Performance Analysis of Hotel Lighting Control System

Erik Page and Michael Siminovitch,
University of California, Davis, California Lighting Technology Center[1]

ABSTRACT

The Lighting Control System (LCS), a wall switch occupancy sensor, was designed with two key features to save energy while maintaining hotel guest acceptance of the system. First, based on a detailed analysis of user patterns, the LCS was programmed with a much longer timeout setpoint than traditionally used. Second, when the bathroom luminaire is turned off, the LCS provides an LED nightlight that is automatically activated. Researchers established detailed criteria to determine representative hotel rooms in the Sacramento area, and selected the Doubletree Hotel as its test site. Hobo light state loggers were installed in 15 rooms and collected data for at least two months. Data was downloaded from the loggers, LCSs were installed in the bathrooms, and the loggers continued to record use for an additional two months. The researchers planned to determine (1) the average burning hours per day before and after installation of the LCS; (2) the effect of the LCS on decreasing long burning periods; (3) the extent to which the reduction of long burning periods contributes to energy savings; and (4) how the LCS change the usage profile as a function of time of day. Analysis of the pre- and post-installation data allowed researchers to gain insight into bathroom luminaire usage patterns in the rooms, and to determine an energy savings of approximately 46 percent with the use of the LCS.

Introduction

Lawrence Berkeley National Laboratory (LBNL), the Sacramento Municipal Utility District (SMUD), Doubletree Hotels, and The Watt Stopper, Inc., formed a partnership to study a new energy-efficient lighting control system under the PIER Lighting Research Program. This report describes the details and results of this study, which had the objective of evaluating the performance of this new lighting control system.

The new Lighting Control System (LCS) is a wall switch occupancy sensor that has been designed specifically for hotel environments to save energy while providing users a higher level of lighting amenity. The LCS has two key features that make it ideally suited for placement in hotel guestroom bathrooms. The first feature is that the LCS is preprogrammed with a timeout setpoint that is significantly longer than what is typically used by occupancy sensors. Findings from prior research conducted by LBNL and The Watt Stopper, Inc. suggested that most of the energy used by hotel bathroom luminaires is from the relatively infrequent periods when they are left on for very long periods of time (i.e. greater than four hours). By utilizing longer timeout setpoints (one hour for the LCS), these long periods can be eliminated while greatly minimizing the chances of generating "false offs" in which the lights turn off when there is a guest in the bathroom.

---

[1] At the time of this study, the authors were staff researchers at the Lawrence Berkeley National Laboratory (LBNL). They have subsequently left LBNL to establish the California Lighting Technology Center at UC Davis.

The second key feature of the LCS is a built-in LED nightlight that automatically turns on whenever the bathroom luminaire is turned off. Prior research also suggested that a small but significant amount of the extended period usage of the bathroom luminaires occurred during nighttime hours. It is thought that these periods represent the hotel guests purposely leaving the bathroom luminaire on as a nightlight when they retire for the evening. The nightlight feature of the LCS has the potential to provide adequate illumination for guests to navigate at night while using only a fraction of the energy of the bathroom luminaire.

LBNL researchers measured the lighting use in 15 guest bathrooms in the Doubletree Hotel in Sacramento, California, over an eight-month period, gathering a minimum of two months of pre-retrofit LCS (baseline) and two months of post-retrofit LCS data from each room. The average savings from the LCS measured from this study was found to be 46.5 percent, though this result was likely limited by a number of factors including the hotel's baseline condition and the occupancy rates of the rooms measured. A conservative estimate of expected savings from the LCS for the hotel industry as a whole is 50 percent. Overall, guests responded very favorably to the LCS, appreciating the effect of the nightlight.

Test Plan

The following section describes the steps taken to identify the practical advantages and disadvantages of using this system. This includes the selection of test rooms, data collection for the baseline condition, installation of the LCS devices, and data collection of the post-LCS condition.

