart Digital Thermostat Model E528 from INNCOM International.

From the manufacturer's literature:

- "The E528 is designed to be intuitive for guest use. ... The user may also elect to participate in the property's sustainability practices by touching the ecoMODE® touch surface.
- "When used as an HVAC controller or thermostat, in conjunction with an external control module, it will automatically adjust fan speeds and valves or compressor run time to achieve set temperature.
- "As the key node in an Energy Management System (EMS), it receives inputs from the PIR motion detector and the wired or wireless door switches to determine guestroom occupancy. During times when the room is rented but the guest is not present, the temperature is allowed to range up or down within a programmable setback band from the guest's selected temperature. This results in energy savings with no impact on guest comfort.
- "... additional energy savings are achieved by using a broader setback band, when the guestroom is un-rented.
- "The on-board ... IR transceiver enables the E528 to control lamps equipped with the INNCOM L206 or L208 Lamp Control Module ...

• "Its core is a Direct Digital Control (DDC) processor capable of controlling virtually any fan coil unit, heat pump or packaged terminal air conditioner found in guestrooms. It includes an easy to read illuminated liquid crystal display and five built-in relays.	• "... it can also receive inputs from other points in the room such as a balcony door, minibar or smoke detector and transmit their status to the central server."

Figure 3: Hotel Guestroom Thermostat / Controller

The lighting and receptacle loads were not controlled by the guestroom control system at this hotel.

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

Hotel 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 3 lists the time-series measurements that were taken in the hotel guestrooms and the monitoring devices that were used to take them. Additional information about each of the monitoring devices is presented in Appendix A. Table 4 contains a description of additional one-time measurements that were made in the guestrooms at the time the monitoring equipment was installed.

Table 3: HVAC Time-Series Measurement Instrumentation

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 Relative Humidity
Return air humidity	Onset Energy Pro Logger with Smart Sensor for Relative Humidity

Table 4: HVAC One-Time Measurement Instrumentation

Measurement	Measurement Device
Air flow rate through the coil (cfm) – Fan has two speeds. Two flow rates were measured.	Alnor flow hood
Current, fan and lighting circuits	Fluke 43B Power Quality Analyzer and Fluke i400s AC Current Clamp

The measurements at the fan coil unit were taken in the plenum space accessed through the door in the ceiling. One-time measurements of the supply air flow were taken at the supply air grille. Measurements were taken for all fan speeds. Room temperature measurements were taken above the ceiling plenum, behind the return air grille. 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 by guests.

Occupancy was monitored using the Energy-Eye wireless system. An occupancy sensor that is similar in appearance to a smoke detector was installed near the ceiling. A wireless transceiver and data logger were installed behind the TV console.

Lighting and Receptacle Monitoring

The measurements of electrical power used by electrical receptacles were taken in the electrical panels. Measurements of bathroom and entrance lighting were taken at a junction box above the ceiling plenum. Each guestroom was served by three electrical circuits: the receptacle load, the entrance lighting load, and the bathroom lighting load. All three circuits for three of the four rooms were monitored. Note that the engineering staff could not identify the breaker for the receptacle loads for room 3099, so measurements were not taken for this room. 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 5: Lighting and Receptacle Time-Series Measurement Instrumentation

Measurement	Measurement Device
Fan Coil Circuit Power (A)	Onset Energy Pro Logger with Watt Transducer and 5 Amp CT
Room Receptacle Circuit Power (kWh)	Onset Energy Pro Logger with Watt Transducer and 20 Amp CT
Entrance Lighting (A)	Onset Energy Pro Logger with 10 Amp CT
Bathroom Lighting (A)	Onset Energy Pro Logger with 10 Amp CT

Monitored Energy Use

The monitoring periods for the four rooms are shown in Table 6. Monitoring of the rooms with the controls active took place in October and November of 2008 and monitoring with the guestroom controls disabled took place in September 2009. Since the active period was later in the year when cooling loads are low, this resulted in a greater energy savings than would have been seen if the monitoring took place under identical weather conditions.

Table 6: Monitoring Periods

Room	Baseline Monitoring Period (Inactive Controls)	Setback Monitoring Period	No. of Days in Each Period
3080	7/2/09 – 7/30/09	10/23/08 – 11/19/08	28
3087	8/26/09 – 9/28/09	11/18/08 – 12/21/08	33
3091	8/27/09 – 9/24/09	10/24/08 – 11/21/08	28
3099	8/27/09 – 9/27/09	10/24/08 – 11/24/08	31

Observed energy usage

The HVAC electricity usage for the four rooms is summarized in Table 7. On average, the guestroom controls achieved a 25% HVAC electricity savings. The savings varied tremendously across the four rooms. For room 3087, there was virtually no chiller energy use during the setback monitoring period. For this room, the period with the active controls extended into the month of December when there is very little cooling load. Moreover, this room experienced a very low occupancy rate of 30% during this period. Rooms 3091 and 3099 showed significant energy savings, while room 3080 saw an increase in energy use during the period with setback control.

Table 7: HVAC Time-Series Measurements (kWh Consumed during Monitoring Period)

	Baseline			With Setback Control			
Room	Fan kWh	Chiller kWh	Total kWh	Fan kWh	Chiller kWh	Total kWh	% Savings
3080	52.76	29.46	82.22	66.53	54.18	120.71	- 47%
3087	57.68	31.00	88.68	11.59	0.99	12.58	85.8%
3091	34.14	39.02	73.16	25.17	17.27	42.44	42.0%
3099	35.13	41.13	76.26	30.71	32.62	63.33	17.0%
Total	179.71	140.61	320.32	134	105.06	239.06	25.4%

Gas use is shown in Table 8 for the four rooms. The setback periods experience higher gas use because of cooler outdoor temperatures.

Table 8: Gas Use during Monitoring Period

Room	Baseline (Inactive)	With Setback Control
3080	0.24 therm	0.43 therm
3087	0.21 therm	1.65 therm
3091	0.22 therm	0.275 therm
3099	0.25 therm	2.47 therm
Total	0.92 therm	4.83 therm

To calculate chiller energy use, the cooling load was calculated using airflow and temperature measurements, and constant chiller efficiency (0.7 kW/ton) was assumed to estimate chiller energy use. Airflow measurements were taken in each of the rooms during the monitoring period and are summarized in the table below. Note that room 3091 was a slightly larger room than the other three rooms monitored.

Table 9: Airflow Measurement Summary

Room	Airflow Measurement
3080	185 cfm
3087	201 cfm
3091	336 cfm
3099	207 cfm

Lighting and plug load energy usage data are shown in Table 10. There were only minor differences in lighting and plug load levels between the inactive and active control periods. Neither lighting nor receptacles were controlled by the occupancy-based control system in the hotel. The lighting load listed is the entrance and bathroom lighting. The desk lamp and floor lamp are included in the plug load total.

Table 10: Lighting and Plug Energy (kWh Consumed during Monitoring Period)

Room	Plug Load kWh (Active)	Plug Load kWh (Inactive)	Lighting kWh (Active)	Lighting kWh (Inactive)
3080	9.24	12.78	12.08	14.2
3087	11.17	10.94	17.51	15.32
3091	16.67	14.25	28.99	24.72

Note: the breaker serving room 3099 could not be identified by engineering staff at the time of the installation, so no plug load data is available for this room.

Plug load patterns were similar in this hotel as in the hotels studied with the card-key control system. The peak hourly usage occurs mid-morning and mid-evening, with lower levels during the early afternoon and late evening hours. For room 3091, the peak hourly average plug load was 83 W. Average hourly load levels ranged from 15 W to 31 W, as shown in Figure 4.

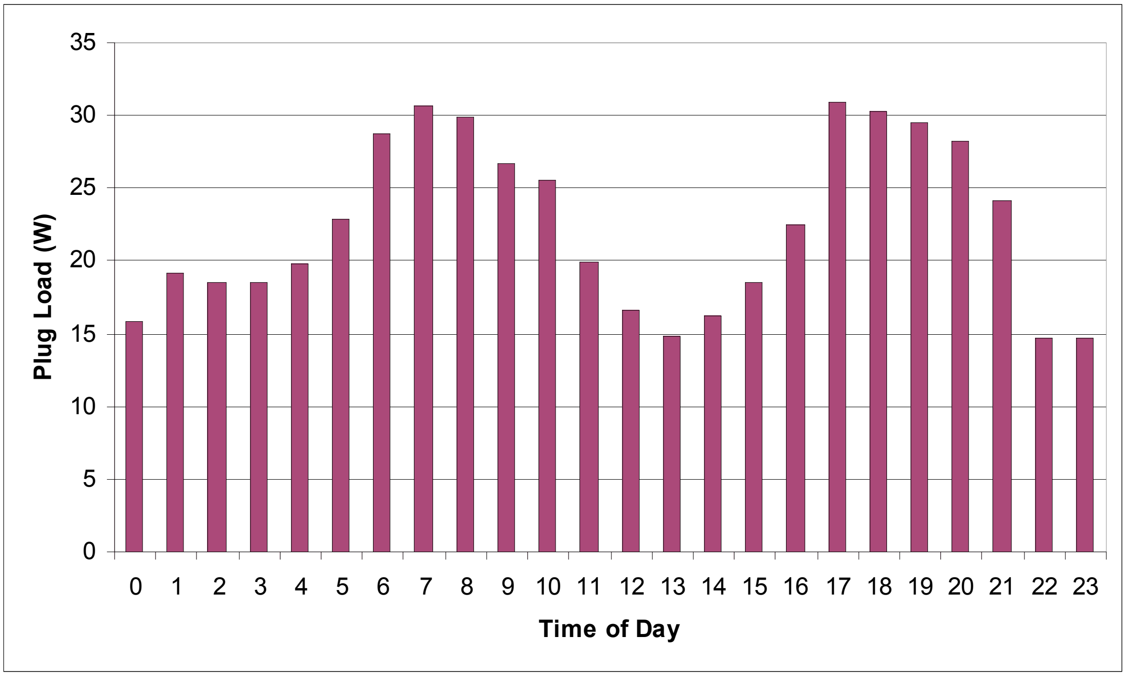


Figure 4: Average Hourly Plug Loads for Room 3091

Occupancy patterns

Occupancy was tracked in each of the rooms with a state logger. However, the loggers were removed by unauthorized personnel in two of the four rooms during the monitoring period. Occupancy summary data for the rooms where occupancy data is available is shown in Table 11.

Table 11: Occupancy Summary Statistics

Room	Baseline (Inactive)	With Setback Control
3087	50.0%	30.0%
3091	51.1%	71.2%

The occupancy rate in room 3087 during the setback period was much lower than during the baseline period. This partially explains why the cooling energy use is dramatically lower during the setback period. The figure below shows that even during the evening hours the room was occupied only about 50% of the time.

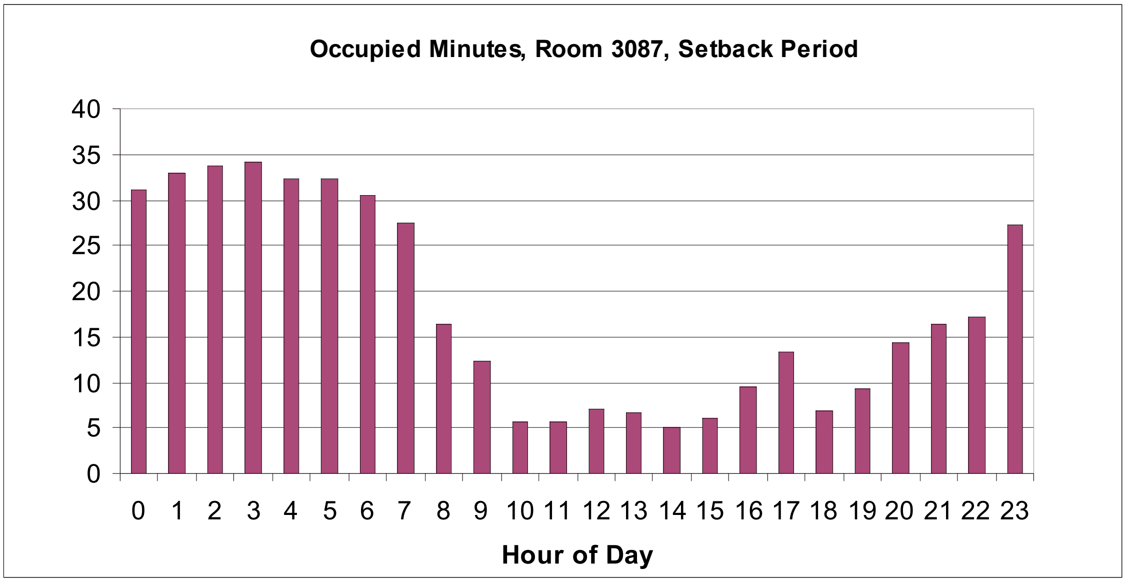


Figure 5: Occupancy Rate for Room 3087, Setback Control Active

The average occupancy schedule for the rooms during the inactive control period is shown in Figure 6 and for the active control period in Figure 7. The occupancy is slightly lower in the early morning hours in the active control period and the occupancy is somewhat higher in the middle of the day in the active control period. Overall, the average occupancy was 50.6% during the inactive control period and 55.5% during the active control period. (This occupancy includes periods when the rooms were unrented.) On average, the occupancy was slightly lower in this hotel than in the two hotels that utilized the card-key system.

