Quantifying Behavior Driven Energy Savings for Hotels

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ABSTRACT

Hotel facilities present abundant opportunities for energy savings. In the United States, there are around 25,000 hotels that spend on an average of $2,196 on energy costs per room each year. This amounts to about 6% of the total annual hotel operating cost. However, unlike offices, there are limited studies on establishing appropriate baselines and quantifying hotel energy savings given the variety of services and amenities, unpredictable customer behaviors, and the around-the-clock operation hours. In this study, we investigate behavior driven energy savings for three medium-size (around 90,000 sf^2) hotels that offer similar services in different climate zones. We first used Department of Energy Asset Scoring Tool to establish baseline models. We then conducted energy saving analysis in EnergyPlus based on a behavior model that defines the upper bound and lower bound of customer and hotel staff behavior. Lastly, we presented a probabilistic energy savings outlook for each hotel. The analysis shows behavior driven energy savings up to 25%. We believe this is the first study to incorporate behavioral factors into energy analysis for hotels. It also demonstrates a procedure to quickly create tailored baselines and identify improvement opportunities for hotels.

INTRODUCTION

A number of studies show great variations in energy use in the hotel sector. With such variation, it is difficult to compare and rank hotels based on whole building performance alone. The variation also challenges hotel owners and managers when they try to determine if their hotel(s) are performing optimally amongst their peers. For example, Energy Star's data trend report published in October of 2012 [1], "Energy Use in Hotels," shows energy use intensity (EUI) ranges from less than 100 to more than 800 kilo-Btu per square foot across all hotel buildings. In addition, hotels in the 95th percentile use quadruple the amount of energy as those in the 5th percentile. The Lawrence Berkley National Laboratory, Department of Energy funding provides a public building performance database [2] that presents the energy related characteristics of commercial and residential buildings. According to the database, the hotel industry's mean annual site energy use per unit area is 200.18 kBTU per square foot (631.5 kWh per square meter). The energy use recorded in the database ranges from 10 to 1200 kBtu per square foot. There is greater variation in energy intensity among the hotels in the Lawrence Berkley National Laboratory database when compared to the Energy Star Portfolio database. The large variation in energy intensity can be attributed but not limited to the difference in operations, services provided, equipment used, building construction, and variations in climate.

In the United States, around 25,000 hotels (excluding motels) spend on average over $2,196 on energy bills, per available room per year. This amounts to approximately 6% of the total annual hotel operating cost. The variety of services and amenities provided to hotel guests and the around-the-clock operation hours present abundant opportunities for energy savings and unique challenges at the same time. Many smaller or older hotels lack advanced building automation systems. Very few real-world studies exist in the literature on the monitoring and analysis of hotel energy efficiency. The objective of this study is to employ DOE's Building Energy Asset Scoring Tool (AST) [3] to make an assessment of energy efficiency of hotel buildings and customize savings through integration of statistical behavior models.

CURRENT STATE-OF-ART OF ENERGY DRIVEN BEHAVIOR STUDIES IN HOTELS

The behavior and occupancy patterns of staff and guests greatly affect the daily operation and energy performance of hotel buildings. A 2009 study on hotel buildings in Singapore found that worker density was highly correlated to hotel building energy use intensity [4]. A 2012 study in Taiwan found that occupancy rate was the most important variable for predicting the energy use in hotels [5]. The same study also found an interesting fact that guests from different regions had very different impact on energy consumption. For instance, guests from Taiwan and Mainland China are less correlated to the total energy consumption; but guests from North America and Europe are highly correlated to the total energy consumption. Due to the highly correlation between occupancy rate and energy consumption in hotels, occupancy-based HVAC, lighting, and plug load controls were recommended for hotel guest rooms starting from early 1990s'.

A European Commission study on hotel energy use in 1994 recommended three heating control mode based on occupancy – "occupied, unoccupied for certain periods, and unoccupied in winter" [6]. Since then, several studies have quantified the energy savings of occupancy-based (sensor or captive card key) HVAC and lighting controls with measured and/or simulated data [7-11]. On average, the occupancy-based controls can save 10 – 30% of HVAC energy and 62% of lighting energy in hotel guest rooms.

Other behaviors of staff and guests may also impact the energy consumptions of hotel buildings. Some simple management tactics can help reduce energy consumption, such as increasing the awareness of sustainability for hotel staff (check on temperature settings, turn off lights, etc.) [12]. However, the authors did not find any quantified energy savings associated with those behaviors.