Choose Representative Hotel Rooms

It was considered critically important to the study to select test rooms that were both representative of the hotel as a whole, and also representative of "typical" hotel rooms. Part of the criteria for selecting the Doubletree Hotel in Sacramento as the test site was that it was considered to contain a wide variety of typical rooms. The hotel was built in the 1970s in several phases and, consequently, its bathroom layouts and fixtures vary widely throughout the hotel. It is mainly a business hotel, but 25 percent of the rooms are rented long term by an airline and are used for flight crews to rest. These factors may affect the test results in that (1) different layouts may affect the user's preference, and (2) flight crews have different schedules than ordinary travelers. Considering these factors, LBNL selected 15 rooms that cover different conditions (different bathroom layouts, and flight crew/no flight crew occupancy), so that the results of this study could be more widely applied.

Install Data-Logging Equipment

LBNL researchers went to the Doubletree Hotel to initialize and install Hobo light state loggers. These loggers are installed close to the luminaires and record every time the lights are switched on or off. These loggers needed to be carefully installed and calibrated in order to be sensitive enough to register the switching of the bathroom luminaire, but not so sensitive as to register the usage of other lighting in the area, such as heat lamps that were present in many of the spaces. The loggers can hold a maximum of 2007 data points, which normally represents about four months of data. The data can then be downloaded into a text file to be analyzed. Table 1 shows a sample of the Hobo light state logger output data.

Table 1. Sample Output from Hobo Light State Loggers

Date	Time OFF (0) /	ON (1)
10/04/02	18:59:59.5 /	ON
10/04/02	19:24:43.5 /	OFF
10/04/02	22:10:25.0 /	ON
10/04/02	22:23:41.0 /	OFF
10/05/02	05:38:39.0 /	ON
10/05/02	08:23:17.5 /	OFF
10/05/02	13:10:01.0 /	ON

The majority of the rooms were fit with a single logger. However, in five rooms three loggers were installed. This was done to ensure the accuracy of the loggers by allowing for data crosschecking between the various loggers.

Baseline Data Collection

After the loggers were installed for at least two months, LBNL researchers went to the Doubletree Hotel to download the data from the loggers. These data represent the baseline data without the LCS. The loggers were then reinitialized and relaunched in anticipation of data collection of the post-LCS period. (For data logging periods in which the loggers recorded both baseline and post-LCS data, the data files were manually parsed at the end of the logging period based on the installation date of the LCS.)

Install Lighting Control System (LCS)

After downloading the baseline data, the LCSs were installed by the Doubletree Hotel engineering staff. The installation process involved removing the existing bathroom luminaire wall switch and wiring in the LCS in its place. These installations generally took about 15 minutes each. The LCSs were preprogrammed with the 1-hour timeout set point and thus needed no additional programming during installation.

Post-LCS Data Collection

After the loggers operated for an additional two months following installation of the LCS, LBNL researchers again went to the Doubletree Hotel to download the data from the loggers. This is the post-LCS data.

Performance Analysis

Five of the 15 original test rooms were logged with redundant loggers. These five rooms each had three loggers measuring the bathroom luminaires during testing, allowing for a cross comparison of data. While most of the data from the 10 rooms with single loggers appeared to be valid, some of them clearly had errors. This led to a decision to base the overall analysis of the LCS on data gathered from the five rooms with redundant loggers. This decision was based primarily on the facts that (1) it was very difficult to separate valid from invalid data in the single logger rooms with a high level of certainty, and (2) the data from the five redundant rooms provided a statistically significant data set. Therefore, the analysis presented below is based on data just from these five rooms. For the purposes of gathering as many data points as possible and to ensure uniformity between the test rooms during the study, these five rooms were kept at near 100 percent occupancy during the study.[2]

It should be stressed that while the analysis was limited to data from these five rooms, the overall data set is still very large. It is also important to note that monitoring hotel rooms is very different from monitoring other types of spaces because the occupants change so frequently. The real "sample" in this study is not the number of rooms but the number of room-days or occupant-days. Since all five of the rooms were monitored for at least two months in both baseline and post-LCS cases, data from these rooms represent over 300 room-days (5 rooms * 60 days) of data. Additionally, as the average stay in a business hotel is one to two days, the data collected represent the usage patterns of approximately 400 unique guests (or data points) over the duration of the test. To get a statistically significant sample, researchers like to typically get 30 to 60 independent data points.

