Energy Performance of Hotel Buildings in Singapore

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ABSTRACT

In this paper, a study of the energy performance in Singapore's hotel industry is reported. Energy consumption data and other pertinent information were collected from 29 quality hotels through a national survey. Building features and operational characteristics contributing to the variations of hotel energy performance were discussed. The annual average total energy use intensity in these hotels is 427kWh/m^2, amongst the highest of all building categories. Electricity and gas are consumed in all the hotels, and some also use diesel to power standby generator or hot water boiler. A predictive model to correlate monthly electricity use and corresponding occupancy was applied to the dataset, but the correlations were found to be weak, indicating the necessity of improving energy management when occupancy rate is low. Step-wise regression analysis of total energy use intensity and possible explanatory indicators was conducted. It was found that three-star developments differ from high class hotels in energy use intensity. The other two significant variables are worker density and years after the last major energy retrofit.

KEYWORDS

Energy use intensity, Occupancy rate, Fuel mix, Hotel building

1. INTRODUCTION

Hotels play a very important role in the prosperity of Singapore's tourism industry, which according to World Travel and Tourism Council, is expected to post SDG 51.9 billion of economic activity in 2006, and will continue its fast growth during the next decade. The hotel industry has also been performing well. In 2004, total hotel room revenue of the 102 gazetted hotels reached SDG 1 billion. Obviously, this large revenue generated wouldn't have been possible without the consumption of a large amount of energy. In fact, both local studies and research conducted in other countries reveal that hotel buildings have the highest energy use intensity amongst all the building categories. Santamouris (1996) collected energy consumption data from 158 Hellenic hotels to study their conservation and retrofitting potential. The annual average total energy consumption in these hotels was 273kWh/m^2. Deng (2000) studied the energy performance in 16 Hong Kong hotels, and found the average energy use intensity to be 564kWh/m^2. Energy use intensity of 612kWh/m^2 was reported in a study of hotels in Ottawa (Zmeureanu, 1994). In the APEC energy benchmark database, energy consumption data of 29 Singapore hotels are included. The average energy use intensity based on energy consumption data of year 1993 was 468kWh/m^2 (Bloyd, 1999). Considering the technological advance in the last decade and the energy consciousness partly raised by the soaring oil price, energy consumption pattern in Singapore hotels could be quite different nowadays. More importantly, the APEC database includes very little information regarding a hotel's physical and operational characteristics. This necessitates a comprehensive study to draw a whole picture for the hotel industry energy performance, hence inefficiencies might be identified and improvement measures can be implemented. In a national survey conducted from 2005 to 2006, energy consumption data and other pertinent information were collected from 29 quality hotels. The data collected and results of analyses are presented as follows.

2. HOTEL BUILDING CHARACTERISTICS

The sampled hotels vary from a boutique hotel with 32 guest rooms (GFA, 1648m^2) to a large development supplying 1200 rooms (GFA, 101998m^2). This sample covers about 28% of the gazetted hotel population. When classified with star rating, there are 11 five-star, 13 four-star and 5 three-star hotels. Number of floors above ground ranges from 4 to 50. While the oldest building was constructed in 1929; the newest construction was only completed in 2003. However, it needs to be noted that most old buildings have had major energy retrofits during the past decade. Retrofitting measures include upgrading façade, replacing chillers, installation of energy efficient lamps, and etc. About 52% (15 out of 29) of hotels have installed building manage systems, but degree of sophistication of these systems varies from one to another.

2.1 Floor Areas for Different Functions

Total number of hotel rooms for the entire sample is 13450, which is 37% of the total number of available rooms in all registered hotels (Annual Report on Tourism Statistics, Singapore, 2004). The guest rooms cover on average 64% of the hotel's GFA. Generally, this percentage is relatively low for high class business hotels, in which more spaces are used for business and leisure activities. Every hotel provides some dining facilities, from small cafes to large restaurants. The area in hotels for dining facilities, including cafes, pubs, restaurants and kitchens, varies from 242m^2 (1.3% of GFA) to 6574m^2 (6.4% of GFA). The average percentage of dining facilities area in GFA is 5.6%. Amongst the 29 hotels, 27 have convention facilities or/and tenanted office spaces. On average, 6.4% of the GFA is devoted to these functions. Shopping centers were found in 7 hotels, which cover an average of 15.9% of GFA in these hotels, varying between 653m^2 and 10362m^2. These shopping centers are mostly in hotels located on high streets, and often occupy the first floors of the buildings. The rest areas in hotels generally fall into one of the following categories: ballroom, data center, common areas (lobby, corridor, etc.), back of the house (housekeeping, laundry, etc.), recreational facilities (swimming pool, spa, gym, etc).