METHODOLOGY

The overall methodology we used to calculate the potential behavior driven energy saving for hotel is shown in Figure 1 below. First, we used the DOE Asset Score tool to develop baseline energy consumption and identify possible saving opportunities under standard operating conditions. Second, we adjusted the baseline models based on actual hotel operation and occupancy in reference to their utility bills. Third, we conducted energy saving analysis in EnergyPlus based on a behavior model that defines the upper bound and lower bound of customer behavior and hotel staff behavior. Lastly, we estimated a probabilistic energy savings outlook for each hotel.

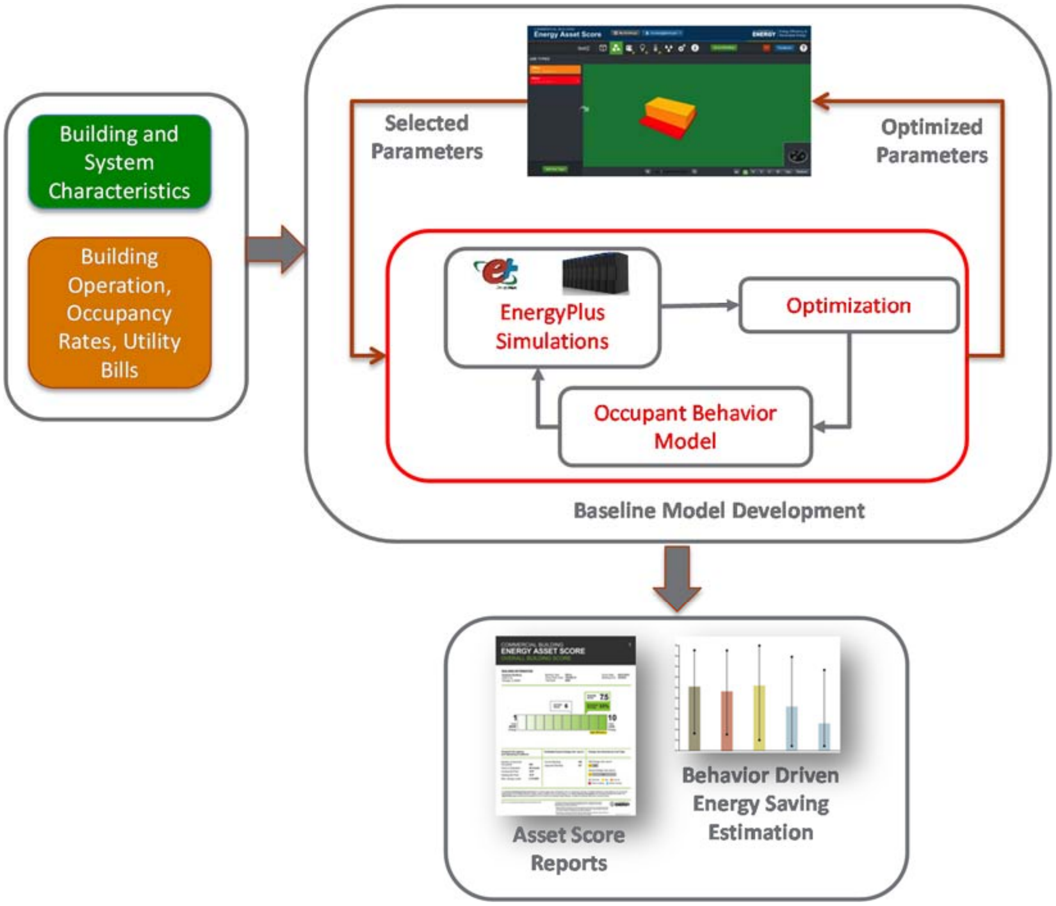


Figure 1 Overview of the Methodology

COMMERCIAL BUILDING ASSET SCORING TOOL

The Asset Score enables building owners and managers to evaluate the as-built physical characteristics of a building's contribution to their overall energy efficiency, independent of occupancy and operational choices. The physical characteristics evaluated include the building envelope, the mechanical and electrical systems, and other major energy-using equipment, such as commercial refrigeration. The Asset Score is generated by simulating building performance under a standard set of typical operating and occupancy conditions. By focusing only on a building's physical characteristics and removing occupancy and operational variations, the system allows "apples-to-apples" comparisons between differently operated buildings

The modeled source EUI is used to generate a building's Asset Score. Each building type has an associated 100-point technical scale (not a statistical scale). The calculated EUI is placed on a fixed scale for each building type and no baseline building is needed for the score calculation. The energy asset scoring scale is intended to reflect the current variability within the commercial building stock and allow for improved energy efficiency of both inefficient and high-performance buildings.