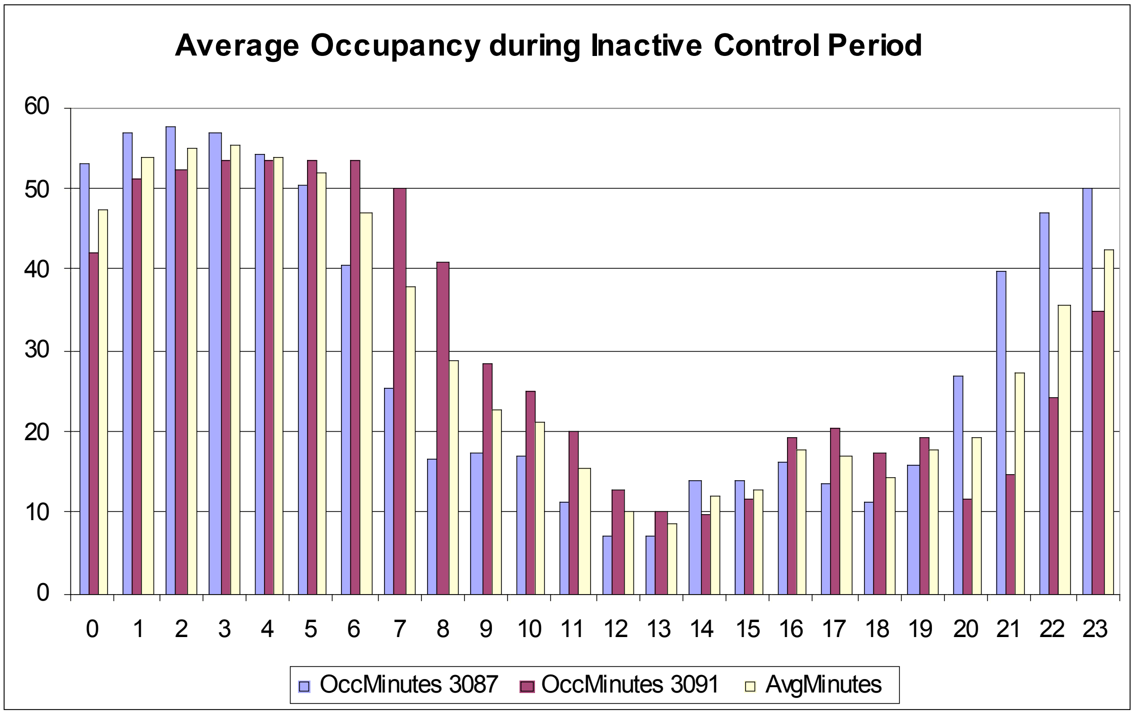


Figure 6: Average Occupancy during Inactive Control Period

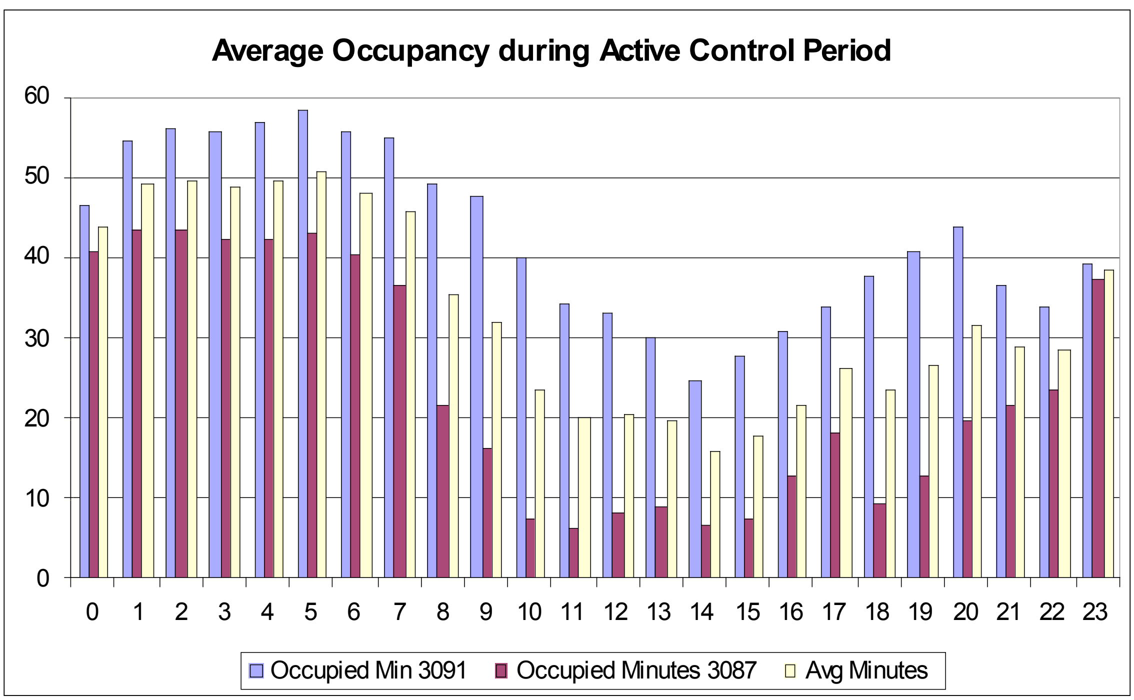


Figure 7: Average Occupancy during Active Control Period

Observed room temperatures and chiller energy

The return air temperatures were monitored to determine heating and cooling loads, and to estimate room temperatures. The following table shows only slight differences between the occupied and unoccupied room temperatures. During the inactive controls period, the rooms were in cooling mode for nearly the entire period. During the setback period, the rooms were predominantly in the cooling mode, but were in heating mode a larger portion of the time, as can be seen by the gas usage in Table 7 above. It is likely that guest operation of the thermostat strongly influences the data. The guest can adjust the thermostat up or down, or shut the fan off.

Table 12: Average Room Temperature during Occupied and Unoccupied Periods

	Setback Control		No Control	
Room	Occupied Temp, F	Unoccupied Temp	Occupied Temp	Unoccupied Temp
3087	70.85	70.23	72.62	73.06
3091	71.10	71.59	73.13	73.63

The thermostat is programmed for a 2-degree F setback when the room is unoccupied. To be consistent with the simulations done for the card-key controls in the previous study, heating and cooling setpoints of 70°F and 72°F are used. Several factors, including occupancy patterns, thermostat settings and lighting and appliance use affect guestroom energy use.

shows how hourly cooling energy use varies with room temperature during the period when the controls were active. The data spans periods when the room was occupied and unoccupied. While there is not a strong correlation, energy use increases with decreasing room temperature (return air temperature was measured as an estimate of room temperature).

Bin analysis

By using the data points collected during the monitoring periods, a bin analysis was used to estimate annual cooling energy usage. First, linear correlations between hourly cooling energy use and hourly average outside air temperature were developed for both occupied periods and unoccupied periods. Since occupancy data was collected every minute, the room was considered occupied if occupied for greater than 80% of the hour, and unoccupied if occupied for less than 10% of the hour. Figure 8 shows a linear regression of cooling energy use to outside air temperature for periods when the room is occupied, and Figure 9 shows a linear correlation of cooling energy use to outside air temperature for periods when the room is unoccupied. Incorporating additional variables such as room temperature into a multivariate regression did not improve the accuracy of the correlation.

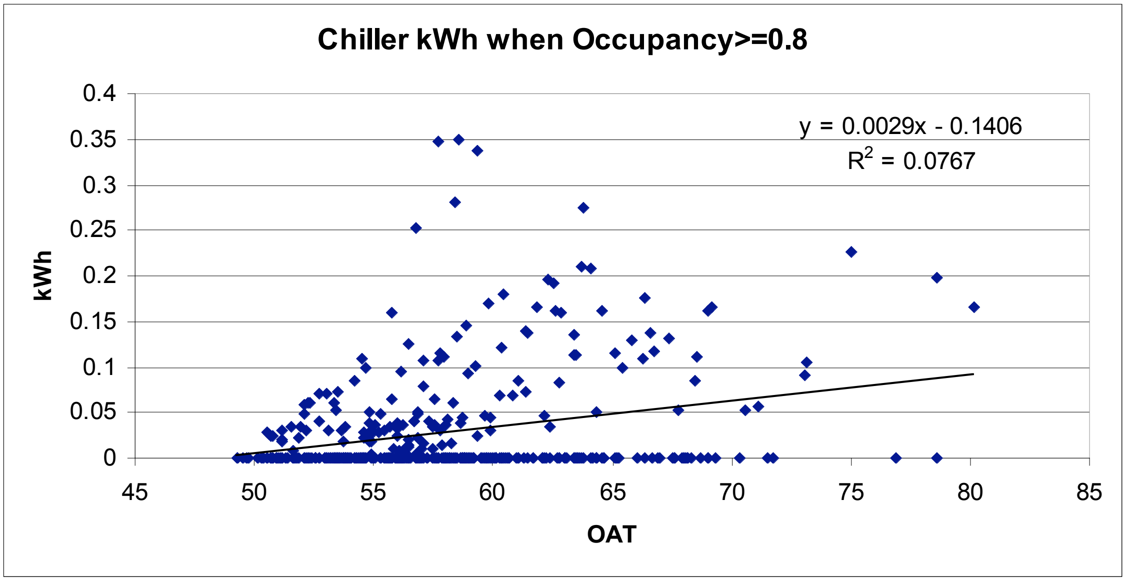


Figure 8: Chiller Energy Use when Room is Occupied, Setback Control

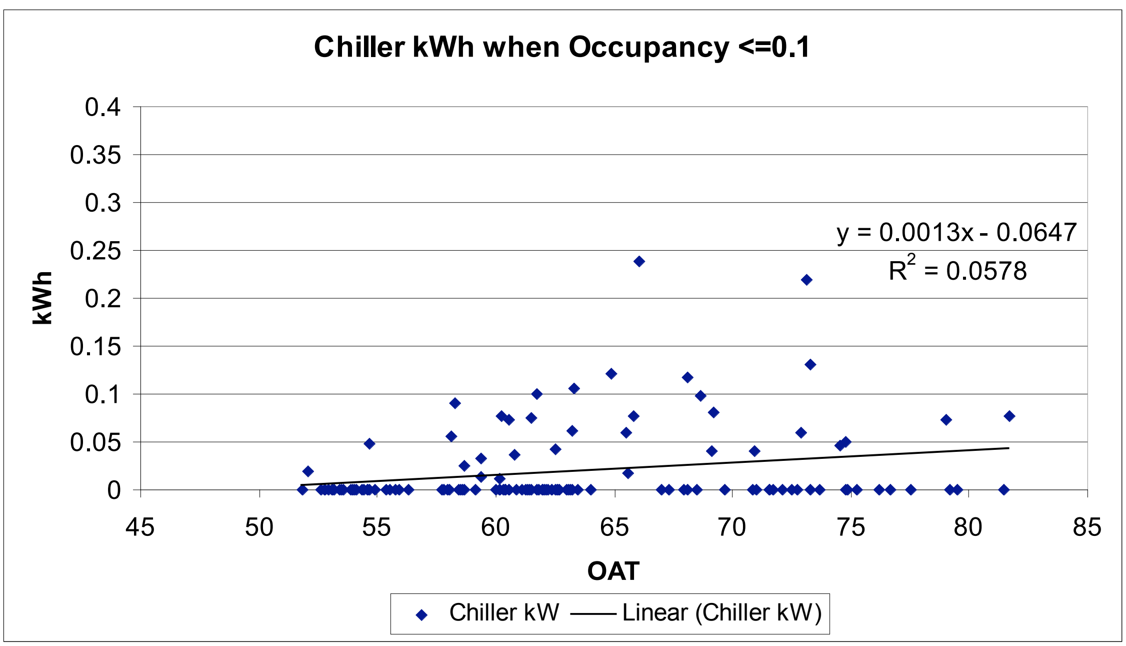


Figure 9: Chiller Energy Use when Room is Unoccupied, Setback Control

The linear regressions in Figure 10 and Figure 11 predict a negative energy use for very low outside air temperatures. To compensate for this limitation of the linear regression, the chiller energy use was set to zero for outside air temperatures below 53°F. Moreover, the chiller is likely to be off during cool outside conditions if the central plant includes a waterside economizer.

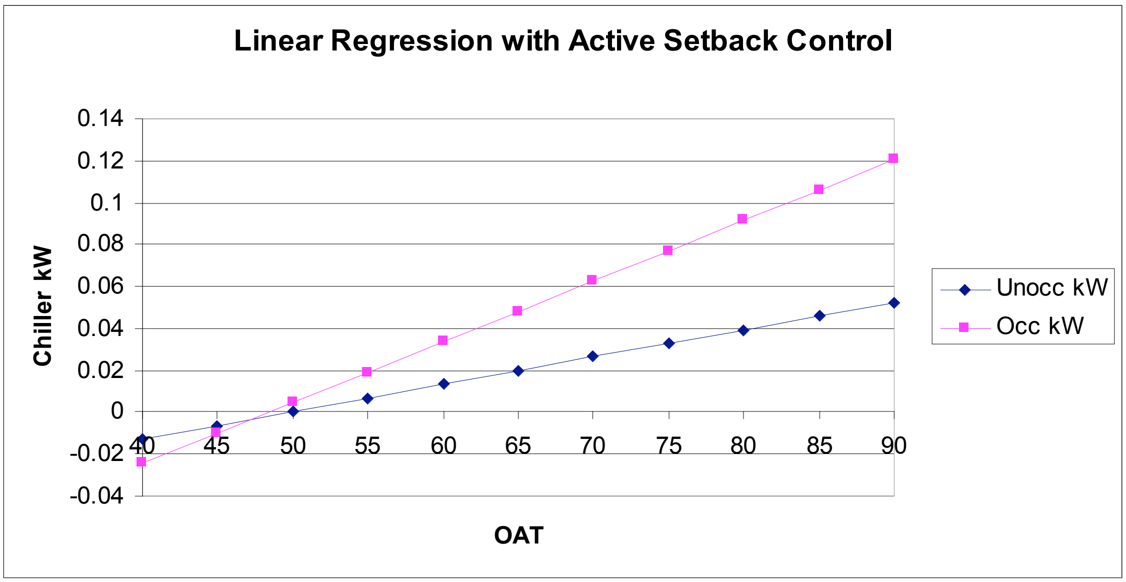


Figure 10: Linear Regression with Outside Air Temperature, Setback Control

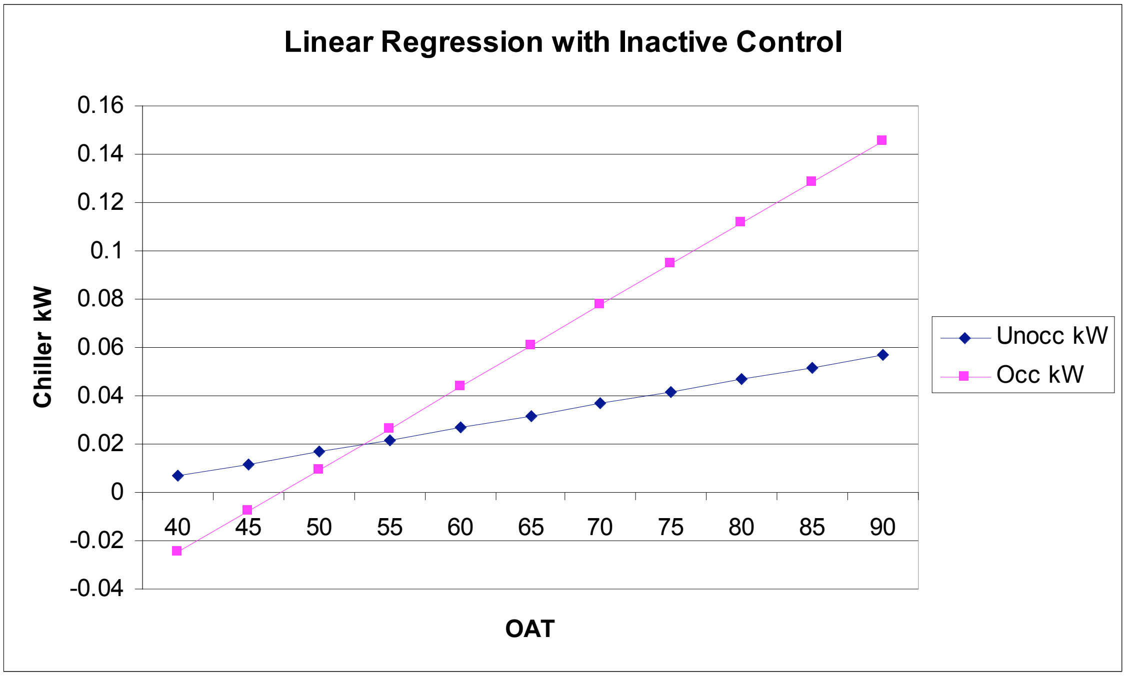


Figure 11: Linear Regression with Outside Air Temperature, Inactive Control

The correlations above were applied to hourly weather data to estimate annual cooling energy with and without guestroom controls. The table below shows that the energy savings is greatest in the mild climates, with a lower energy savings in the inland valley climates (climate zones 12 and 13). The energy savings predicted for climate zone 3 is consistent with the monitored data. However, the level of energy savings for setback control predicted by the bin analysis is higher than that predicted by the energy simulations. It is possible that both the small sample size of the room and the relatively poor correlation of cooling energy use to outside air temperature limit the accuracy of the bin analysis predictions.

Table 13: Annual Chiller Energy Use Predicted by Bin Analysis (kWh/yr per Room)

Climate Zone	Inactive Controls	Active Controls	Savings (%)
3	202.8	135.1	33.4%
4	188.4	141.4	25.0%
5	171.3	119.6	30.2%
12	191.0	150.8	21.1%
13	278.7	228.5	18.0%

Based on this analysis, a 100-room hotel would save between 4,020 and 6,770 kWh in cooling energy, or approximately $540 to $915 annually. Based on the data from the four rooms monitored in this study, the average fan energy savings with occupancy-based controls was 128% of the chiller energy savings (the range for individual rooms was 40 to 150%). Adding this fan energy savings would place the annual HVAC energy savings at $1,240 to $2,080. Caution is advised in using these estimates.

Computer Modeling

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 occupies it. Among the variables are 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, whether or not lights are turned off when the guest leaves the room, etc.

The empirical measurements taken in this project greatly increase understanding of 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, the 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 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.

Methodology

The measured return air temperature was used to estimate the thermostat settings during the monitoring period. Monitored occupancy data was used to develop occupancy schedules used in the simulations. To provide a consistent basis of comparison with simulations of a hotel with a card-key control system, the same occupancy schedules were used in the simulation of occupancy sensor controls.

Simulations were run for a typical hotel with 300 ft^2 rooms in each of five climates. A second set of simulations was run for a hotel with 450 ft^2 rooms. The 300 ft^2 room size is consistent with the three hotels monitored in this study. The 450 ft^2 room size is the average room size referenced in the previous study, *Application Assessment Report #0609, Marketable Technologies for the Hospitality Segment* (2007).