The primary objective of this study was to answer the following questions.

- What are the average burning hours per day before and after installation of the LCS?
- To what extent does the LCS eliminate the long burning periods?
- To what extent does the reduction in long burning periods contribute to energy savings?
- How does the LCS change the usage profile as a function of time of day?

Answering these questions should give an initial indication of the effectiveness of the LCS and perhaps provide broader insights into the potential usefulness of the device.

Average Burning Hours per Day

Table 2 shows the average usage data. The average burning hours per day for each of the five rooms were between four and five hours before installation of the LCS, while this number decreased to 1.5 to three hours after installing the LCS. In an "average" room, the luminaires were generally left on for 4.4 hours every day without the LCS, while this number decreased to about 2.4 hours with the LCS. The overall reduction is 46.5 percent.

Table 2. Average Burning Hours per Day

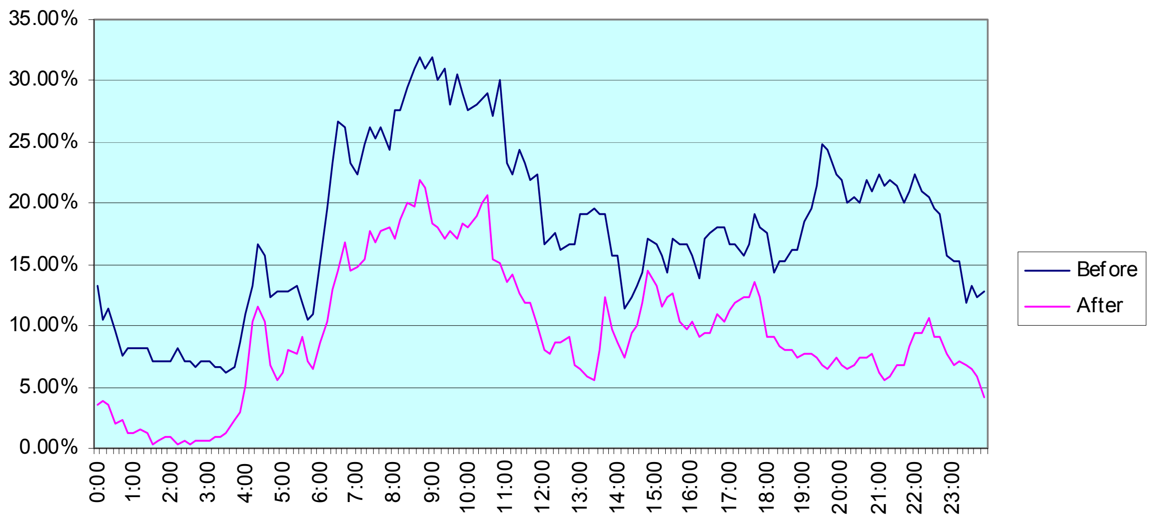
Room #	**Average**	**210**	**215**	**242**	**588**	**616**
Hours – baseline	4:25:33	4:09:54	4:30:27	4:18:35	5:00:17	4:08:33
Hours – post-LCS	2:22:02	3:00:02	2:22:19	2:12:43	1:30:48	2:44:17
Reduction (%)	46.5	28.0	47.4	48.7	69.8	33.9

[2] The overall effect of occupancy rates on the energy savings of the LCS will be touched on further in the analysis later in this report.

Usage Profile as a Function OF Time of Day

Figure 1 looks at the same set of data and shows when, on average, the bathroom luminaires were operated during both the baseline and the post-LCS periods. Both cases experience peak usage in the morning, but the LCS reduced both the amplitude and duration of this peak. In the evening, the usages for the post-LCS are less than half of the baseline; after midnight the usages for the post-LCS cases were reduced even more, as they approached zero. During the peak load period, from noon to 6 p.m., an average of approximately 40 percent energy savings was obtained.