2.2 HVAC and Indoor Environment

Singapore lies just north of the Equator near Lat 1.5 deg N and Long 104 deg E. The hot and humid tropical climate makes it necessary to provide year round air-conditioning in hotels. Except in a boutique hotel where split units are used throughout the whole building, all the other 28 hotels are centrally air-conditioned, with 25 hotels operate and maintain their own chiller plants. The remaining three share parts of two district cooling systems; chilled water is pumped to the premises and billed based on the tons of refrigeration supplied. For the air side, large public areas like lobby, restaurants are usually conditioned with Constant Air Volume (CAV) or Variable Air Volume (VAV) systems, whereas guest rooms are often served with Fan Coil Unit (FCU).

Singapore Code of Practice (CP 13, 1999) mandates the indoor dry bulb temperature to be maintained within 22.5 and 25.5 degree C, and the average relative humidity not to exceed 70% when the air-conditioning system is in operation. In the surveyed hotels, set-point temperature is usually kept around 23 degree C, with the minimum of 21 degree C and the maximum of 26 degree C. Relative humidity (RH) is generally satisfactory; the average is 63% for all hotels. But outliers do exist. Four hotels maintain their indoor relative humidity between 70% and 80%. It should also be noted that thermal setting in guest rooms is actually at the discretion of occupants. Hence, the set-points of temperature and relative humidity reported herein are more representative of the settings in common areas like lobby, restaurant as well as the default setting in guest rooms.

3. HOTEL ENERGY CONSUMPTION

Unlike office buildings, in which electricity is usually the only fuel consumed, hotels often use more than one type of energy sources due to the diversified activities in them. Monthly energy bills of all fuels consumed in the hotels were collected.

3.1 Fuel Mix and Breakdown of Energy Use

Electricity is the primary energy source, which is used to power HVAC, lighting, vertical transport, and almost all the equipment. Gas is mainly used for cooking, but in 3 cases also for gas boilers. In hotels which only consume electricity and gas, the average proportions of two fuels are 91% and 9% respectively. In addition, some hotels also use diesel as the third fuel. Two functions are observed in these hotels to be accomplished by using diesel, standby electricity generation and hot water or steam generation. The former incurs very little consumption, often negligible, as diesel is only consumed in regular (monthly, or even quarterly) test-runs of the emergency generator to ensure it works when in need. In 12 hotels where diesel boilers are used, the percentages of electricity, gas and diesel are 77%, 8% and 15% respectively. This fuel mix is similar to that reported in a study of 16 Hong Kong hotels (Deng, 2002), in which 73% of the energy consumed was found to be in electrical form, and the rest was gas and diesel. Although detailed information is lacking, which doesn't allow a definite conclusion to be drawn, the diesel boilers used in hotels are in general quite inefficient. Some hotels have been aware of this problem and already made plans to decommission their boilers in the near future. Domestic hot water is produced by electricity in hotels with no diesel or gas boiler. There seems to be no relationship between hotel star rating or capacity and the way they choose to supply DHW, since all the three means can be found in hotels of different stars and sizes.

Decomposition of energy consumption into major end-uses like HVAC, lighting, DHW, vertical transport requires continuous monitoring of the facilities. Kinney (2000) reported an energy audit performed in a 5-star Singapore hotel. The monitored data shows that central plant constitutes the largest proportion, consuming 39% of the electricity energy, which is followed by AHU/FCU using 24% of electricity. Due to the time and resource constraints, such monitoring was not carried out in the surveyed hotels. However, in the three hotels using district cooling systems, chiller plant energy consumption is separately metered for billing purpose. Since year-long data is available, this portion of energy use can be determined with high accuracy. The proportions of chiller plant (inclusive of cooling tower, condensing water pumps) energy consumption were found to be 40%, 44% and 35% respectively, of total electricity use in the three hotels.

3.2 Energy Use Intensity

Regression analyses were conducted to correlate energy consumption with GFA, number of guest rooms, number of occupied rooms per year, and number of workers, so as to determine the primary variable for normalization. Most of these capacity indicators are well correlated with electricity, fossil fuel energy (gas cum diesel) and total energy consumption, but GFA is still the best correlated one, which is manifested by high R^2s of 0.86, 0.73 and 0.9. Hence, it was chosen as the primary normalization variable. This is also in line with the convention of kWh per square meter with which building energy performance is often compared. Some of the descriptive statistics are summarized in Table 1. Variations of energy use intensities are large, especially for fossil fuel use, which can be partially attributed to the difference of business activities existing across the hotels. And the rest is largely due to the difference in energy efficiency in hotel buildings. For gas consumption, number of food covers is probably the best explanatory indictor, but most hotels were unable to provide this information. Amongst other capacity indicators, area for dining facilities is best correlated, with an R^2 of 0.55, indicating that it cannot explain the gas use variations very well.