Schedules

To be consistent with the analysis for the two hotels that used a card-key control system, similar occupancy schedules were used in the simulations for the occupancy-based controls. The occupancy schedule used in the simulation of the card-key control system factored in additional fan runtime for periods when the guest would override the cardkey control system. The occupancy schedule used in the simulation of the occupancy-based control system did not include this override.

The hotel that used the occupancy-based control system did not control the lighting or receptacle loads. Therefore, in the simulation the same lighting and plug load schedules were used in both the baseline simulation run and the case with active setback control.

The computer model

The computer simulation of the typical hotel was developed using Visual DOE, which uses the DOE2.1e simulation engine. To incorporate the diversity of occupancy schedules, 60 hotel rooms were 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 (<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 46% for the entire building.

The front of the modeled hotel is oriented north, and each floor consists of 20 rooms with ten rooms facing north and ten facing south. Fenestration is double-paned clear glass with a U-factor of 0.483 Btu/h-ft^2-F and a solar heat gain coefficient (SHGC) of 0.698. The building is 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 are modeled since the principal area of concern is the energy savings potential for guestrooms.

The occupancy schedules were set so that the average occupancy rate of all 60 rooms in the model matched the averages from the monitored data for the hotels in the card-key study.

A second set of simulations was performed using a building consisting of 60 rooms, each with floor area of 450 ft^2 per room. For this model, the window-wall ratio, building construction and other characteristics were held to be the same as the 300 ft^2 simulations. This larger room size reflects the average room size assumed in the 2007 study, *Application Assessment Report #0609, Marketable Technologies for the Hospitality Segment.*

Lighting and plug load schedules

Schedules for both lighting and plug loads were developed from average hourly data collected over four weeks in two of the monitored rooms. 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 75W maximum to develop hourly schedules for input to the computer simulations. Since lighting was not controlled by the occupancy-based control system, the same lighting schedule was used in the active and inactive controls cases. The schedules for both the active and inactive controls periods are shown for lighting in Figure 12 and for plug loads in Figure 13.

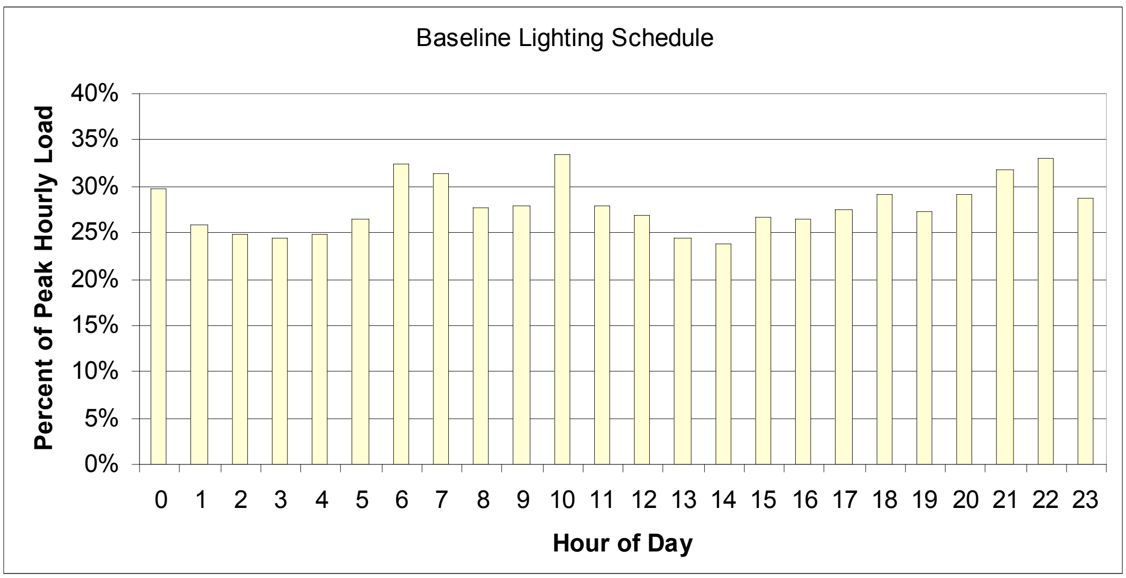


Figure 12: Guestroom Control Lighting Schedule

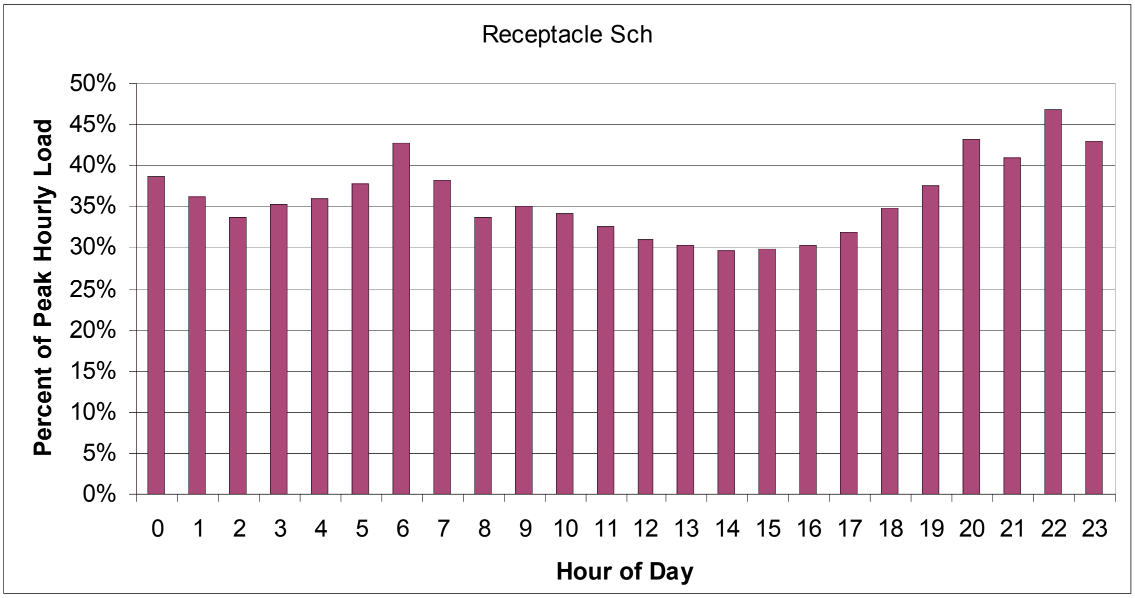


Figure 13: Receptacle Schedule

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 supply air 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 in any given zone). The sizes of 200, 300, 400 and 600 cfm were chosen as representative of fan coil units on the market.

The central plant consists of a water-cooled chiller with medium efficiency (0.7 kW/ton nominal) and a central boiler with an 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

The default fan schedules for the baseline system (without guestroom controls) were modeled as continuously on when the room is occupied. In practice this is not always the case as some fans are set to cycle with the call for cooling or heating. For the guestroom control case, the fan schedule for each room was set to match the occupancy schedule: when the room is occupied the fan is on and when the room is unoccupied the fan is off.

The heating and cooling setpoints were set at 70°F and 72°F, respectively. A 2°F setback was modeled for the guestroom controls, resulting in a heating setback temperature of 68°F and a cooling setback temperature of 74°F.

The occupancy-based controls at the monitored hotel utilize a thermostat setback when the room is unoccupied. For the simulations, both setback control and an “on/off” control were modeled, to predict the energy savings for these different control strategies.

Simulation Results

Hotels were simulated in each of five climate zones. The room size modeled was 300 ft^2, consistent with the size of the rooms in the hotels studied in this project. The simulations were performed for the hotel with 300 ft^2 rooms and 450 ft^2 rooms for both On/Off control and setback control, and the occupancy schedules did not include a guest override when modeling the occupancy-based controls.

Setback control

The simulated energy usage for 300 ft^2 rooms with setback control is given below in Table 14. The results for HVAC electricity savings for setback controls are summarized in Table 15 and the gas savings are in Table 18. Table 16, Table 17 and Table 19 show the same results for 450 ft^2 rooms. Savings for setback controls were moderate, ranging from 2.0% for climate zone 5 to 8.2% for climate zone 12.

Table 14: Electricity End Use Results (kWh) from Simulation, Setback Control (300 ft2 Rooms)

Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	Total	Savings (kWh)	%
cz3_base	12,531	11,366	26,314	3,817	5,387	33,943	93,358		
cz3_Setback Control	12,531	11,366	27,039	3,898	5,500	30,917	91,251	2,107	2.3%
cz4_base	12,531	11,366	30,383	3,847	5,600	34,144	97,871		
cz4_ Setback Control	12,531	11,366	30,189	3,677	5,415	32,232	95,410	2,461	2.5%
cz5_base	12,531	11,366	26,380	3,464	4,964	35,471	94,176		
cz5_ Setback Control	12,531	11,366	27,033	3,471	4,972	33,410	92,783	1,393	1.5%
cz12_base	12,531	11,366	32,948	4,177	6,117	38,148	105,287		
cz12_ Setback Cntrl	12,531	11,366	30,448	3,414	5,175	35,639	98,573	6,714	6.4%
cz13 base	12,531	11,366	36,983	4,029	5,830	37,972	108,711		
cz13_Setback Control	12,531	11,366	35,452	3,558	5,320	34,520	102,747	5,964	5.5%
Average of Results									
No Control	12,531	11,366	30,602	3,867	5,580	35,936	99,881		
Setback Control	12,531	11,366	30,032	3,604	5,276	33,344	96,153	3,728	3.7%

Table 15: HVAC Electricity Results (kWh) from Simulation, Setback Control (300 ft^2 Rooms)

Climate Zone	HVAC Base	HVAC Setback	Savings	% Savings
3	69,461	67,354	2,107	3.0%
4	73,974	71,513	2,461	3.3%
5	70,279	68,886	1,393	2.0%
12	81,390	74,676	6,714	8.2%
13	84,814	78,850	5,964	7.0%
Average	75,984	72,256	3,728	4.7%

Energy results from the simulation using 450 ft^2 rooms showed the largest energy savings in climate zones 3 and 12.

Table 16: Electricity End Use Results (kWh) from Simulation, Setback Control (450 ft^2 Rooms)

Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	Total	Savings (kWh)	%
CZ3_Baseline	18,797	17,049	29,828	3,611	5,249	41,245	115,779		
CZ3_Setback	18,702	17,049	28,540	3,691	5,310	33,247	106,539	9,240	8.0%
CZ4_Baseline	18,797	17,049	36,829	4,276	6,328	39,227	122,506		
CZ4_Setback	18,702	17,049	36,426	4,499	6,560	38,496	121,732	774	0.6%
CZ5_Baseline	18,797	17,049	30,451	3,763	5,497	37,440	112,997		
CZ5_Setback	18,702	17,049	29,518	3,802	5,488	34,283	108,842	4,155	3.7%
CZ12_Baseline	18,797	17,049	40,667	4,614	6,840	43,446	131,413		
CZ12_Setback	18,702	17,049	38,148	4,226	6,378	38,900	123,403	8,010	6.1%
CZ13_Baseline	18,797	17,049	51,158	5,208	7,364	44,673	144,249		
CZ13_Setback	18,702	17,049	48,613	4,788	6,931	42,477	138,560	5,689	3.9%
Average of Results									
No Control	18,797	17,049	37,787	4,294	6,256	41,206	125,389		
Setback Control	18,702	17,049	36,249	4,201	6,133	37,481	119,815	5,574	4.4%

Table 17: HVAC Electricity Results (kWh) from Simulation, Setback Control (450 ft^2 Rooms)

Climate Zone	HVAC Base	HVAC Setback	Savings	% Savings
3	79,933	70,788	9,145	11.4%
4	86,660	85,981	679	0.8%
5	77,151	73,091	4,060	5.3%
12	95,567	87,652	7,915	8.3%
13	108,403	102,809	5,594	5.2%
Average	89,543	84,064	5,479	6.2%

No gas savings were calculated for setback controls for the hotel with 300 ft^2 rooms. A modest gas savings of 1 to 8% was achieved for the hotel with 450 ft^2 rooms.

Table 18: HVAC Gas Energy Savings (therms) from Simulation (300 ft^2 Rooms)

Alternative	Heating	Hot Water	Total	% Savings
cz3_base - Natural Gas (Therm)	887	652	1,539	
cz3_reset_NoOverride - Natural Gas (Therm)	908	652	1,560	-2.37%
cz4_base - Natural Gas (Therm)	1,070	636	1,706	
cz4_reset_NoOverride - Natural Gas (Therm)	1,080	636	1,716	-0.93%
cz5_base - Natural Gas (Therm)	885	649	1,534	
cz5_reset_NoOverride - Natural Gas (Therm)	901	649	1,550	-1.81%
cz12_base – Natural Gas (Therm)	1,351	630	1,981	
cz12_reset_NoOverride - Natural Gas (Therm)	1,360	630	1,990	-0.67%
Cz13_base – Natural Gas (Therm)	1,309	593	1,902	
cz13_reset_NoOverride - Natural Gas (Therm)	1,318	593	1,911	-0.69%
Average for all climate zones, No Control	1,100	632	1,732	
Average for all climate zones, Setback Control	1,113	632	1,745	-1.3%

Table 19: HVAC Gas Energy Savings (therms) from Simulation (450 ft^2 Rooms)

Alternative	Heating	Hot Water	Total	% Heating Savings
CZ3_Baseline	1,248	652	1,900	
CZ3_Setback	1,236	652	1,888	1.0%
CZ4_Baseline	1,512	636	2,148	
CZ4_Setback	1,400	636	2,036	7.4%
CZ5_Baseline	1,245	649	1,894	
CZ5_Setback	1,140	649	1,789	8.4%
CZ12_Baseline	1,935	630	2,565	
CZ12_Setback	1,876	630	2,506	3.0%
CZ13_Baseline	1,560	578	2,138	
CZ13_Setback	1,489	578	2,067	4.6%
Average for all climate zones, No Control	1,500	629	2,129	
Average for all climate zones, Setback Control	1,428	629	2,057	4.9%

Setback controls provide a significant demand reduction (6.7% to 12.9%), with a greater demand reduction in the hotter inland valley climates. Demand reduction was smaller for the building with 450 ft^2 rooms, in part because the lighting and plug loads were a greater percentage of building energy use.

Table 20: Peak Demand from Simulation (300 ft^2 Rooms)

Climate Zone	Demand Base (kW)	Demand Setback (kW)	% Savings
3	25.2	23.5	6.7%
4	25.2	23.5	6.7%
5	23.1	21.5	6.9%
12	29.5	23.5	20.3%
13	27.2	23.7	12.9%
Average	26.0	23.1	10.7%

Table 21: Peak Demand from Simulation (450 ft^2 Rooms)

Climate Zone	Demand Base (kW)	Demand Setback (kW)	% Savings
3	23.4	23.6	-0.9%
4	27.3	28.6	-4.8%
5	23.5	23.2	1.3%
12	32.2	29.4	8.7%
13	33.6	30.3	9.8%
Average	28.0	27.0	2.8%

On/off control simulation results

On/off controls provide greater energy savings than setback controls. The following tables show energy and demand reduction that can be achieved with on/off controls for occupancy-based control systems. An assumption was made that lighting and receptacles are not controlled by the system. Even greater energy savings is possible if lights and plugs are controlled.

Energy savings varied from 15.1% to 25.4% across the five climate zones. Energy savings on a percentage basis was a bit lower in the inland valley climates (climate zones 12 and 13).