Figure 1. Usage Profile As A Function Of The Time Of Day



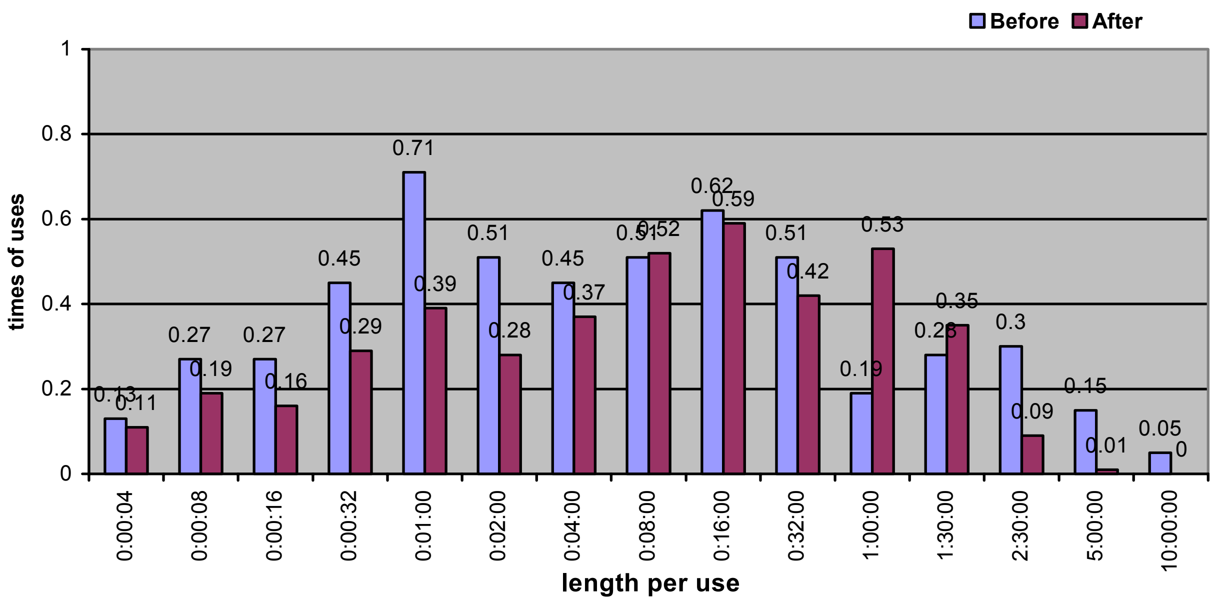
Reduction of Long Burning Uses

The LCS saves energy by reducing the time of operation of the bathroom luminaires. With its preprogrammed timeout set to one hour, the LCS should eliminate most of the long-burning uses, which, though infrequent, consumed a significant amount of energy. Figure 2 presents a comparison of the usage pattern profile that demonstrates the length of burning for each use. It shows, on average, how frequently the luminaires were used for a given length of time each day. For example, the bars for 0:16:00 indicates that the luminaires on average are turned on greater than 16 minutes and less than 32 minutes for only 0.62 times per day. Interesting points demonstrated by Figure 2 are:

- Uses with burning lengths greater than 2.5 hours were reduced significantly by the LCS. Eighty percent of the uses falling in this interval were eliminated. The number of uses per day with durations greater than 2.5 hours was changed from 0.50 to 0.10, a reduction of 0.40.
- Uses with burning lengths between one hour and 2.5 hours increased. The number of uses in this interval was changed from 0.47 to 0.88, an increase of 0.41, which was approximately the reduction from 2.5+ hours. Intuitively, this is a direct effect of the LCS cutting the long burning uses into shorter ones.

- Uses with burning lengths up to one hour decreased slightly. This is an interesting finding because uses less than one hour should not have been affected by the occupancy sensors timeout of one hour. One possible explanation of this result is that the night light on the LCS provides enough light for some functions allowing the user, on average, to turn on the bathroom luminaire less frequently.
- The average number of uses per day can be found by adding up all the bins in Figure 2. This results in a finding that the baseline has an average of five uses a day while the LCS yields an average of four uses a day. This result goes against conventional wisdom that occupancy sensors tend to increase the number of switches encountered by a luminaire, but does seem consistent with the theory above that the presence of the nightlight may at times eliminate the number of uses of the bathroom luminaire. Although this finding has little effect on the energy consumption, it shows an unexpected usage pattern change caused by the LCS, which may actually suggest a further maintenance advantage as a reduced number of switches a day should have a positive impact on lamp life.