TABLE 1
Summary statistics of energy use intensities

EUI (kWh/m^2)	Minimum	Maximum	Mean	Std. Deviation
Electricity	221.169	495.764	361.391	82.862
Fossil fuel	1.743	197.291	65.566	48.915
Total	264.713	592.326	426.958	95.890

3.3 Electricity Use and Occupancy Rate

The yearly average occupancy rate in surveyed hotels ranges from 66% to 88%, with an average of 78%. No doubt a hotel's energy consumption will be affected by occupancy rate. Reddy (1997) acknowledged the necessity of normalizing for changes in number of occupants when baselining facility-level monthly energy use. It was also noted by the author that number of occupants is a nebulous parameter to measure and keep track of. In hotels, fortunately, recording of occupancy rate is the normal practice as a management need. Though walk-in guests, such as patrons to the restaurants are usually not counted, occupancy recording is relatively a good indicator of the population in a hotel. Energy use in a building, for example, does not necessarily double if the number of occupants is doubled, so a simple proportional relationship is unlikely (Reddy, 1997). Papamarcou (2001) postulated an exponential regression model for monthly electricity use and number of guests in a Cyprus hotel, and the model has an R^2 of 0.95. In the same way, monthly electricity consumption was plotted against number of occupied rooms for the 29 hotels. However, no clear exponential relationship could be perceived. This was further confirmed by adding exponential trend lines to the scatter plots. Many of these trend curves are statistically insignificant. And even the significant ones have very low R^2s, mostly around 0.5.

A few possible reasons might be able to account for this lack of fit. Firstly, the exponential relationship is rather a special case, which can not be generalized to other hotels. Secondly, as was noted in a study of Australian hotels, with room occupancy rates between 70% and 100% there is little effect on the energy consumption of a hotel and energy intensity only starts to drop off when occupancy rates fall below 70%. In our dataset, the hotel monthly occupancy rates are mostly quite stable, and rarely fall below 70%. Thirdly, interviews with hotel engineers reveal that air-conditioning is usually kept on in guest rooms even when they are not occupied (but set-point temperature is a bit higher, say 25 degree C). This is especially true in high-class hotels, in which thermal discomfort and bad IAQ are less tolerable. Since high proportion of electricity is used for cooling in this tropical country, continuous air-conditioning of guest rooms may result in the electricity consumption’s insensitivity to occupancy rate.

4. EUI AND SECONDARY DETERMINANTS

In the analysis of secondary determinants, which result in the variation of energy use intensity across the hotels, step-wise regression technique was adopted. A total of 21 independent variables were subject to this analysis, including derived variables like percentage of office area in GFA and dummy variables such as whether diesel boiler is used. Three of them were selected by the step-wise selection procedure to enter into the final model: worker density, years after last major retrofit and whether the hotel is a three-star development. The regression model, with an R^2 of 0.77, is as follows:

$$EUI = 302.974 + 20.174 WKDENS + 2.730 RETROFIT - 124.635 STAR3 \quad (1)$$

where: WKDENS – number of workers on main shift per 1000m^2 of GFA
RETROFIT – years after last major energy retrofit
STAR3 – dummy variable, 1 for three-star hotel, 0 if it is four or five-star

With the increase of worker density, energy use intensity in a hotel also increases. Superficially, it is because hotel workers also consume energy. But a more important and persuasive reason is that worker density is an indicator of the activity level in a hotel. Those hotels with more patronage (not only hotel room guests) and providing more services will consume more energy on a per floor area basis. And on the other hand, they also need more workers to support the guest activities. As described before, most old hotels have had major energy retrofit during the last decade, upgrading façade, HVAC and other building systems. Such a retrofit, in many cases, will lift a hotel's energy performance to a higher level. The presence of star rating as a dummy variable in the regression model implies the difference of energy use behavior between three-star hotels and those of four and five stars. A one-way ANOVA analysis of mean confirms this; it shows that at 95% confidence level, the EUI of three-star hotels differs from that of four and five-star ones, whereas the difference between that of four and five-star hotels is not significant.

5. CONCLUSION

This survey revealed that energy use intensity in Singapore hotels is lower than that reported in Ottawa and Hong Kong, but is higher than that of Hellenic hotels. A Comparison with hotels in APEC database shows a difference of 41kWh/m^2, which represents, on an industry scale, the energy performance improvement during the last over ten years, provided the two samples are all representative of the hotel industry. Electricity consumption is not well correlated with occupancy; some possible reasons may account for this, but it also suggests that hotel managers should improve energy management when occupancy rate is low. This paper also discussed the secondary determinants that result in variations of energy consumption across hotels. A regression model was postulated to correlate energy use intensity with these factors.

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