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A study on energy performance of hotel buildings in Singapore

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ABSTRACT

This paper presents a study on energy performance of Singapore's hotel buildings. 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 in hotel energy performance were discussed. The annual average total energy use intensity (EUI) in these hotels is 427 kWh/m^2. Electricity and gas are used in all sampled hotels, and some hotels also use diesel to power standby generator or hot water boiler. We also investigated relationships between electricity consumption and number of occupied rooms in individual hotels; the weak correlations found indicate it is necessary to improve energy management when occupancy rate is low. Besides, Pearson correlations between hotel energy use intensity and possible explanatory indicators revealed that three-star hotels differ from high class establishments in energy use. Worker density and years after the last major energy retrofit were also found to be highly correlated to hotel building energy use intensity. Also discussed in this paper is the effect of weather conditions on electricity consumption of the hotels.

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1. Introduction

Hotels play a very important role in Singapore's prosperous tourism industry, which according to the World Travel and Tourism Council, is expected to post SGD 51.9 billion of economic activity in 2006, and will continue its fast growth during the next decade [1]. Singapore's hotel industry, when evaluated in economical terms, has been very successful. In 2004, total hotel room revenue from the 102 gazetted hotels reached SGD 1 billion; food and beverage revenue from outlets in these hotels was over SGD 700 million [2]. When compared to residential or office buildings, hotels usually constitute a relatively small proportion of the building stock in an economy. Nevertheless, both local studies and research conducted in other countries reveal that hotels are among the most energy intensive of all building categories. As a result, their energy use and environmental impact can be quite large, especially in popular tourist destinations.

Santamouris et al. [3] collected energy consumption data from 158 Hellenic hotels, and estimated the energy savings potential which could be achieved by application of practical retrofitting techniques, materials or energy efficient systems. The annual average total energy consumption in these hotels was 273 kWh/m^2. Deng and Burnett [4] reported an average energy use intensity of 564 kWh/m^2 when studying energy performance of 16 Hong Kong hotels. A breakdown of energy consumption in those hotels showed that one-third of total energy was used for air-conditioning. In a later study, the same researchers [5] presented an energy use intensity of 542 kWh/m^2 in 36 Hong Kong hotels. Zmeureanu et al. [6] investigated the energy performance of 16 hotels in Ottawa. The average energy use intensity was found to be 612 kWh/m^2. In addition, the researchers tried to disaggregate total energy use into weather-dependent and weather-independent components by using the weather normalization method PRISM. In a study of the Australian hotel industry, benchmark indicators of best practice performance were proposed for accommodation and business hotels [7]. They are 208 kWh/m^2 and 292 kWh/m^2, respectively. The British hotel benchmark established by CIBSE also separates hotels of different types [8]. For each type, i.e., luxury, business or holiday, and small, there are detailed benchmark indicators for every end-use like heating, hot water and so on.

A search of literature retrieved only one study aimed at the energy performance of Singapore's hotel industry. Average total energy use intensity of 468 kWh/m^2 was reported for 29 Singapore hotels [9]. This energy consumption data, which is also included in the APEC energy benchmark database was collected in 1993. Considering the technological advance in the last decade or so and energy consciousness partly raised by the soaring oil price, energy use behavior in the Singapore hotel industry could be quite different

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Table 1
Summary of the data collected from 29 hotels.

Hotel no.	GFA (m^2)	Con year	Retrofit	No of rooms	Star	Swim pool	Laundry	No of workers	Electricity (kWh)	Gas (kWh)	Diesel (kWh)
1	42,483	1979	2000	439	5	1	1	280	12,636,614	1,546,049	5,136,555
2	20,799	1985		413	5	1	0	150	9,352,900	143,897	1,004,188
3	32,124	1992		254	5	1	1	270	15,661,700	2,120,019	
4	27,829	1992		459	5	1	0	170	10,131,533	763,968	
5	101,998	1969	2003	1200	5	1	0	500	31,851,977	2,848,095	8,401,800
6	37,809	1999		540	5	1	1	295	16,317,698	3,953,240	9540
7	35,972	1969	2000	422	5	1	1	200	11,202,807	838,979	3,879,749
8	34,293	1982	2003	575	5	1	0	195	13,792,024	1,618,997	
9	43,473	1993		509	5	1	0	200	17,539,441	689,746	
10	50,470	1982		775	5	1	1	570	21,517,597	2,293,158	6,083,939
11	94,000	1977	2002	751	5	1	1	600	27,640,026	3,431,775	6,386,303
12	37,877	1995		476	4	1	1	100	11,465,969	2,158,152	
13	19,206	1984	1997	354	4	1	0	161	8,980,832	1,054,136	914,550
14	25,916	1995		546	4	1	1	150	10,153,800	1,143,572	20,100
15	23,018	2000		539	4	1	0	195	10,800,506	610,936	
16	17,194	2004		380	4	1	0	100	6,460,361	431,689	
17	21,260	1996		299	4	1	0	70	6,313,847	452,216	
18	27,291	1973		529	4	1	1	284	12,366,217	927,065	482
19	14,742	1998	2003	393	4	1	0	67	5,998,934	25,698	
20	26,866	1969	1998	387	4	1	0	70	8,402,605	16,176	684,153
21	28,546	1980		402	4	1	0	120	10,154,457	444,047	5,187,810
22	19,410	1996		330	4	1	0	160	8,575,358	889,327	
23	50,959	1980		653	4	1	1	320	25,263,645	3,095,558	
24	49,424	1982	2002	380	4	1	1	270	15,552,148	1,209,242	1,183,890
25	28,112	1985	1993	440	3	1	0	85	6,908,706	825,719	
26	18,133	1984	2001	272	3	1	0	125	4,782,440	49,235	753,750
27	20,591	1982	2002	229	3	1	0	90	5,250,378	276,000	482,400
28	1648	1929	2002	32	3	1	0	12	378,741	115,822	
29	24,394	1983	2002	472	3	1	0	80	5,395,205	1,062,204	