Figure 2. Frequency on an Average Day



Energy Saving Benefit from Reduction of Long Burning Uses

Findings from prior research conducted by LBNL and The Watt Stopper, Inc. suggested that most of the energy used by hotel bathroom luminaires is from the relatively infrequent periods when the luminaires are left on for very long periods of time. This result was reinforced by the current data. Figure 3 shows the frequency and energy used for the given length of burning before installation of the LCS. The frequency has a similar meaning as in Figure 2, except Figure 3 data is presented as a percentage instead of an absolute number. The total time represents the percentage that the ON periods from each time interval contributed to the total operating time of the luminaire. The energy usage is directly related to the total time, as it is merely the product of the total time and the wattage of the luminaire. Figure 3 shows that while the bathroom lights are left on for longer than 2.5 hours only 9.5 percent of the time, these longer burning periods account for 65 percent of the fixture's energy consumption.

Figure 3. Frequency vs. Energy (Baseline)

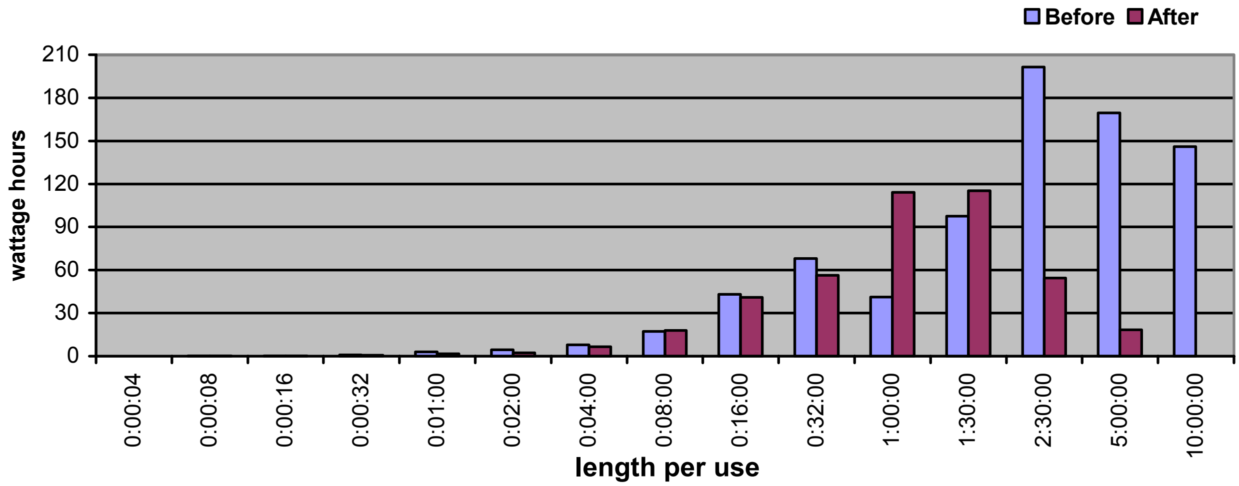


Figure 4. Energy on an Average Room-Day

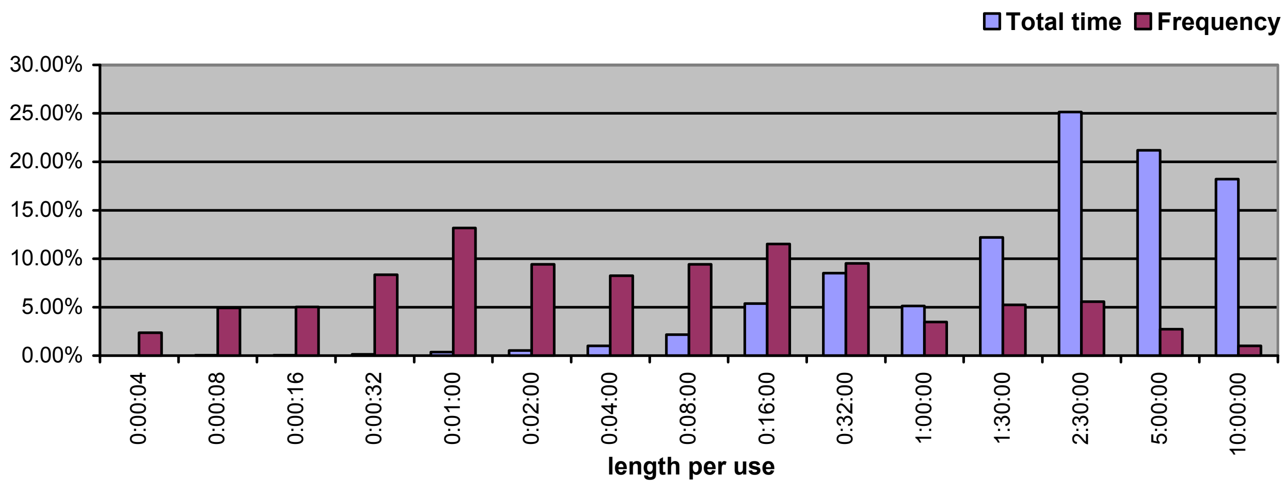


Figure 4 presents the overall energy savings generated by the LCS. Using the average luminaire power of 180W, Figure 4 shows average room-day energy consumption for both before and after installation of the LCS. For time durations greater than 2.5 hours, the energy savings were significant at 86 percent. The energy consumption between one hour and 2.5 hours increased about 56 percent. The total energy savings were 46.5 percent, which is consistent with the analysis of average burning hours per day.