Table 22: Electricity End Use Results (kWh) from Simulation, On/Off Control (300 ft^2 Rooms)

Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	Total	Savings (kWh)	%
cz3_base	12,531	11,366	26,314	3,817	5,387	33,943	93,358		
cz3_OnOff Control	12,531	11,366	18,740	2,153	3,163	27,768	75,721	17,637	18.9%
cz4_base	12,531	11,366	30,383	3,847	5,600	34,144	97,871		
cz4_ OnOff Control	12,531	11,366	23,704	2,765	4,139	29,377	83,882	13,989	14.3%
cz5_base	12,531	11,366	26,380	3,464	4,964	35,471	94,176		
cz5_ OnOff Control	12,531	11,366	20,504	2,355	3,422	30,056	80,234	13,942	14.8%
cz12_base	12,531	11,366	32,948	4,177	6,117	38,148	105,287		
cz12_ OnOff Control	12,531	11,366	24,874	2,755	4,234	33,274	89,034	16,253	15.4%
cz13_base	12,531	11,366	36,983	4,029	5,830	37,972	108,711		
cz13_ OnOff Control	12,531	11,366	30,535	3,008	4,574	33,912	95,926	12,785	11.8%
Average of Results									
No Control	12,531	11,366	30,602	3,867	5,580	35,936	99,881		
Setback Control	12,531	11,366	23,671	2,607	3,906	30,877	84,959	14,922	14.9%

Table 23: HVAC Energy Savings (kWh) from Simulation, On/Off Control (300 ft^2 Rooms)

Climate Zone	HVAC Base	HVAC On/Off Control	Savings	% Savings
3	69,461	51,824	17,637	25.4%
4	73,974	59,985	13,989	18.9%
5	70,279	56,337	13,942	19.8%
12	81,390	65,137	16,253	20.0%
13	84,814	72,029	12,785	15.1%
Average	75,984	61,062	14,921	19.8%

Table 24: Electricity End Use Results (kWh) from Simulation, On/Off Control (450 ft^2 Rooms)

Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	Total	Savings (kWh)	%
CZ3_Baseline	18,797	17,049	29,828	3,611	5,249	41,245	115,779		
CZ3_ On-Off Control	18,797	17,049	22,617	2,279	3,684	30,430	94,856	20,923	18.1%
CZ4_Baseline	18,797	17,049	36,829	4,276	6,328	39,227	122,506		
CZ4_ On-Off Control	18,797	17,049	28,893	2,913	4,730	34,953	107,335	15,171	12.4%
CZ5_Baseline	18,797	17,049	30,451	3,763	5,497	37,440	112,997		
CZ5_ On-Off Control	18,797	17,049	23,848	2,394	3,827	33,066	98,981	14,016	12.4%
CZ12_Baseline	18,797	17,049	40,667	4,614	6,840	43,446	131,413		
CZ12_ On-Off Control	18,797	17,049	34,342	3,591	5,707	40,404	119,890	11,523	8.8%
CZ13_Baseline	18,797	17,049	51,158	5,208	7,364	44,673	144,249		
CZ13_ On-Off Control	18,797	17,049	45,465	4,465	6,797	43,122	135,695	8,554	5.9%
Average of Results									
No Control	18,797	17,049	37,787	4,294	6,256	41,206	125,389		
Setback Control	18,797	17,049	31,033	3,128	4,949	36,395	111,351	14,038	11.2%

Table 25: HVAC Energy Savings (kWh) from Simulation, On/Off Control (450 ft^2 Rooms)

Climate Zone	HVAC Base	HVAC On/Off Control	Savings	% Savings
3	79,933	59,010	20,923	26.2%
4	86,660	71,489	15,171	17.5%
5	77,151	63,135	14,016	18.2%
12	95,567	84,044	11,523	12.1%
13	108,403	99,849	8,554	7.9%
Average	89,543	75,505	14,037	16.4%

Gas savings are substantial (10.5% to 24%) for on/off controls. On a percentage basis, gas savings are a bit higher for the coastal climates (climate zones 3 through 5) than in the inland valley climates (climate zones 12 and 13).

Table 26: HVAC Gas Energy Savings from On/Off Control (300 ft^2 Rooms)

Alternative	Heating	Hot Water	Total	% Savings
cz3_base - Natural Gas (Therm)	887	652	1,539	
cz3_withGC_noOverride - Natural Gas (Therm)	732	652	1,384	17.47%
cz4_base - Natural Gas (Therm)	1,070	636	1,706	
cz4_withGC_NoOverride - Natural Gas (Therm)	874	636	1,510	18.32%
cz5_base - Natural Gas (Therm)	885	649	1,534	
cz5_withGC_NoOverride - Natural Gas (Therm)	675	649	1,324	23.73%
cz12_base – Natural Gas (Therm)	1,351	630	1,981	
cz12_withGC_NoOverride - Natural Gas (Therm)	1,158	630	1,788	14.29%
cz13_base – Natural Gas (Therm)	1,309	593	1,902	
cz13_withGC_NoOverride - Natural Gas (Therm)	1,171	593	1,764	10.54%
Average for all climate zones, No Control	1,100	632	1,732	
Average for all climate zones, Setback Control	922	632	1,554	16.9%

Table 27: HVAC Gas Energy Savings (therms) from On/Off Control (450 ft^2 Rooms)

Alternative	Heating	Hot Water	Total	% Heating Savings
CZ3_Baseline	1,248	652	1,900	
CZ3_GuestroomControls	1,106	652	1,758	11.4%
CZ4_Baseline	1,512	636	2,148	
CZ4_GuestroomControls	1,255	636	1,891	17.0%
CZ5_Baseline	1,245	649	1,894	
CZ5_GuestroomControls	935	649	1,584	24.9%
CZ12_Baseline	1,935	630	2,565	
CZ12_GuestroomControls	1,671	630	2,301	13.6%
CZ13_Baseline	1,560	578	2,138	
CZ13_GuestroomControls	1,320	578	1,898	15.4%
Average for all climate zones, No Control	1,500	629	2,129	
Average for all climate zones, Setback Control	1,257	629	1,886	16.5%

Peak demand is also reduced significantly with on/off controls (14.7% to 31.7%). On a percentage basis peak demand reductions are greatest in the mild climates. Peak demand reductions are greater for the building with the 300 ft^2 rooms than for the building with the 450 ft^2 rooms.

Table 28: Peak Demand Reduction for On/Off Controls (300 ft^2 Rooms)

Climate Zone	Demand Base (kW)	Demand On/Off (kW)	% Savings
3	25.2	17.2	31.7%
4	25.2	21.1	16.3%
5	23.1	18.8	18.6%
12	29.5	22.5	23.7%
13	27.2	23.2	14.7%
Average	26.0	20.6	21.0%

Table 29: Peak Demand Reduction for On/Off Controls (450 ft^2 Rooms)

Climate Zone	Demand Base (kW)	Demand On/Off (kW)	% Savings
3	23.4	19.2	17.9%
4	27.3	24	12.1%
5	23.5	20.1	14.5%
12	32.2	29.1	9.6%
13	33.6	32.5	3.3%
Average	28.0	25.0	11.5%

The on/off controls also provide an opportunity to downsize the central plant, particularly the chiller. This can save first costs and allow the plant to operate more efficiently by operating at closer to design conditions.

Comparison with Other Guestroom Control Studies

Comparison with Emerging Technologies Report

A previously issued Emerging Technologies Program report, *Application Assessment Report #0609*, *Marketable Technologies for the Hospitality Segment*, produced by Pacific Gas & Electric Company (PG&E) (September 2007), contains a compilation of information derived from publicly available sources regarding hotel occupancy-based guestroom controls.

We found that actual savings are approximately 25% of what has been reported in earlier literature. The peak demand reduction reported in the literature is approximately 200 W per room. The demand savings calculated in this research project for on-off control ranged from 67 W to 133 W per room with an average across all climate zones of 91 W per room. This is roughly 45% of what is commonly reported.

Comparison with Card-Key Control

With all other factors being equal, the occupancy-based control provides a slightly greater energy savings than the card-key control, since the guest occasionally overrides the card-key control system. The card-key system was modeled with a fan override by adding one hour of operation to 49 of the 60 rooms. This override slightly reduced energy and demand savings, since the override will increase both fan energy and cooling energy slightly. As shown in Table 30, the occupant-sensor based control provides a slightly greater savings than the card-key system for an on/off control strategy. The energy savings for setback control are virtually the same between the card-key and occupant sensors.

Table 30: Comparison of Energy Savings from Card-Key and Occupant-Sensor Controls (300 ft^2 Rooms)

Climate Zone	On/Off Savings, Occupancy Sensors	On/Off Savings, Card-Key System	Setback Savings, Occupancy Sensors	Setback Savings, Card-key Control
3	25.4%	23.7%	3.0%	3.0%
4	18.9%	18.4%	3.3%	3.3%
5	19.8%	18.9%	2.0%	1.9%
12	20.0%	19.0%	8.2%	7.3%
13	15.1%	15.2%	7.0%	7.3%

Appendix C provides more detailed monthly predictions of electricity and gas use by the simulation models.

Comparison with Monitored Data

The monitored data showed a much larger percentage energy savings for the guestroom setback controls than is predicted by the simulation on an annual basis. As mentioned earlier, this is partially explained by the fact that the inactive and active monitoring periods were only about a month long, and occurred at different times of the year. The inactive period occurred in September while the active period occurred in October and November, when cooling loads would be expected to be lower anyway. Monthly results from the simulation were reviewed to determine how the electricity use varied between these months. We compared the monthly simulation results for *September* for the inactive control period with the results for *October* for the active control period.

The results for the sixty-room hotel in Table 31 below show an HVAC energy savings of 23.9% for climate zone 3, which is closer to the average monitored energy savings of 25%. This comparison reveals the difficulties in comparing electricity use from two different times of the year in monitored data.

Table 31: Monthly Electricity Use, September Inactive Period and October Active Period

Alternative	Lights	Equip.	Cooling	Tower	Pumps	Fans	HVAC Total	% Savings
CZ3 No Controls	1,030	934	3,214	322	425	2,218	6,179	
CZ3 Setback	1030	934	2353	307	416	1,624	4,700	**23.9%**
CZ4 No Controls	1030	934	3883	352	468	2,679	7,382	
CZ4 Setback	1030	934	2738	330	456	1,889	5,413	**26.7%**
CZ5 No Controls	1030	934	3134	302	407	2,162	6,005	
CZ5 Setback	1030	934	2493	291	398	1,720	4,902	**18.4%**
CZ12 No Controls	1030	934	4369	440	571	3,015	8,395	
CZ12 Setback	1030	934	2790	370	531	1,925	5,616	**33.1%**
CZ13 No Controls	1030	934	5152	439	560	3,555	9,706	
CZ13 Setback	1030	934	3188	357	495	2,200	6,240	**35.7%**
Average of Results, No Control	1,030	934	3,950	371	486	2,726	7,533	
Average of Results, Setback Control	1,030	934	2,712	331	459	1,872	5,374	**27.6%**

Sample Payback Calculation

Using the average savings listed above for electric energy, demand and gas; typical utility rates as shown below; and the installation cost for the controls given in the report leads to the following:

Table 32: Sample Simple Payback Calculation

Per Room	Electric Savings	On-Peak Demand Reduction	Natural Gas Savings
Annual Savings	249 kWh / yr	0.092 kW	3.0 therms / yr
Utility Cost	$ 0.13 / kWh	$ 10.00 / kW-month	$ 0.80 / therm
# months Demand savings		6	
Annual Cost Savings	$32.33	$5.52	$2.38
Total Annual Cost Savings	$40.23		
Estimated Installation Cost	$530		
Simple Payback	13.2 Years		

The finding of savings in the amount of approximately 250 kWh/yr/room is a significant change from previous work. While the fraction of energy saved by room controls is comparable to previous studies, the absolute magnitude of the energy savings is less. A previous study[2] estimated guestroom annual energy use at 2850 kWh. Energy simulation results predict an average annual energy use of 1664 kWh, and 2090 kWh for the 300 ft^2 and 450 ft^2 hotel rooms, respectively.

The lower energy use on a per room basis can be attributed to the low lighting and plug loads observed in the monitored hotels, an efficient newer building envelope, and shading from adjacent buildings. Another assumption made, to be consistent with the system in the monitored hotel, was that only HVAC units were controlled. Control of lighting and receptacles would increase savings. The smaller savings values lead to longer payback periods than has been previously considered.

Control system manufacturers promote paybacks of 2-3 years. We reiterate that the monitored data matches the averages savings noted above, but also note that the data is based on a small sampling of hotel rooms. Occupant behavior can have a large influence on achieved savings. In addition, the estimated installation cost of $530 per guestroom includes two hours of labor that might be reduced on a per-room basis in a large installation. Furthermore, as guestroom control technology becomes more widespread, hardware prices may decrease. Finally, utility rates can vary from the typical rates used above and will most likely increase in the future. Any finding of higher

[2] *Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004,* American Council for an Energy-Efficient Economy, Report Number A042, October 2004.

baseline energy consumption or cost, or reduced installation cost, will decrease the payback period from that shown here.

Hotel Room Controls Incentive Calculator

In parallel with this report, a simple electronic calculator was developed that is capable of estimating the annual electrical and gas energy savings and peak demand reduction achievable by installing hotel guestroom controls. The savings are based on the simulation results presented in both this study and in the Card-Key Guestroom Controls Study referenced earlier.

The “Hotel Room Controls Incentive Calculator” also determines the annual energy cost savings and, if an installation cost is input, the corresponding simple payback period. Finally, it estimates the incentives PG&E may offer hotel customers to install either card-key or occupancy-based guestroom controls.

The calculator supports marketing room controls to hotel customers, and enables PG&E to calculate energy savings for processing incentive applications. It has a simple input - output screen developed using Microsoft Visual Basic. The underlying calculation procedures are built in Microsoft Excel. The inputs and results may be saved as Excel worksheets.

The inputs for the calculator include:

- Hotel contact information,
- The calculator user’s, or “Provider” contact information,
- PG&E Account Representative contact information,
- Climate zone where the hotel is located (the same five climate zones as used in this analysis),
- Choice of card-key or occupancy-based control system,
- Control strategy when rooms are unoccupied -- on/off operation or temperature setback of 2 degrees Fahrenheit,
- Systems controlled (HVAC, lighting and plug loads, singly or in combinations),
- Average size of hotel guestroom (in square feet),
- Number of guestrooms in the hotel that will be controlled.

A separate screen contains PG&E’s rates and incentives. These parameters can be modified from time to time by PG&E, as necessary.

Conclusions

1. The energy savings with the occupancy-based control system with thermostat setback varied widely from room to room, and overall the energy savings observed in the monitored data were greater than those predicted by energy simulations. Weather differences between the inactive and active monitoring periods contributed to the higher savings.

2. A simple bin analysis using linear regressions of measured cooling energy use to outside air temperature during the monitoring periods does not provide a very accurate prediction of annual energy savings. Guest thermostat settings, use of lighting and appliances, occupancy patterns, and other factors affect guestroom energy use.

3. The occupancy-based control system is expected to have an energy savings level slightly higher than the card-key based system, since there is no potential for the guest to override the system.

4. Electric energy savings are much greater for on-off control (15.1% to 25.4%) than for setback control (3.0% to 8.2%). For on/off control, in a hotel with sixty 300-ft2 rooms, simulations indicate HVAC savings per room ranging from 213 kWh/year to 294 kWh/year depending on climate zone, with an average across all climate zones of 249 kWh/year. For setback control, the savings per room range from 23 kWh/year to 112 kWh/year, with an average across all climate zones of 62 kWh/year. These savings represent HVAC energy only, as lighting and plug loads were not controlled in this project.

5. Gas energy savings are about 3.0 therms/yr per room for on/off control (10.5% to 23.7%), but are negligible for setback control.

6. Peak demand reductions are greater for on/off control (15% to 32% for the 300 ft^2 room hotel) than for setback control (6% to 20%). For on/off control, simulations indicate a peak demand average reduction across the five climate zones of 21%, ranging from 67 W to 133 W per room, with an average of 91 W per room. For setback control, the average reduction in peak demand is 10.7%, ranging from 28 W to 100 W per room, with an average of 48 W per room. These savings represent HVAC demand only, as lighting and plug loads were not controlled in this analysis.

7. For new construction, there is opportunity to downsize the central plant, since the majority of the hotel rooms are unoccupied during the afternoon hours when demand is typically highest.

8. The finding of savings in the amount of approximately 250 kWh/yr/room is a significant change from previous work, where savings in the neighborhood of 1000 kWh/yr/room have been found. While the fraction of energy saved by room controls is comparable to previous studies, the absolute magnitude of the energy savings is less. The smaller savings values lead to longer payback periods than typically stated by vendors.

9. The monitored data is based on a small sampling of hotel rooms. Occupant behavior can have a large influence on achieved savings.

10. The estimated installation cost of $530 per guestroom includes two hours of labor that might be reduced on a per-room basis in a large installation. As guestroom control technology becomes more widespread, hardware prices may decrease. Utility rates can vary from the typical rates used in this analysis, and will most likely increase in the future. Any finding of higher baseline energy consumption or cost, or reduced installation cost will decrease the payback period from the results shown in this report.