nowadays. On top of that, the APEC database includes very little information regarding the hotels' physical and operational characteristics. This necessitates a comprehensive study to draw a whole picture of the hotel industry energy performance, and consequently improvement measures can be implemented where inefficiencies have been identified. In light of this, a national survey was carried out by the Energy Sustainability Unit, National University of Singapore from December 2005 to March 2006 as part of the Building energy efficiency Labelling programme [10]. A comprehensive data collection form was developed and these forms were sent to the hotel authorities through post and e-mail. Also further follow up was done through phone calls. After the data collection forms from all the hotels were collected, site visits and meetings with the hotel facility managers were conducted to seek further clarification. Also, few spot measurements were conducted to verify the indoor environmental conditions of the facilities. Finally, energy consumption data and other pertinent information for 1 year were obtained from 29 quality hotels. A summary of the data is shown in Table 1. The results of analyses are presented as follows.

2. Hotel building characteristics

The sampled hotels are very heterogeneous in terms of size. They vary from a boutique hotel with 32 guest rooms to a large establishment supplying 1200 rooms. Number of floors above ground ranges from 4 to 50. This sample covers about 28% of the 102 gazetted hotels in Singapore. When classified with star rating, there are 11 five-star, 13 four-star and 5 three-star hotels. The oldest building was constructed in 1929; whereas 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. Retrofit measures include upgrading façade, replacing chillers, and installing energy efficient lamps. About 52% (15 out of 29) of the hotels have their building management 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 13,450, which is 37% of the total number of available rooms in all registered hotels [2]. The guest rooms cover on average 64% of the hotel's gross floor are (GFA). Generally, this percentage is relatively low in high class luxury hotels, in which more spaces are used for leisure activities. Every hotel provides some dining facilities. The area in hotels for dining facilities, including cafe, pub, restaurant and kitchen, varies from 242 m^2 (1.3% of GFA) to 6574 m^2 (6.4% of GFA). On average, 5.6% of the GFA is used for this purpose. Among the 29 hotels, 27 have convention facilities or/and tenanted office spaces. The average percentage of GFA devoted to these functions is 6.4%. Shopping centers are found in 7 hotels, which cover an average of 15.9% of the GFA in these hotels, varying from 653 m^2 to 10,362 m^2. These shopping centers are mostly in hotels located on high streets, and often occupy the first floors of the buildings. The rest of the areas in the hotels generally fall into one of the following categories: common areas (lobby, corridor, etc.), back of the house (housekeeping, laundry, etc.), recreational facilities (swimming pool, spa, gym, etc.), and technical service rooms.

2.2. Air-conditioning and indoor environment

Singapore lies just north of the Equator near Lat. 1.5°N and Long. 104°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, among which 25 hotels operate and maintain their own chiller plants. The remaining three hotels share parts of two district cooling systems; chilled water is pumped to the premises and billed based on the tons of refrigeration supplied. Large public areas like lobby, restaurant are usually conditioned with constant air volume (CAV) or variable air volume (VAV) systems, whereas fan coil units (FCU) are often used to serve guest rooms.

Singapore Code of Practice (CP 13, 1999) mandates that indoor dry bulb temperature should be maintained within 22.5 °C and 25.5 °C, and the average relative humidity should not exceed 70% when the air-conditioning system is in operation [11]. In most of the surveyed hotels, set-point temperature is kept around 23 °C, with the minimum of 21 °C and the maximum of 26 °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 settings in guest rooms.