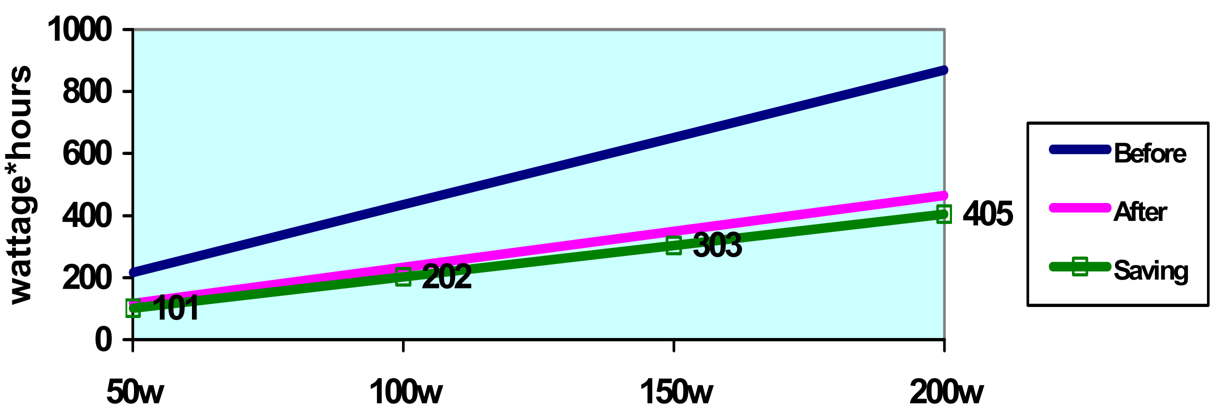
Discussion

The analysis above provides a great deal of insight into the usage patterns and energy savings at the Sacramento Doubletree Hotel. The next step is to determine how these results relate to the hotel industry as a whole. There are many different types of hotels (business, vacation, conference, etc.) with a variety of baseline conditions that may affect the specific LCS savings at any given site. In this section several baseline factors, such as baseline usage and hotel occupancy rates, will be discussed. Finally, a brief discussion of customer feedback is included.

Baseline Conditions

Connected load. The energy savings produced by the LCS are largely dependent on the load or watts (W) of the existing bathroom luminaire. This can range from under 50 W for a single fluorescent lamp to well over 200 W for an incandescent vanity luminaire. Figure 5 demonstrates what energy reduction is represented by a 46.5 percent reduction in operating hours for luminaires of various wattages. The average load in the rooms at the Doubletree was 180 W, yielding savings of approximately 360 W-hours per day per room. Obviously, larger loads would result in greater energy savings from the LCS, which would produce shorter paybacks for the cost of purchasing and installing the LCS.