Appendix A: Equipment Used to Monitor Hotels

This Appendix contains brief descriptions of the data acquisition equipment described in the report. This equipment was used in the monitoring phase of the project. Monitoring equipment was used for:

- Fan-coil and electrical circuit continuous monitoring;
- Guestroom occupancy continuous monitoring; and
- Weather parameter continuous monitoring.

Hand-held meters were used for:

- Making one-time measurements.

Fan-Coil and Electrical Circuit Monitoring Equipment

HOBO H22-001 Energy Logger Pro from Onset Computer Corporation.

The HOBO Energy Logger Pro Data Logger, shown in Figure A-1, is a modular, re-configurable data logging system for energy and other monitoring applications. The 15-channel system enables users to quickly and easily configure the logger for a broad range of monitoring applications, without having to purchase dedicated-purpose data loggers. Snap-in signal conditioning modules allow signals from nearly any type of sensor to be used with the logger. A suite of pre-defined plug-and-play smart sensors is also available. The HOBOware® software is used in the set up, deployment, and data retrieval processes.

Figure A-1: HOBO Energy Logger Pro

Onset S-THB-M002 Temperature/RH Smart Sensor

The 12-bit Temperature/RH Smart Sensor, shown in Figure A-2, is designed to work with all Onset data loggers that accept Smart Sensors. All sensor parameters are stored inside the Smart Sensor, which automatically communicates configuration data information to the logger without any programming, calibration, or extensive user set up.

Figure A-2: Onset Temperature and Relative Humidity Smart Sensor

Onset S-UCC-M006 Electronic Switch Pulse Input Adapter

The Electronic Switch Pulse Input Adapter, shown in Figure A-3, connects sensors with pulse outputs to loggers with smart sensor inputs. This Smart Sensor is compatible with electronic switch closures such as FET or open-collector outputs, or CMOS-level logic signals with a maximum input frequency of 120 Hz (120 pulses per second).

Figure A-3: Onset Electronic Switch Pulse Input Adapter

Onset S-FS-TRMSA FlexSmart True RMS Module (two channels)

The 12-bit two-channel FlexSmart True RMS Current / Voltage Module, shown in Figure A-4, accepts an input range of 5mV to 512mV and is compatible with 333mV FS output sensors. Field wiring is 2-wire via screw terminals.

Figure A-4: Onset FlexSmart True RMS Module

Continental Control Systems WNB-3Y-208-P3 WattNode three channel watt transducer

The Pulse WattNode is a true RMS AC watt-hour transducer with pulse output (solid state relay closure) proportional to kWh consumed. The WattNode provides accurate measurement at low cost for sub-metering, net-metering, energy management, and performance contracting applications.

Figure A-5: Continental Control Systems WattNode

Magnelab SCT-075-XXX Split Core Current Transducer (CT)

Split-core current transformers "sense" AC current from 1 to 200 Amps passing through the center conductor. Split-core transformers are ideal for installation on existing electrical wiring by snapping around the conductor. The Magnelab SCT series, shown in Figure A-6, have one of the highest industry standards both for interleaving joints and the self-locking mechanism.

Figure A-6: Magnelab Split Core Current Transducer

Guestroom Occupancy (occupied/unoccupied)

Energy Eye™ Wireless System Components:

The Energy Eye System is a line of products developed to decrease energy use in apartments, schools, offices, and hotels. These wireless products are designed to sense occupancy using passive infrared (PIR) technology and to control HVAC and other equipment in response to occupancy. In this project, these devices were only used to determine when hotel rooms were occupied and unoccupied. They were not used for control.

EE-IR-05 Wireless PIR Sensor

The EE-IR-05 Wireless PIR Sensor is a passive infrared occupancy sensor with wireless communication to a receiver/controller. The PIR sensor is concealed in a proprietary and custom designed casing that makes this unit appear to be a smoke detector. This prevents the guest from thinking this motion sensor is a camera, which can occur with thermostat-mounted or corner-mounted PIR sensors.

Figure A-7: Energy Eye Wireless Passive Infrared Sensor

EE-MT-03 Wireless Micro Door Sensor

The wireless micro door sensor, shown in Figure A-8, is a standard part of the Energy Eye System. Signals from this device are used as part of the input to ensure accurate occupancy detection. It provides a signal to the receiver/controller necessary to eliminate falsely determining a room is unoccupied when no infrared energy is detected, as would happen when a guest is in the bathroom or is sleeping.

Figure A-8: Energy Eye Wireless Micro Door Sensor

EE-RXS-O Receiver/Controller

The EE-RXS-O receiver/controller, shown in Figure A-9, receives the wireless signals from both the PIR sensor and door sensor and determines when a room is occupied. It is normally used to control HVAC and lighting. For this project, the controller closed a switch whenever the room was occupied.

Figure A-9: Energy Eye Receiver/Controller

Onset U9-001 State Data Logger

The Onset U9-001 state data logger, shown in Figure A-10, monitors state changes using an internal magnetic read switch that determines contact closures. It records the date and time of the state change. In this project, this feature was used to record when rooms changed from occupied to unoccupied and vice versa.

Figure A-10: Onset State Data Logger

Weather Station Equipment

Onset H21-002 HOBO Micro Station

The compact HOBO Micro Station, shown in Figure A-11, is designed for reliable, accurate outdoor monitoring, even in severe weather conditions. It accepts up to four plug-and-play Smart Sensors, and can run for up to one year on 4 standard AA batteries. The HOBO Micro Station was used to measure weather parameters in this project.

Figure A-11: HOBO Micro Station

Onset S-LIB-M003 Solar Radiation Sensor (Silicon Pyranometer)

The Solar Radiation Smart Sensor, shown in Figure A-12, is a light sensor (silicon pyranometer) with a measurement range of 0 to 1280 W/m2 over a spectral range of 300 to 1100 nm. This sensor reports the average light intensity over a user-set logging interval from a minimum of 1 second. It was used in this project to measure the solar radiation on the roof of Hotel #1.

Figure A-12: Onset Solar Radiation Sensor

Onset S-THB-M002 Temperature/RH Smart Sensor

The 12-bit Temperature/RH Smart Sensor, shown in Figure A-13, is designed to work with all Onset data loggers that accept Smart Sensors. In this project it was used to transmit ambient temperature and humidity information to the Micro Station.

Figure A-13: Onset Temperature and Relative Humidity Smart Sensor

Onset RS3 Solar Radiation Shield

The RS3 Solar Radiation Shield, shown in Figure A-14, protects external sensors from the effects of sunlight and rain to ensure highly accurate measurements. Designed to allow maximum air flow around the sensor, the RS3 Shield offers 2.5x faster response time to changing conditions.

Figure A-14: Onset Solar Radiation Shield

One-Time Measurements

Fluke 43B Power Quality Analyzer

The Fluke 43B Power Quality Analyzer, shown in Figure A-15, is a high-quality handheld instrument that performs all measurement necessary to analyze power quality, including current, voltage, frequency, phase angle, harmonics. It was used in this project to take one-time measurements of fan power.

Figure A-15: Fluke 43B Power Quality Analyzer

Fluke i400s AC Current Clamp

The Fluke i400s current clamp, shown in Figure A-16, is a companion to the 43B power quality analyzer. It was used to measure current for purposes of calculating power.

Figure A-16: Fluke AC Current Clamp

Alnor EBR721-A1 Digital Electronic Balometer (flow hood)

The Alnor EBT721-A1 digital electronic balometer, shown in Figure A-17, was used to measure volumetric air flow from the supply diffusers in the guestrooms. Multiple measurements were made for systems with multi-speed fans.

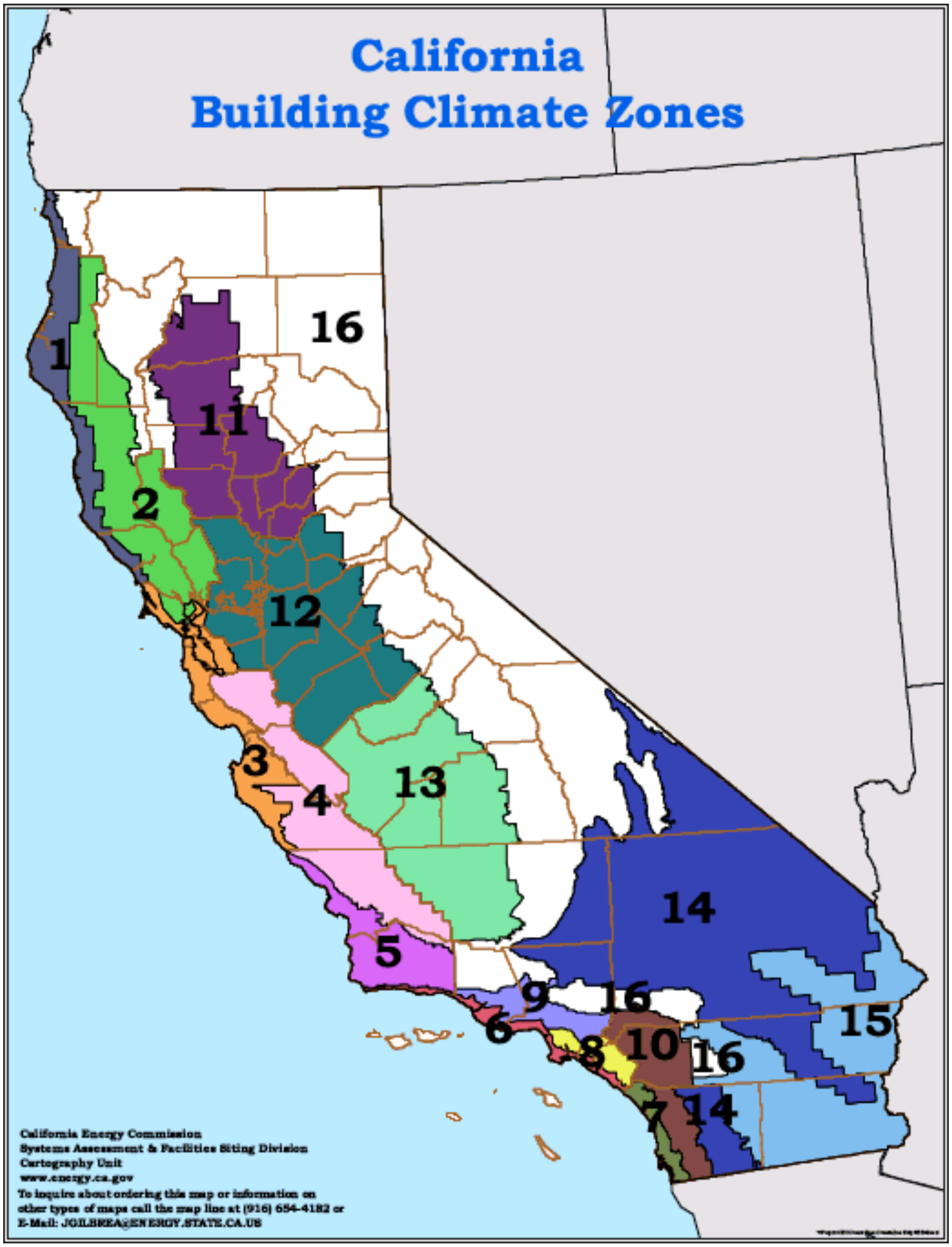
Figure A-17: Alnor Digital Electronic Balometer

Appendix B: California Climate Zones

The map below indicates the climate zones defined for the state of California (source: California Energy Commission, www.energy.ca.gov/maps/building_climate_zones.html). The climate zone definitions are based on geographic areas that have similar energy use, temperatures, weather and other factors. For more information or to determine the climate zone for a particular location, see the above website.

Representative cities for the five climate zones applicable to this study are:

- Climate Zone 3: Oakland
- Climate Zone 4: Sunnyvale
- Climate Zone 5: Santa Maria
- Climate Zone 12: Sacramento
- Climate Zone 13: Fresno


California
Building Climate Zones
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
16
16
14
16
California Energy Commission
Systems Assessment & Facilities Siting Division
Cartography Unit
www.energy.ca.gov
To inquire about ordering this map or information on
other types of maps call the map line at (916) 654-4182 or
E-Mail: JGILBREA@ENERGY.STATE.CA.US

Appendix C: Monthly Simulation Results by Climate Zone

The following graphs show energy model predictions of monthly hotel electricity and gas use for each of the five climate zones studied and two room sizes studied. Each graph is for a 60-room hotel and includes the guestrooms only (lobbies, dining areas, offices, etc., are not modeled).