OCCUPANT BEHAVIOR MODEL

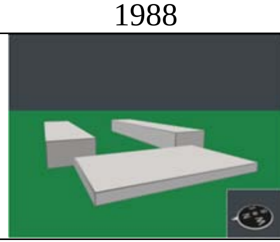
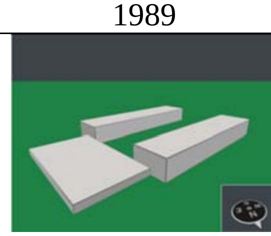
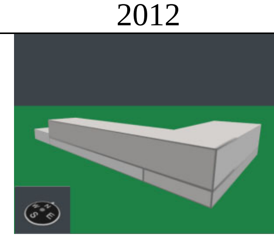
Previous studies in hotels indicated that occupancy rate plays a key role to the total hotel building energy consumption. However, none of the previous studies quantified the impacts of occupancy behavior. In this paper, we developed a model based on physics-based building model optimization to evaluate such impacts. Energy related occupancy behavior with the largest impact in hotels includes mainly turning on/off lighting, using plugs and adjusting thermostat. Typical small and medium-sized hotels lack advanced building automation system so that thermostat cannot be controlled remotely. Some hotels also do not have occupancy sensors so that they depend on customer or house keeping staff to turn down A/C set-points. Unfortunately, such behavior is almost impossible to capture.

Hence, we used an optimization method that uses simulations with the physics-based EnergyPlus model to capture such behavior. Since only monthly utility bills are available in this study, we included four unknown parameters: monthly average temperature set-point, *T_set_occ*, and plug usage factor, *P_occ*, for rented room, and monthly average temperature set-point, *T_set_unocc*, and plug usage factor, *P_unocc*, for un-rented room. Based on the occupancy rate, the hotel building is divided into three major blocks: common area, occupied room and un-occupied room. The unknown parameters are used as input schedules into EnergyPlus and minimize the difference between modeled and measured energy consumption using a genetic algorithm (GA).

DESCRIPTION OF CASE STUDIES

We picked three hotels in three difference climate zones and locations – Texas, Pennsylvania and Arizona – as case studies. Some basic information of each of the three hotels is shown Table 1 below:

Table 1 Overview of case studies

	Hotel A	Hotel B	Hotel C
Total floor area (ft^2)	85,158	78,418	96,384
Occupant rate (monthly average)	70%	68%	60%
Set-point for public area (F)	Heating: 66 Cooling: 72	Heating: 65 Cooling: 70	Heating: 65 Cooling: 70
Number of Rooms	149	149	158
Year Built	1988	1989	2012
Model in AST			

RESULTS AND DISCUSSIONS

RESULTS FROM ASSET SCORE TOOL

The Asset Scoring Tool (AST) was implemented in the preliminary energy study of three hotels located in various climate locations. In this study, the building type is “Lodging”. Information from hotel management, mechanical and architectural drawings was used to gather the input information required to perform the analysis. Mechanical and architectural drawings were referenced for equipment specifications, calculating window to wall ratios, total floor area, and structural materials. Adjustments had to be made for hotel geometry in the model to maintain the total floor of the actual space due to the limitations in the AST’s modeling tools. The hotel models in the AST were placed in the global position facing the direction as the actual buildings. The score generated is on a scale from 1 to 10. A “1” indicates that the building uses more energy and a “10” indicates that the building uses less energy operating at maximum efficiency. Along with the score, AST will make recommendations on possible cost effective upgrades to areas such as the building envelope, interior lighting, HVAC systems, and hot water systems. The structure and systems are also ranked as “Fair”, “Good”, and “Superior” to allow the user to identify the components most in need of attention.

Figure 2 shows the overall AST for three hotels: A, B and C. Hotel C, built in 2012, received the highest score and lowest potential energy savings due to a relatively new building envelope. Both hotel A and B have more than 25% potential energy savings in theory. Figure 3 shows the results from AST in terms of source energy use intensity by end use. Following path (1), hotel B uses twice as much energy for heating compared with hotel A, while it uses 25% less cooling energy following path (2). Compared to hotel A, hotel C uses 50% less lighting energy and 20% less cooling energy.

Table 2 shows cost-effective realistic upgrade opportunities for all 3 hotels. There are other recommended upgrades on the building envelope such as installing high performance windows, and adding roof/floor insulation, but these upgrades were not realistic after discussion with facility team due to ROI. In later sections, we will investigate in detail the actual energy savings likely to be realized given what the hotel is willing to upgrade and possible behavior changes.