Figure 5. Energy Savings for Different Wattage Luminaires



Baseline hours of operation. Another variable that has a substantial effect on the energy savings and payback for the LCS is the baseline hours of operation of the bathroom luminaire. The average of 4.4 hours per day found in this study is significantly lower than that of previous LBNL studies that had found up to eight hours per day at vacation hotels. Hotel industry sources have indicated that these findings are consistent with their experience. Vacation hotels tend to have more occupants spending more time in the hotel rooms than do business hotels. This leads to longer baseline hours of operation for the guestroom luminaires. This difference in baseline hours is significant, as a doubling of the baseline hours could result in cutting the payback for the LCS in half.

The most accurate method to document LCS energy savings potential in the hotel industry as a whole would be to monitor the usage patterns of many different hotels. Baseline data and post-LCS installation data from each site could be compared to gather averages and trends. As this was not practical for this study, LBNL performed an estimate of the LCS energy savings potential for vacation hotels based on a dataset obtained in a previous study. The discussion is presented below and is not intended to conclusively state what the expected savings in vacation hotels would be. However, it is meant to serve as an approximation of the potential savings at such sites.

Table 3 shows the process of the estimation. This table includes data from the bin analysis discussed previously in Figure 2, as well as "prior data" from the previous vacation hotel study. The savings potential (column 1) represents the energy savings that the LCS was found to generate for each use period at the Doubletree Hotel. By multiplying this savings potential (column 1) by the baseline energy consumption (column 2) that was found for each bin, the energy savings generated by the LCS can be calculated (column 4). If the assumption is then made that the savings potential (column 1) of the LCS is independent of hotel, then for any hotel in which a breakdown of baseline usage is available, the energy savings can be estimated.

Table 3. Energy Savings Estimate for Vacation Hotel Baseline Data Set

Length per use		**Savings Potential**	**Energy consumption percentage before installing the LCS**		**Energy Savings**	
			Current data	**Prior data**	**Current data**	**Prior data**
		(1)	**(2)**	**(3)**	**(4)=(1)*(2)**	**(5)=(1)*(3)**
Sec	4	18.44%	0.00%	0.00%	0.00%	0.00%
	8	25.52%	0.02%	0.01%	0.00%	0.00%
	16	43.50%	0.04%	0.02%	0.02%	0.01%
	32	35.56%	0.13%	0.07%	0.05%	0.02%
Min	1	44.83%	0.38%	0.22%	0.17%	0.10%
	2	46.55%	0.55%	0.41%	0.26%	0.19%
	4	18.01%	1.00%	0.62%	0.18%	0.11%
	8	-4.74%	2.15%	1.37%	-0.10%	-0.07%
	16	4.55%	5.37%	3.51%	0.24%	0.16%
	32	17.29%	8.50%	5.86%	1.47%	1.01%
Hour	1	-96.40%	11.85%	10.41%	-11.42%	-10.03%
	2	41.26%	18.29%	14.38%	7.55%	5.93%
	4	92.27%	29.68%	24.62%	27.38%	22.72%
	8	88.00%	11.89%	20.14%	10.46%	17.72%
	16	100.00%	10.14%	18.35%	10.14%	18.35%
Overall					**46.40%**	**56.24%**

Essentially, this assumption allows for various hotels to have different usage profiles, but calculates the percentage reduction of each of the bins by the introduction of the LCS to match that found at the Doubletree. The energy savings estimate (column 5) of the prior data (column 3) can then be found by multiplying those data by the savings potential (column 1).

This analysis yields the overall result that the energy savings for the current data set is about 46 percent, while for the prior data set it is about 56 percent. This increase in savings is primarily due to the higher percentage of energy consumption by the prior dataset in the five and 10 hour usage bins. This result is noteworthy because not only does the absolute energy savings increase simply because the baseline is larger, but the savings percentage actually increases due to changes in the usage pattern.