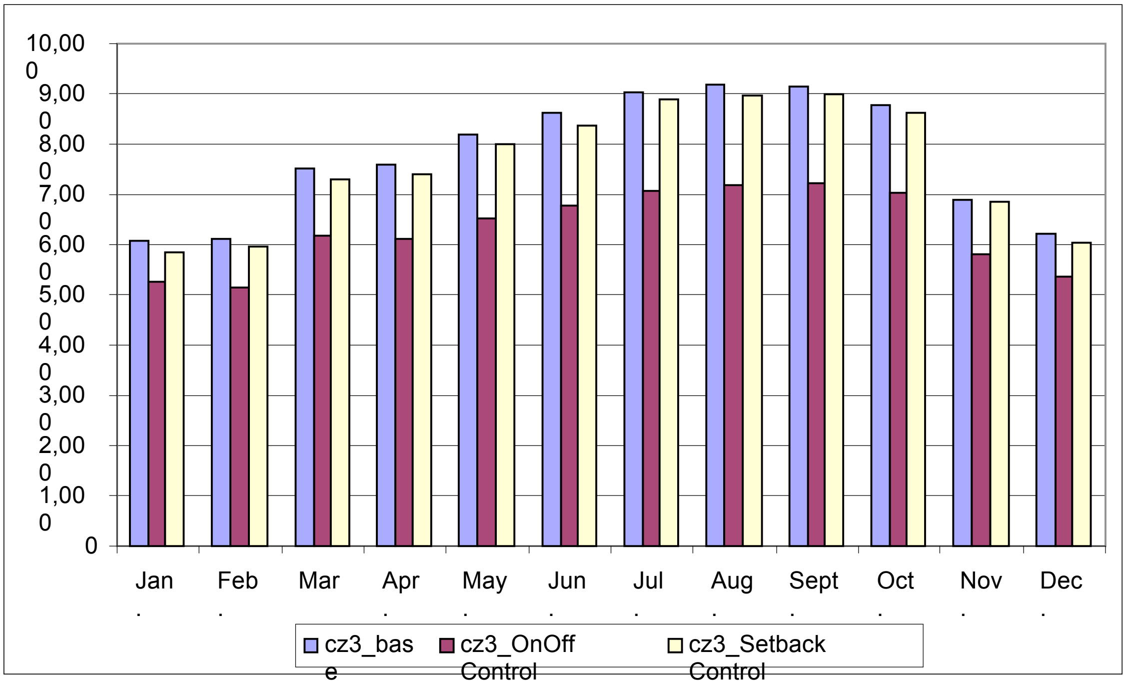


Figure C-1: Monthly Electricity Use (kWh), Climate Zone 3, 300 ft^2 Rooms

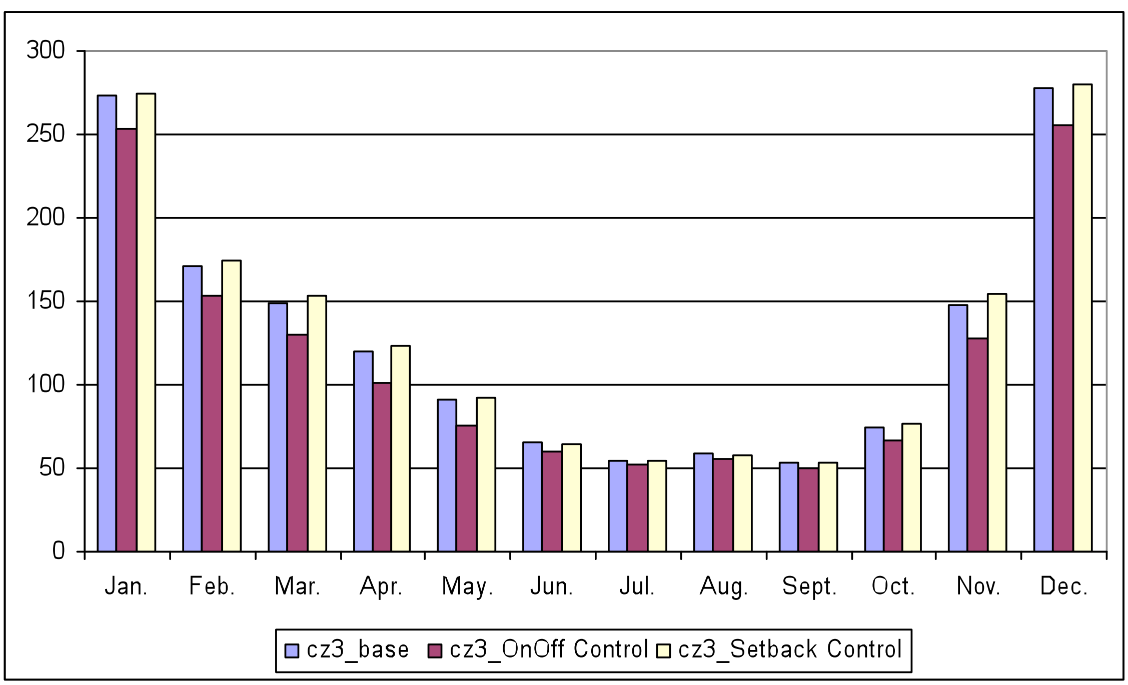


Figure C-2: Monthly Gas Use (therm), Climate Zone 3, 300 ft^2 Rooms

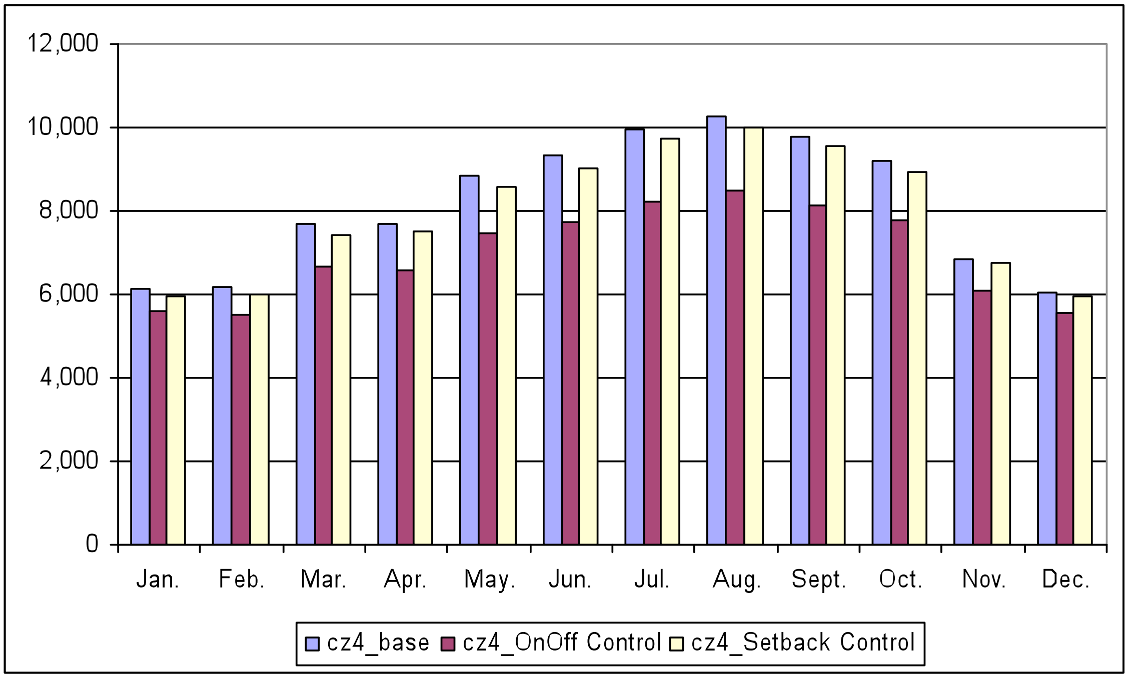


Figure C-3: Monthly Electricity Use (kWh), Climate Zone 4, 300 ft^2 Rooms

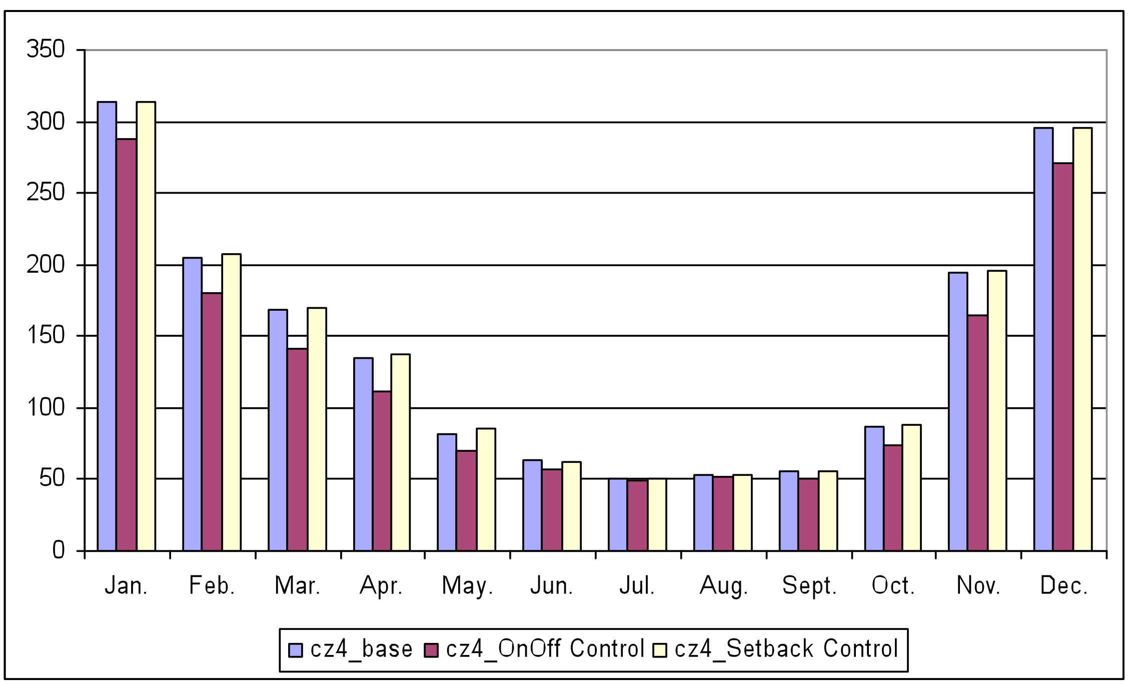


Figure C-4: Monthly Gas Use (therm), Climate Zone 4, 300 ft^2 Rooms

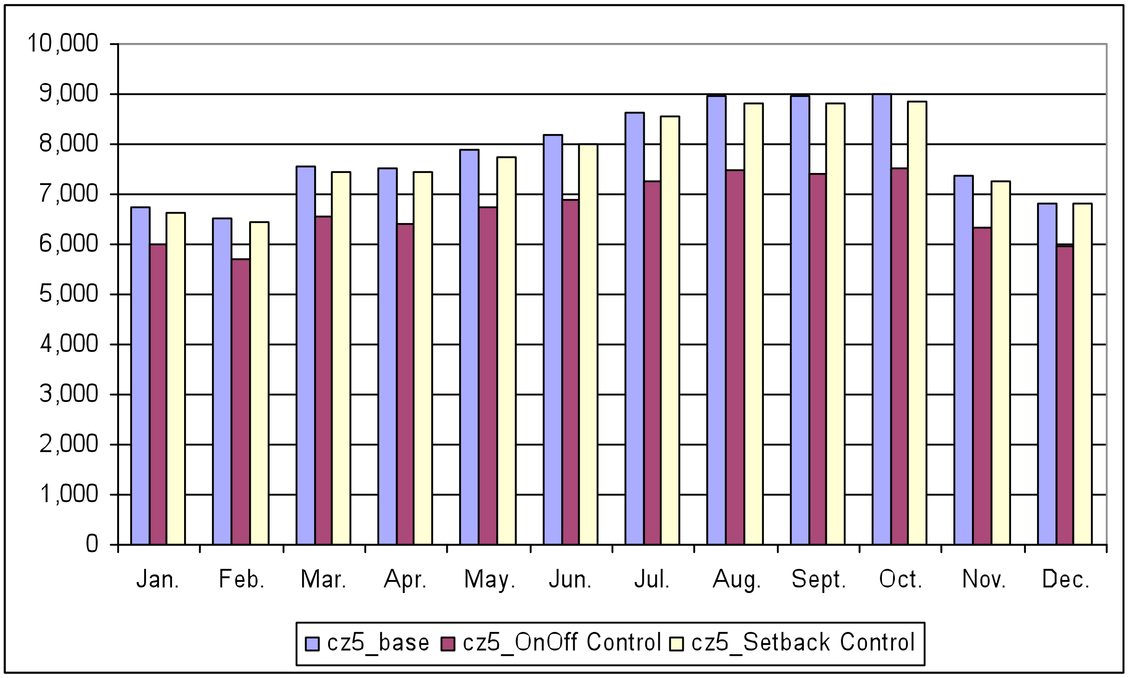


Figure C-5: Monthly Electricity Use (kWh), Climate Zone 5, 300 ft^2 Rooms

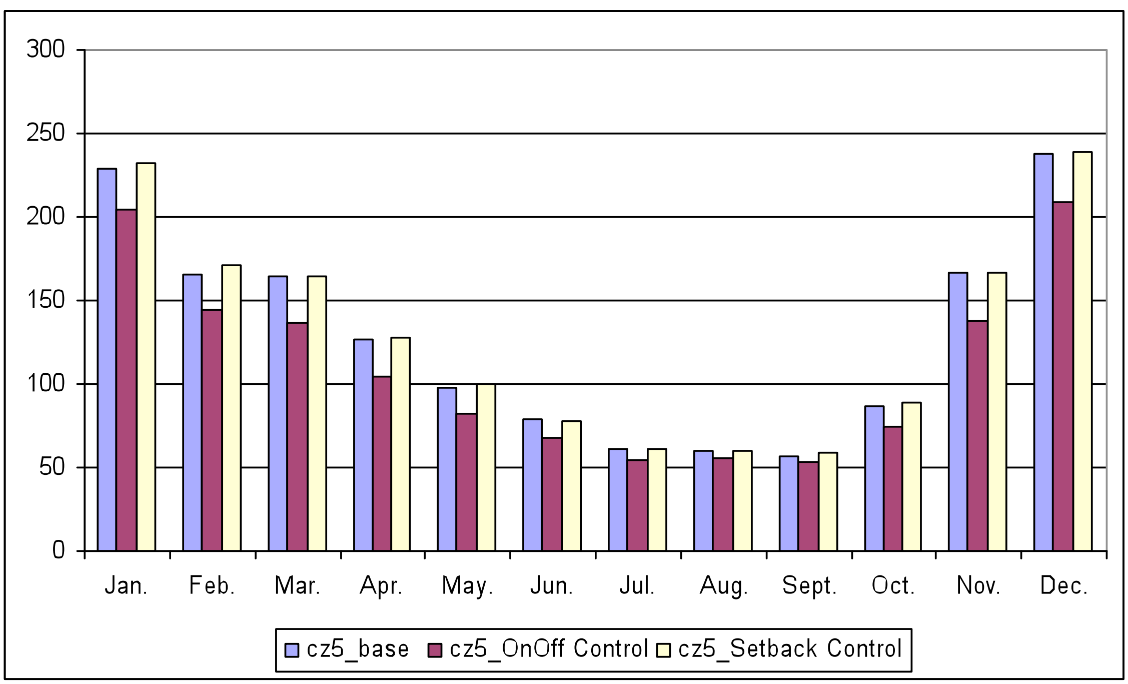


Figure C-6: Monthly Gas Use (therm), Climate Zone 5, 300 ft^2 Rooms

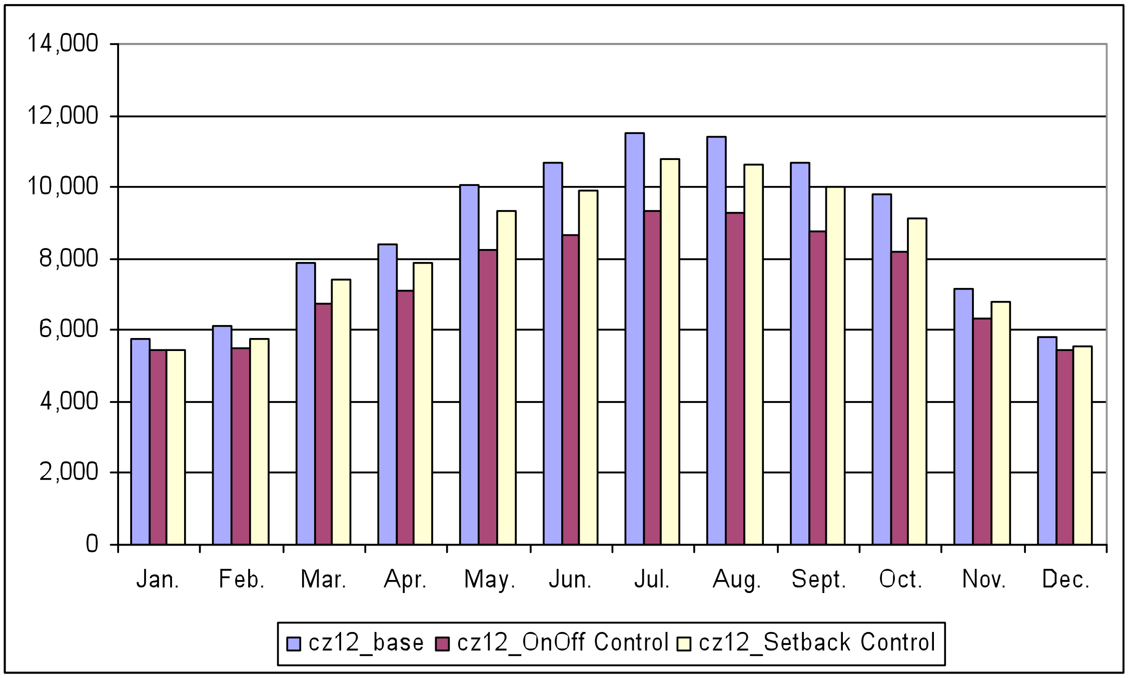


Figure C-7: Monthly Electricity Use (kWh), Climate Zone 12, 300 ft^2 Rooms