Figure 2 Results from AST_Part1: Overall Score

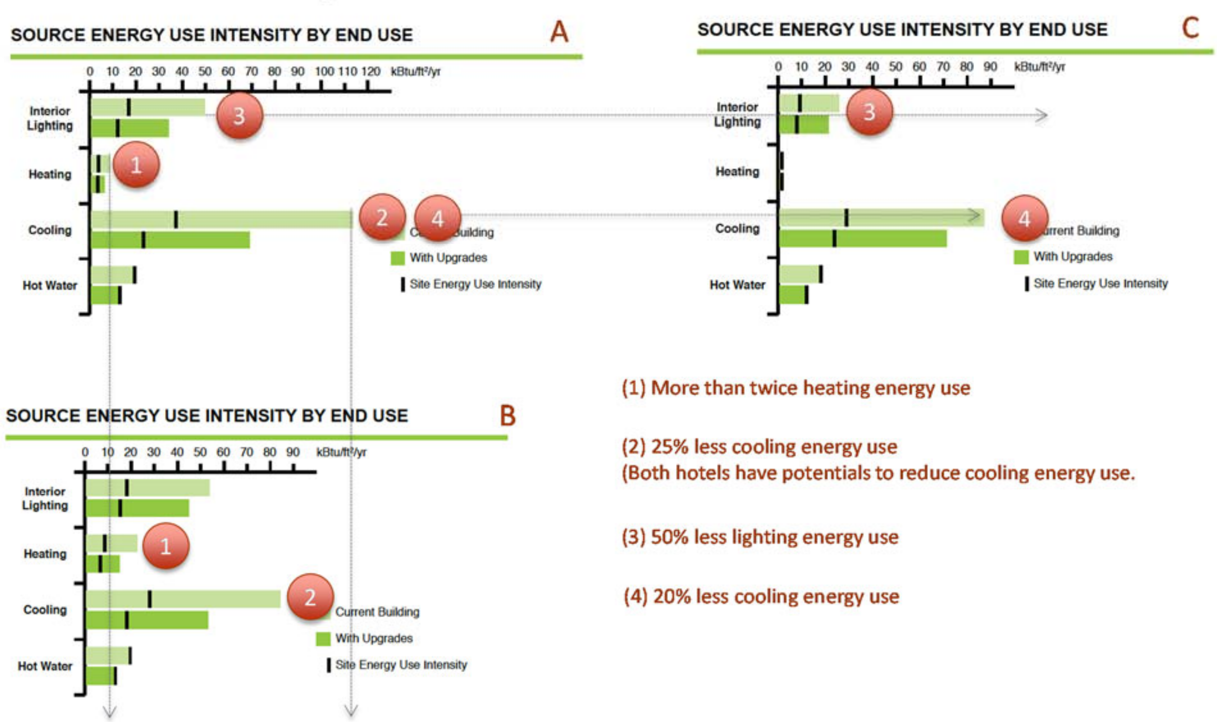


Figure 3 Results from AST_Part1: Energy Use and Building Systems

Table 2: Cost-effective Upgrade Opportunities

Upgrades	Energy Savings	Cost
Upgrade T8 with LED lighting for hotel A, B and C	Low	$$
Add air-side economizer in lobby/public area for hotel A, B and C	Medium	$-$$

RESULTS FROM BASELINE MODEL VALIDATION

Figure 4 shows the baseline model validation results in terms of percentage differences between measured and simulated whole hotel monthly energy consumption. The measured data is from monthly utility bills. Because AST cannot simulate swimming pools, simulated energy is less than the measured baseline particularly in the winter months. In winter months, swimming pool consumes more energy. However, this will not affect the analytical results of behavior impacts.

Figure 4. Results of baseline energy validation (without simulation hotel swimming pool)

RESULTS FROM BEHAVIOR DRIVEN ENERGY SAVINGS

In order to quantify the behavior impacts on total hotel energy consumption, we first need to understand the current operating schedules (e.g. temperature set-points for public area). After this analysis, we then selected cost-effective upgrades from Table 1 for three hotels. Finally, we estimated potential behavior improvements from staff and hotel guests. The details and results for all three hotels are below:

Common upgrades for hotel A, B and C:
1. Pick LED upgrade from results of Asset Score Tool, providing around 4% (hotel A), 6% (hotel B) and 3% (hotel C) energy savings;
Potential behavior impacts:

1. Behaviors on unoccupied rooms, providing additional 6%~8% (hotel A), 5% to 13% (hotel B) and 8% to 25% (hotel C) energy savings.