LCS Timeout Delay

While the LCS can be programmed with various timeout delays, all of the units used in this study were set to one hour. The effective increase in energy savings from a shorter timeout delay, such as 30 minutes, would be useful to explore. Again, the more accurate method of determining this result would be to monitor a statistically significant number of rooms with shorter timeout delays and compare the results. Unfortunately, this also was not practical during the current study. The data from this study did allow for a first order approximation of increased savings from shorter timeout delays.

A detailed analysis of the data found that decreasing the setpoint to 30 minutes would have only a modest effect on the overall savings of the LCS. This analysis found that, depending on the assumptions made, dropping the setpoint from one hour to 30 minutes would only result in overall energy savings of an additional 1 to 4 percent. Based on this result, it certainly appears that the modest increase in energy savings would not justify the hotel guest complaints from increased "false offs" that would be the likely result of changing the LCS timeout delay from one hour to 30 minutes.

Occupancy Rates

The effect of the occupancy rate on the energy savings potential of the LCS was not studied directly. It was determined early in the study that the Doubletree Hotel could not provide LBNL with the desired information on the actual occupancy information for each test room during the test period. Thus, LBNL was required to make the assumption that on the days in which the bathroom light was never used the room was unoccupied. Because of the uncertainty of this method of estimating occupancy and the desire to maximize the number of data points, the hotel staff was asked to keep the study rooms at an occupancy rate of 100 percent for the duration of the study in order to maximize the number of data points.

The relationship between the occupancy rate and the LCS savings and usage patterns clearly would be useful to know. While the current data set does not contain enough information to fully characterize this relationship, it does provide some clues. Four of the study rooms were kept very near the 100 percent occupancy rate requested, but one of the rooms (#588) had an occupancy rate near 80 percent for both the baseline and post-LCS periods. Interestingly, room #588 was found to have a larger baseline and a smaller post-LCS period than any of the other four rooms, with energy savings of nearly 70 percent vs. 46.5 percent from the overall average (see Table 2). A closer look at the data from this room suggests that this result may not be a coincidence, but rather the effect of the room's increased vacancy. During the baseline period, the bathroom luminaire will remain in the state in which the guest or housekeeper left it until the room is visited again. Thus, a luminaire that is left on prior to a period of vacancy will generate a very long "on" period. Even if these occurrences are extremely rare, these "super-usages" will have a significant impact on the energy usage of the luminaire. But in the post-LCS period, the super-usages will never occur. This appears to be the difference in room #588. While there are not enough data to calculate the numerical effect of occupancy on the LCS energy savings, data from room #588 give a strong indication that there is such an effect. As the industry average occupancy rate is even lower than that of room #588 (65 percent vs. 80 percent), this remains a very important open question that merits further investigation.

Customer Feedback

The Doubletree Hotel staff collected informal user feedback on the LCS. Production, placement, collection, tabulation and analysis of a formal user survey placed in the guestrooms was determined to be impractical. Still, significant feedback was obtained from guest interactions with the hotel's customer service representatives and engineering staff. The initial response from hotel guestroom users has been almost uniformly very positive. This is noteworthy because typically the only feedback the hotel staff receives when making changes to the guestrooms is complaints. However, the staff has already received a number of complimentary comments regarding the unit's nightlight feature.

Report Conclusions

As a result of (1) the collaboration established between LBNL, The Watt Stopper Inc., SMUD and the Doubletree Hotel; (2) the LCS units and logging equipment installed at the hotel test site; and (3) the quantitative methodologies described in this report, the LCS was found to significantly reduce energy usage in hotel guestroom bathrooms. The average savings from the LCS measured from this study was found to be 46.5 percent, though this result was likely limited by a number of factors including the hotel's baseline condition and the occupancy rates of the rooms measured.

A conservative estimate of expected savings from the LCS for the hotel industry as a whole is 50 percent. Based on a hotel's current baseline (hours/day), the bathroom luminaire wattage, and the final cost of the LCS, a conservative payback based on 50 percent savings can be easily calculated. The LCS timeout delay of one hour was found to effectively limit long periods of operation without adversely effecting guest comfort. Decreasing the LCS timeout would only slightly increase energy savings, but may adversely affect guest comfort. Overall, guests responded very favorably to the LCS, appreciating the effect of the nightlight.