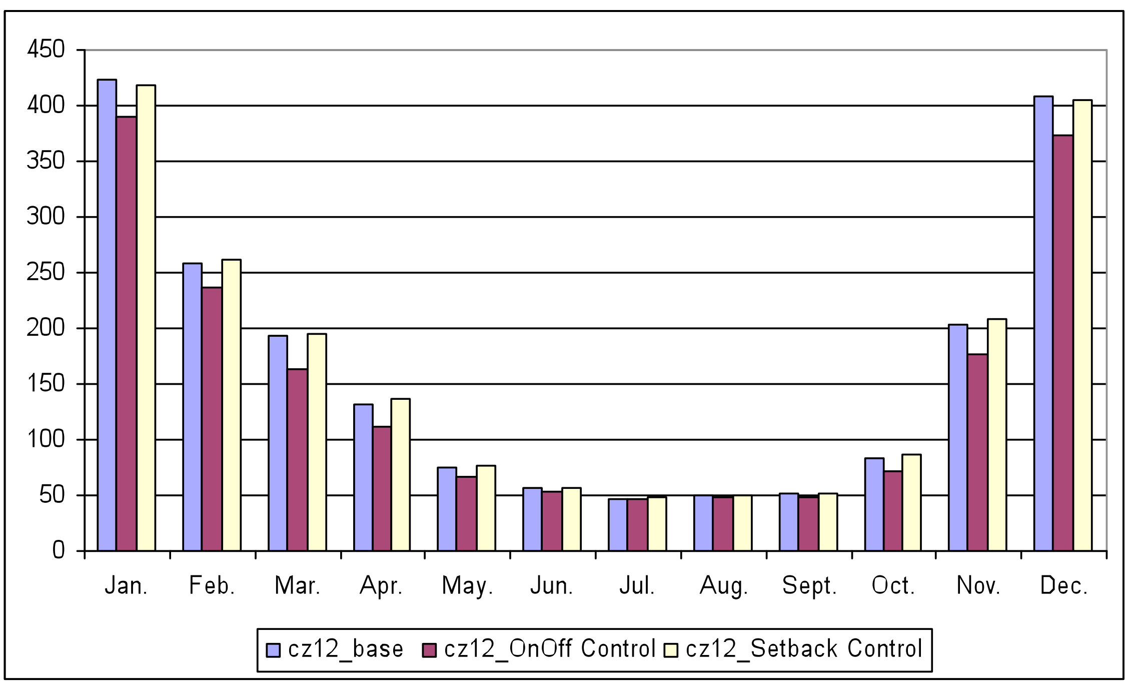


Figure C-8: Monthly Gas Use (therm), Climate Zone 12, 300 ft^2 Rooms

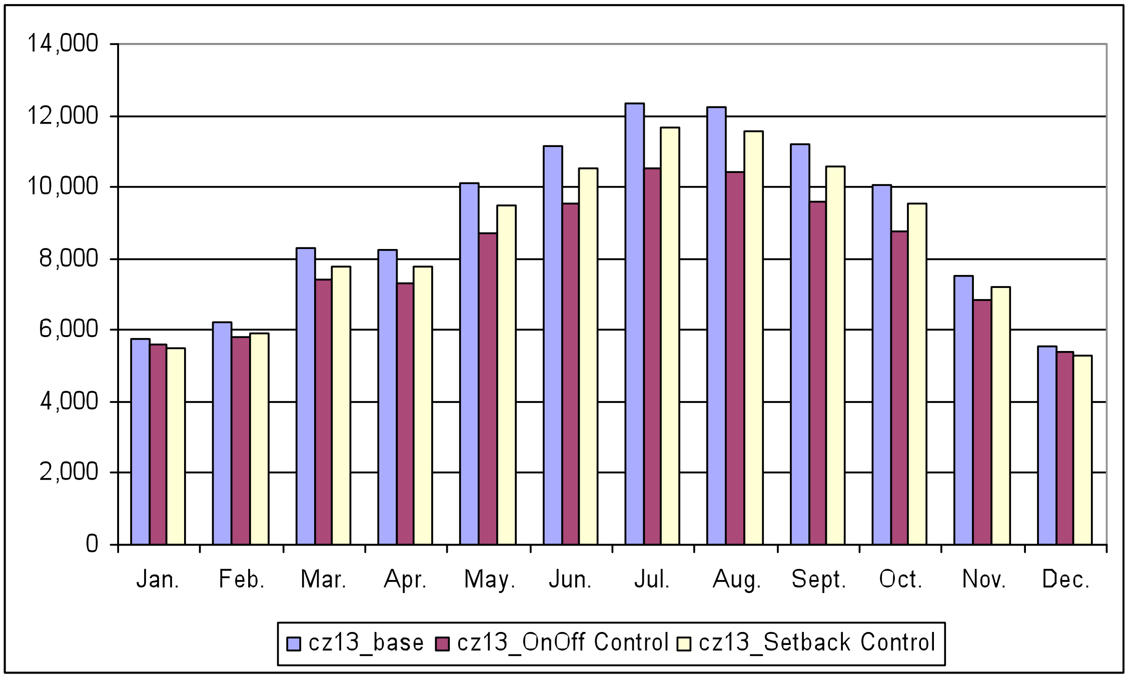


Figure C-9: Monthly Electricity Use (kWh), Climate Zone 13, 300 ft^2 Rooms

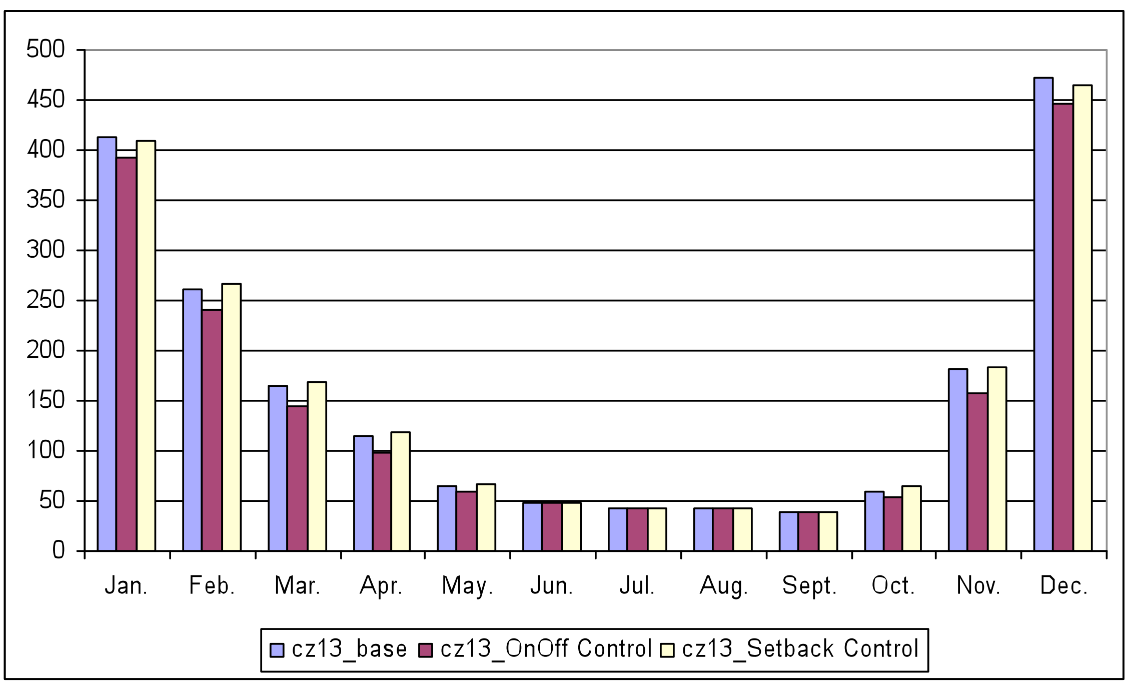


Figure C-10: Monthly Gas Use (therm), Climate Zone 13, 300 ft^2 Rooms

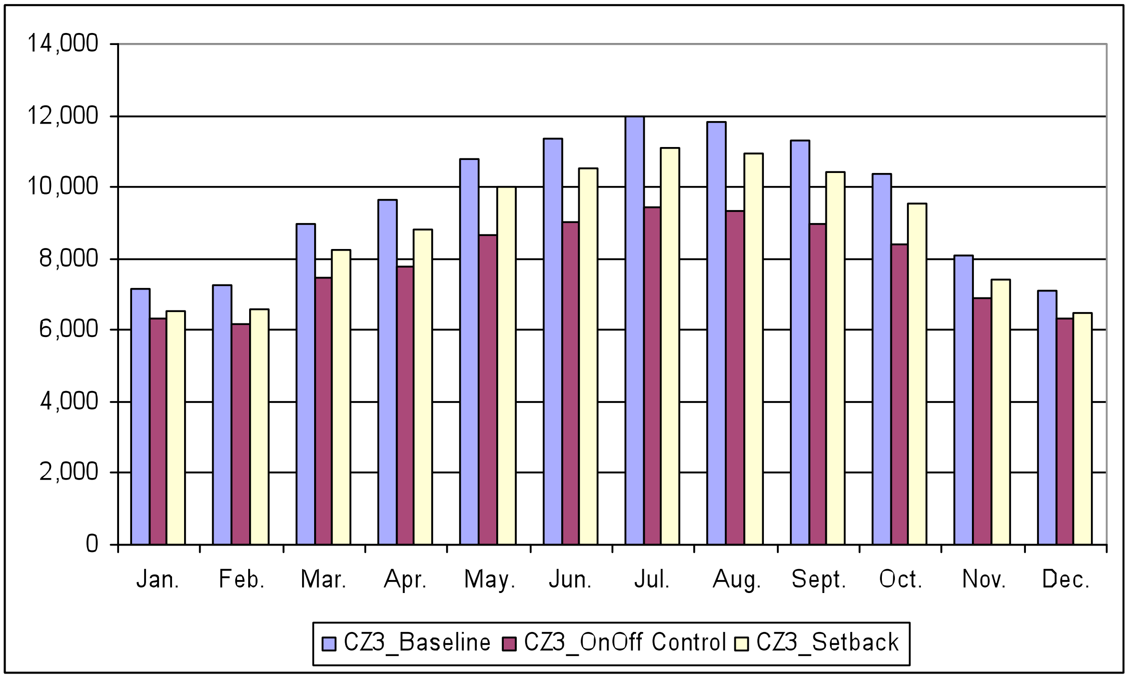


Figure C-11: Monthly Electricity Use (kWh), Climate Zone 3, 450 ft² Rooms

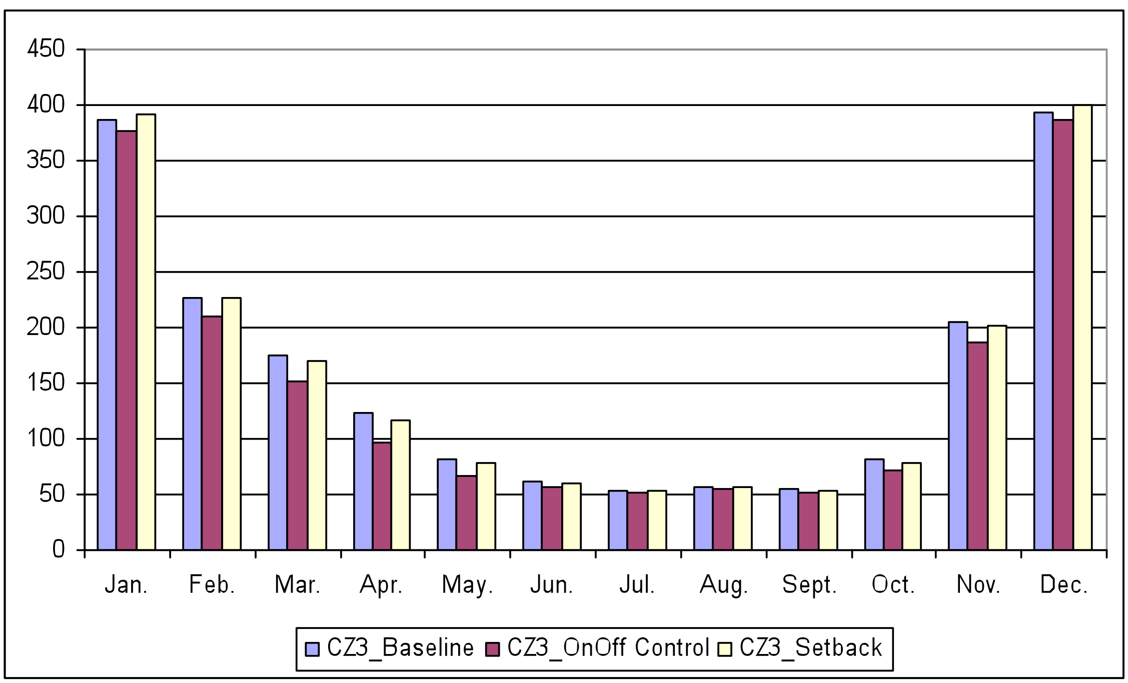


Figure C-12: Monthly Gas Use (therm), Climate Zone 3, 450 ft² Rooms

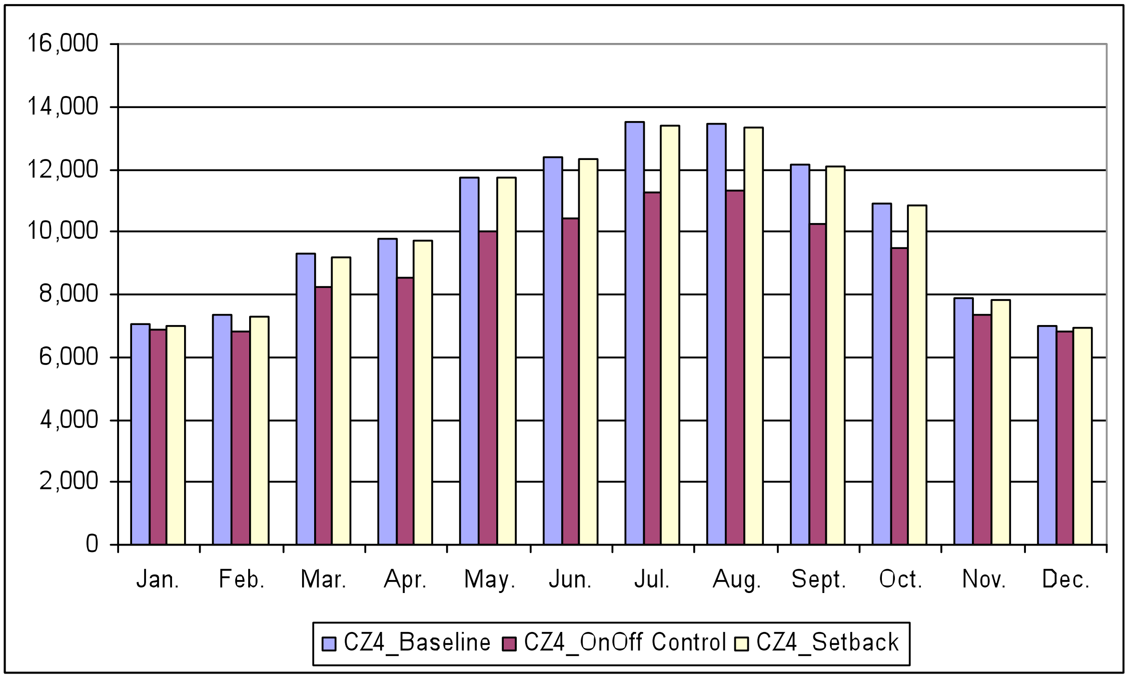


Figure C-13: Monthly Electricity Use (kWh), Climate Zone 4, 450 ft^2 Rooms

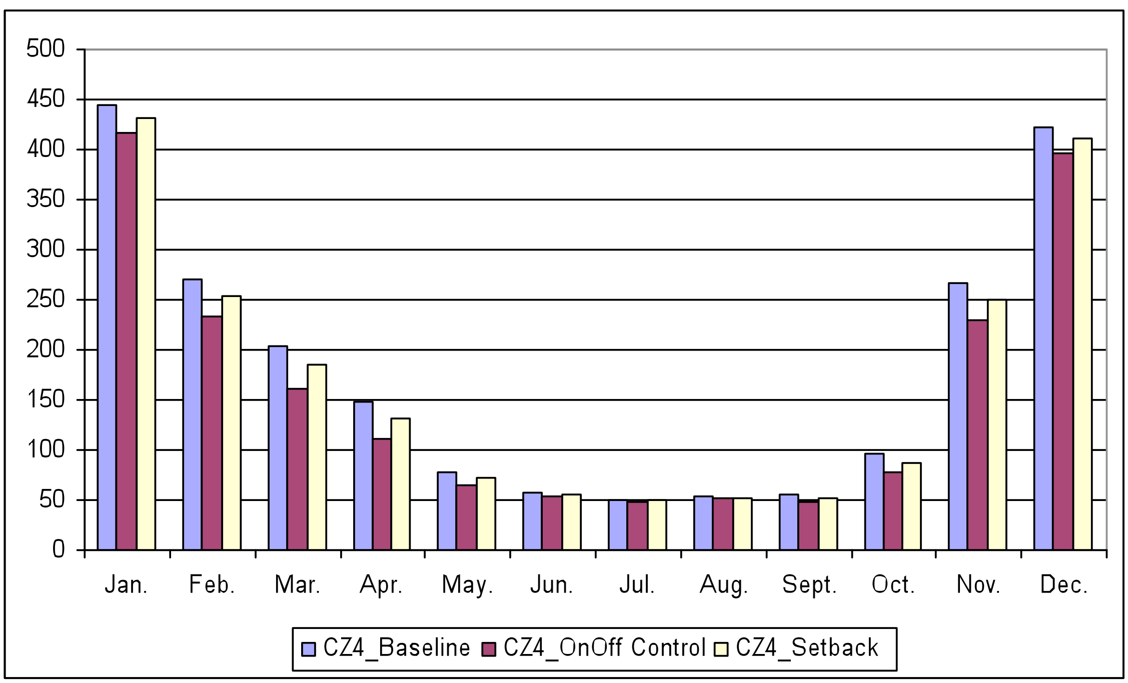