- Assume lights and electrical equipment are already off for unoccupied rooms
- Put setback temperature: Heating: 64 F; Cooling: 78 F for unoccupied rooms;

2. Assume minimum and maximum occupied room temperature behavior: Heating: 70F ~75F, Cooling: 72F~77F.

We will use hotel C as one example to explain energy savings. As shown in Figure 5, the 'baseline' refers to the calibrated model outputs from AST, which considers actual hotel operations. The "After Retrofit" is with LED upgrades. The behavior potential includes room temperature setbacks, and lighting and electrical equipment off in the unoccupied rooms. This behavior model resulted in additional 8% to 25% energy savings. The dotted lines of upper and lower bounds indicate the possible minimum and maximum energy savings due to unpredictable hotel guest behaviors.

This result provides not only a more accurate estimation of energy savings from equipment upgrades, but also potential savings from hotel staff behaviors (i.e., lighting controls and temperature setbacks in the unoccupied rooms). Some hotel rooms may have been equipped with occupancy sensors and HVAC controls; others may have energy efficiency management policies in place. By integrating behavior analysis, the data could reveal whether the expected savings have been realized, and what the range of potential energy savings might be after retrofit due to unexpected hotel guest behavior. Furthermore, due to the unexpected hotel guest behavior, this study provides a range of potential energy savings after retrofits. This baseline is important for the hotel facility team to understand, so that they can establish corresponding goals, understand the risks and opportunities, and better estimate return on investment.

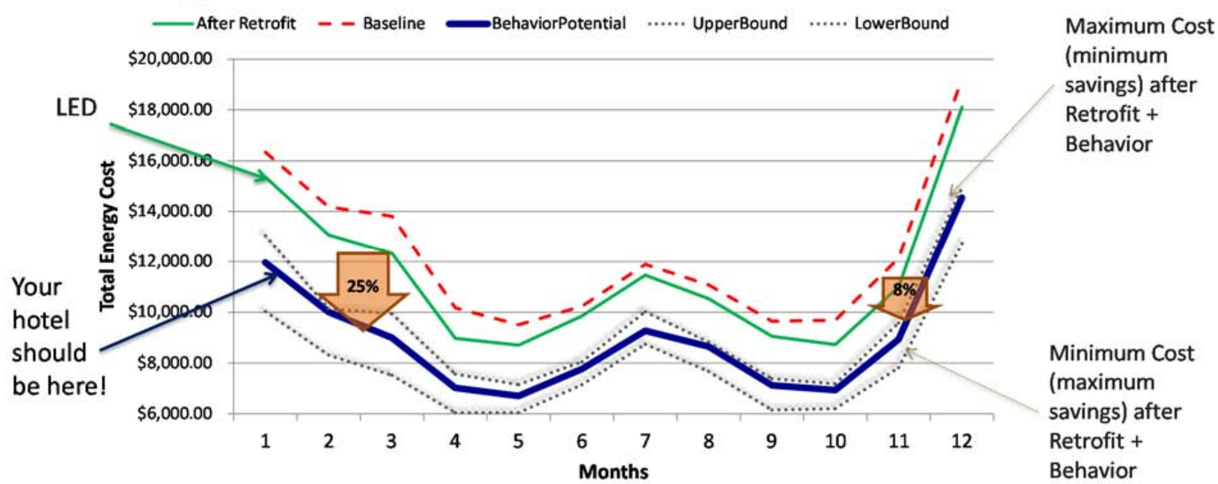


Figure 5 Results of Behavior Driven Energy Impacts for Hotel C

CONCLUSIONS

Current state-of-the-art to improve hotel energy efficiency is constrained by staff limitations in small- and medium-sized hotels. Examining utility bills is the primary means to monitor energy use and savings in these hotels. While utility bill analysis can provide a useful comparison of a building's energy consumption and its historical status, it does not give insight into a hotel's operation without a more in-depth analysis. The barriers preventing effective integration of energy efficiency evaluation with hospitality business include:

- Lack of a scalable and easy-to-use tool that can rapidly assess potential energy savings; and
- Lack of analysis on behavior driven energy impacts due to unpredictable customer behaviors, which makes the energy assessment more difficult

We use AST to generate a baseline energy model with inputs from actual operations, validated again monthly utility bills, then analysis potential energy from upgrades and through optimization of behavior of staff and guests. The final results show that with cost-effective upgrades and no-cost behavior changes, energy savings can vary from 8% to 25%. With the AST, preliminary energy efficiency analyses can be quickly performed on a large number of hotels at the management level. This addresses the first barrier related to staff time limitations surrounding identification of energy savings opportunities in individual hotels. In addition, this paper tries to address the second barrier through preliminary analysis on a correlation between uncontrolled human behavior and energy consumption, and quantify behavior-related energy impact. It brings the traditional baseline modeling and benchmarking into a new level.

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