Figure C-14: Monthly Gas Use (therm), Climate Zone 4, 450 ft^2 Rooms

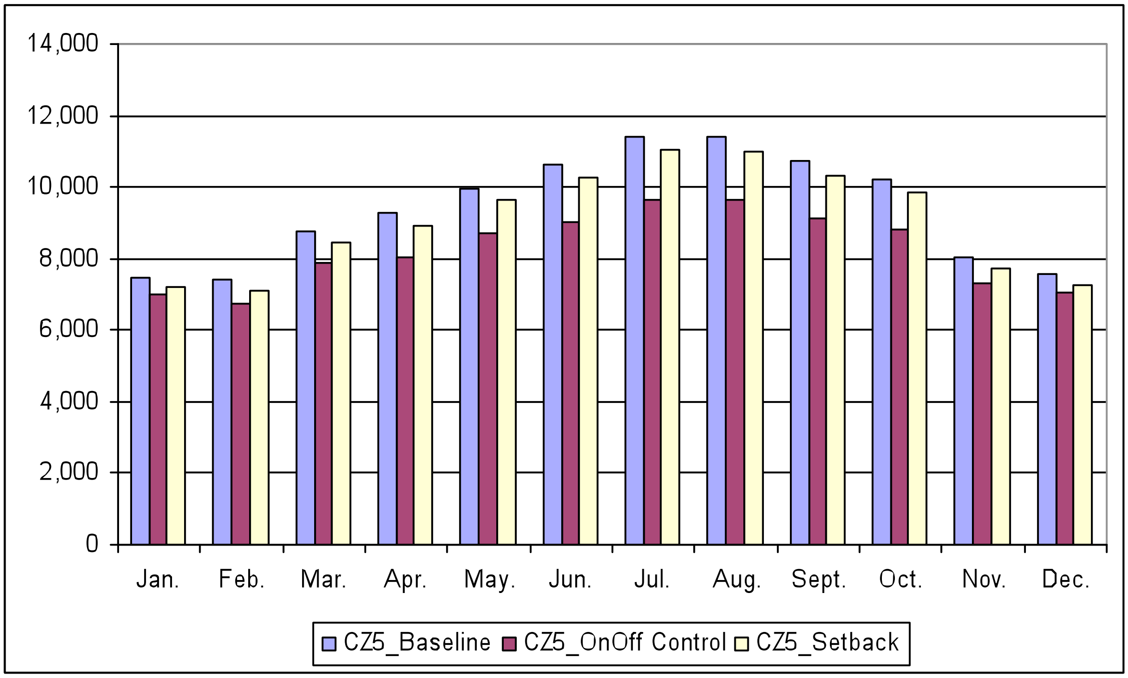


Figure C-15: Monthly Electricity Use (kWh), Climate Zone 5, 450 ft^2 Rooms

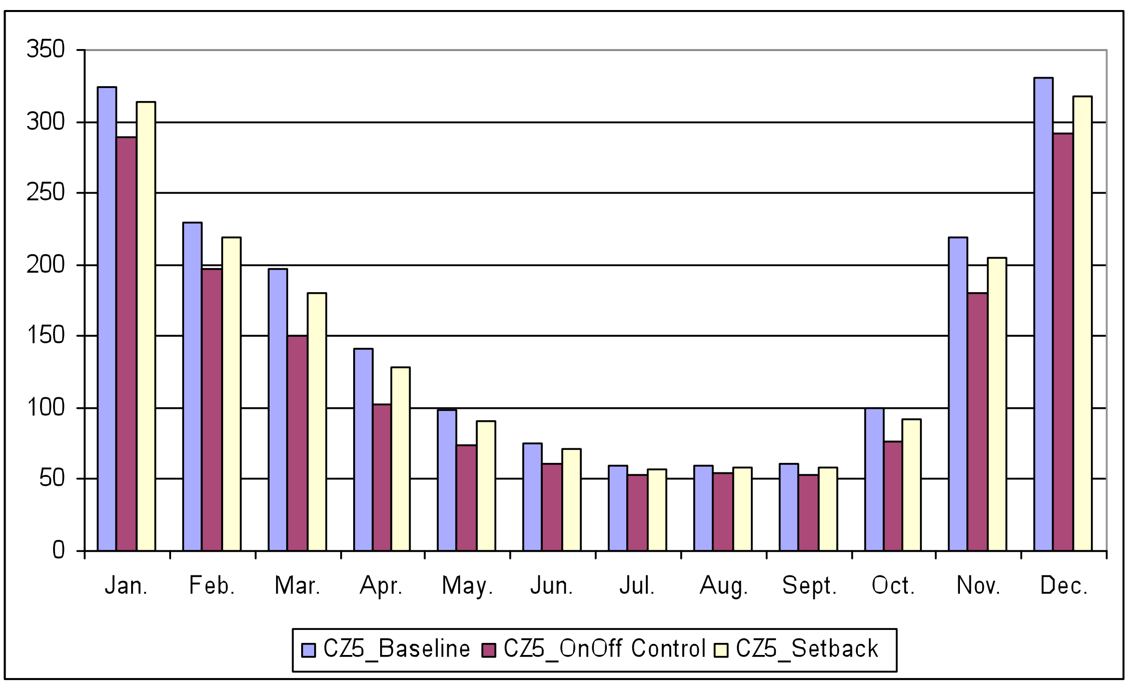


Figure C-16: Monthly Gas Use (therm), Climate Zone 5, 450 ft^2 Rooms

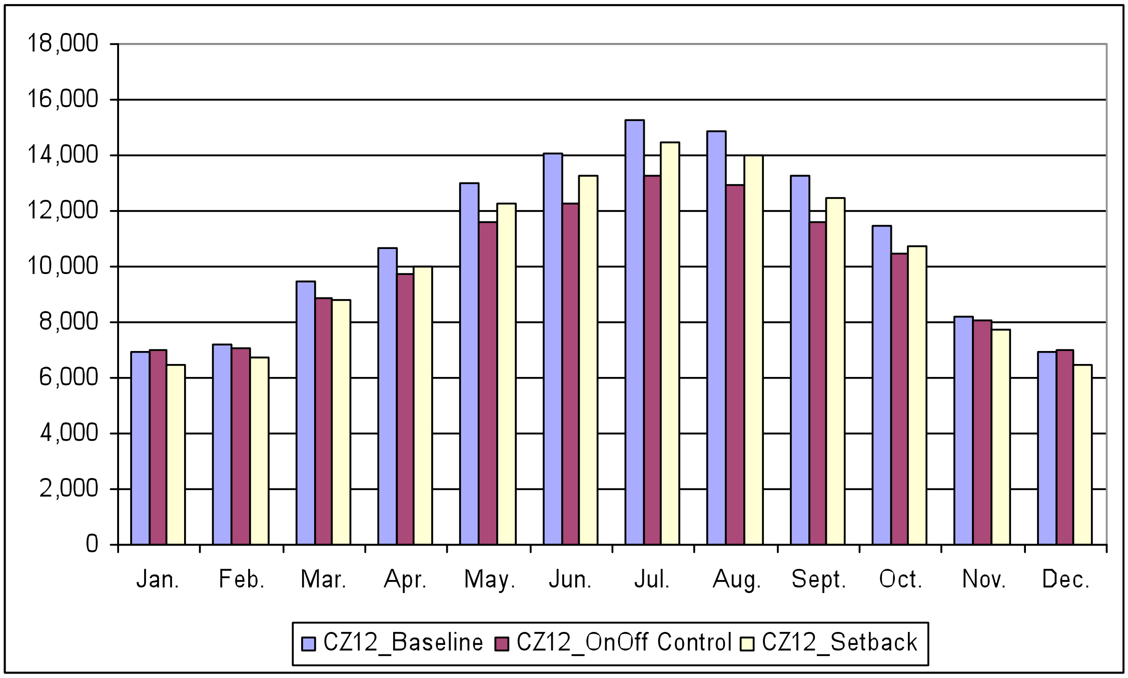


Figure C-17: Monthly Electricity Use (kWh), Climate Zone 12, 450 ft^2 Rooms

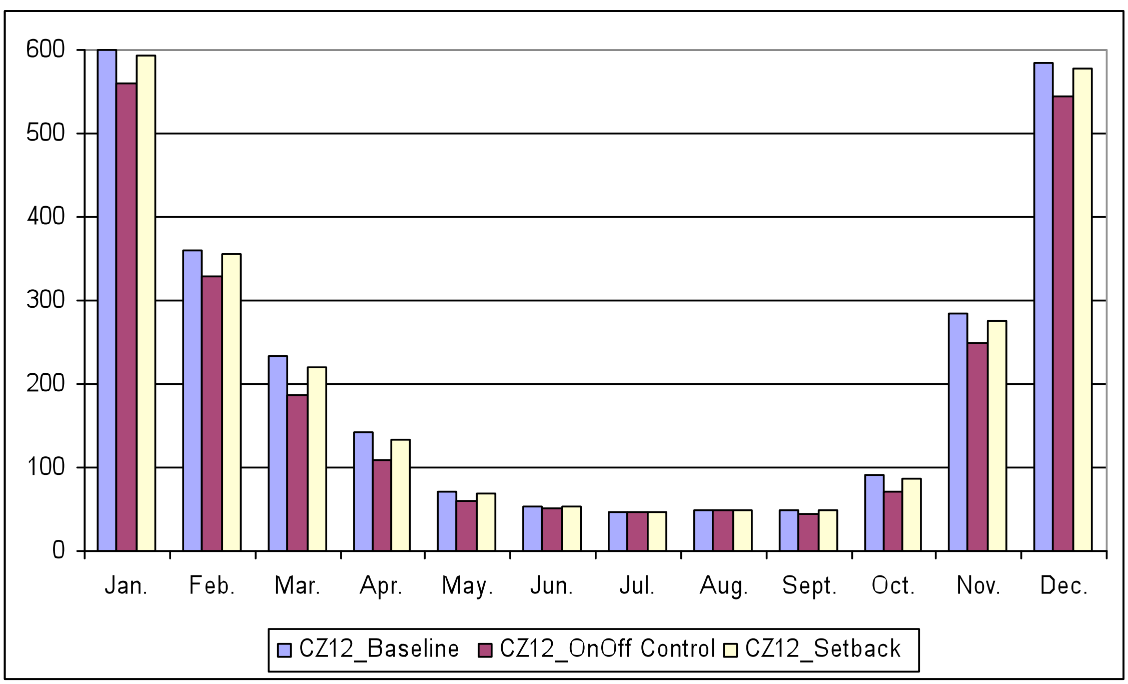


Figure C-18: Monthly Gas Use (therm), Climate Zone 12, 450 ft^2 Rooms

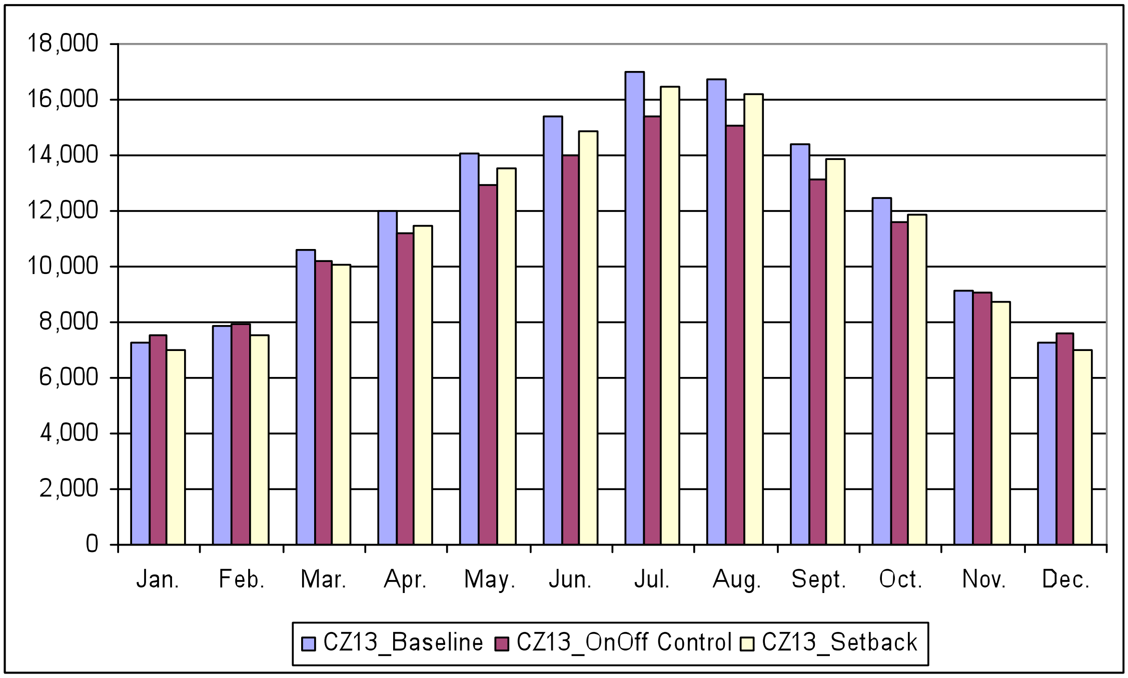


Figure C-19: Monthly Electricity Use (kWh), Climate Zone 13, 450 ft^2 Rooms

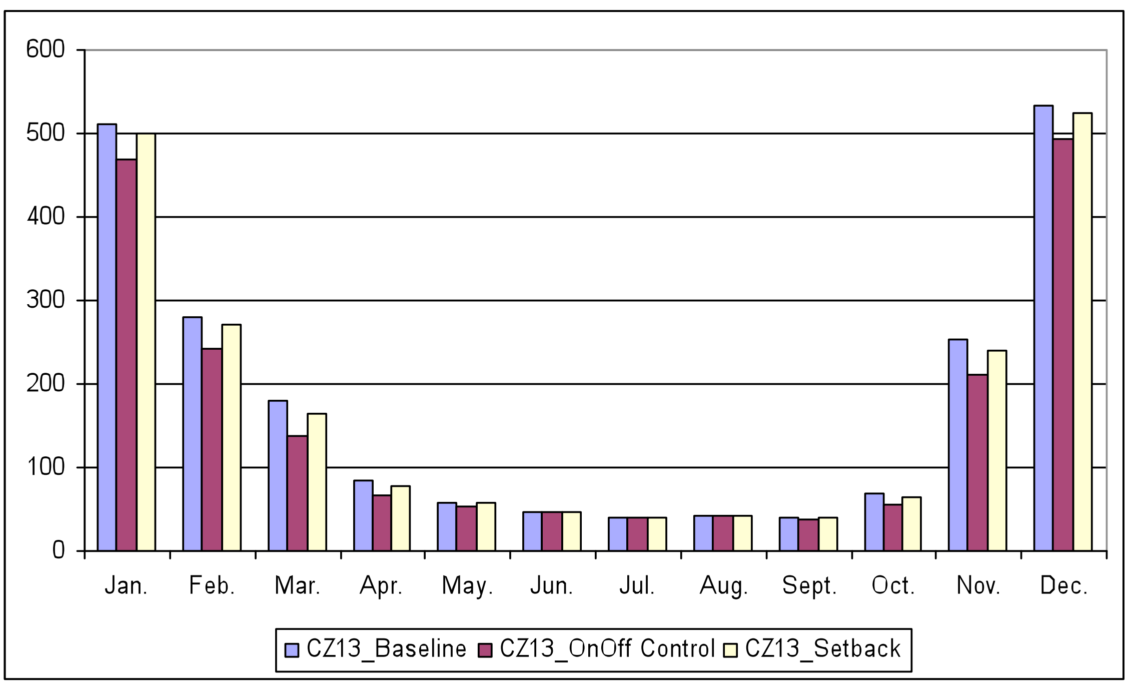


Figure C-20: Monthly Gas Use (therm), Climate Zone 13, 450 ft^2 Rooms