3. Hotel energy consumption

Unlike office buildings in Singapore, in which electricity is usually the only fuel consumed, hotels often use more than one type of energy sources due to the diverse activities accommodated. In the survey, monthly energy bill of all fuels consumed in 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 transportation, and almost all the equipment. Gas is mainly used for cooking, but in three hotels it is also used for gas boilers. In hotels where only electricity and gas is consumed, the average proportions of two fuels are 91% and 9%, respectively. Some hotels also use diesel for 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 comparable to that reported in the study of 16 Hong Kong hotels [12], 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 makes it difficult to draw a definite conclusion, the diesel boilers generally appear to be quite inefficient. In interviews with hotel engineers, it was found that some hotels are aware of this problem and plans have already been made to decommission the boilers in the near future. Domestic hot water (DHW) is produced by electricity in hotels with no diesel or gas boiler. There is no obvious 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 transportation requires continuous monitoring of these systems. Kinney and Lee [13] reported the results of an energy audit performed in a five-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 part 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% of total electricity use in the three hotels.

Table 2
R^2s of linear models correlating energy use with primary factors.

Capacity indicator\Energy	Electricity	Fossil fuel	Total
GFA	0.86	0.73	0.90
No. of guest rooms	0.72	0.53	0.72
No. of room-nights per year	0.71	0.48	0.70
No. of workers on main shift	0.81	0.70	0.85

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 variable, which is manifested by higher R^2s (Table 2). Therefore, it was chosen as the primary normalization variable. This is also in-line with the convention of kWh per square meter when building energy performance is compared. The average annual electricity, fossil fuel energy, and total energy intensities, after doing floor area normalization, are about 361 kWh/m^2, 66 kWh/m^2 and 427 kWh/m^2, respectively. For gas consumption, number of food covers (number of meals served) is probably the best explanatory indictor, but most hotels were unable to provide this information. Among other capacity indicators, area for dining facilities is the best correlated variable, with an R^2 of 0.55, indicating that it cannot explain the gas use variation very well.

It was presumed that star rating might have some bearings on the energy use intensity of hotels. In Fig. 1, energy use intensities are plotted against the star ratings of individual hotels. There seems to be not much difference between four and five-star hotels, but three-star hotels generally use less energy on a per floor area basis. A one-way ANOVA test of mean confirmed this observation, which 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 those of four and five-star hotels is not significant.

3.3. Energy consumption of hotel industry

Through regression analysis, GFA was found to be the best correlated primary variable, but only total number of hotel rooms

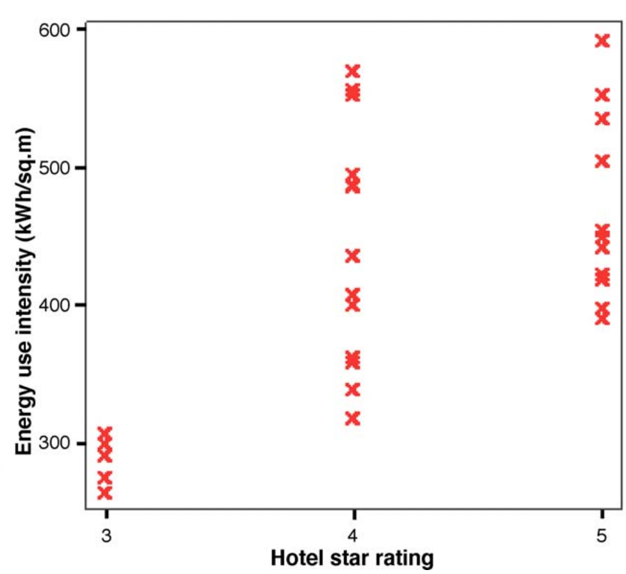

Fig. 1. Energy use intensity vs. hotel star rating.

Table 3
Summary statistics of energy use intensities.

EUI (kWh/m² or MWh/room)	Minimum	Maximum	Mean	Std. deviation
Electricity[a]	221.169	495.764	361.391	82.862
Fossil fuel[a]	1.743	197.291	65.566	48.915
Total[a]	264.713	592.326	426.958	95.890
Electricity[b]	11.431	61.660	25.462	10.062
Fossil fuel[b]	0.065	15.222	5.012	4.317
Total[b]	13.681	70.007	30.474	12.618

[a] Energy consumption per floor area (kWh/m²).
[b] Energy consumption per room (MWh/room).

is known to us on the industry scale. Due to this reason, energy use per hotel room was estimated in order to make inferences to the whole population. The results together with those based on floor area are summarized in Table 3. The mean total energy consumption per year is 30.474 MWh/room, with a standard error of 12.618 MWh/room. Since total number of available hotel rooms is 36,756 according to the Annual Report on Tourism Statistics [2], energy consumption of the hotel industry on an annual basis (T) can be estimated at 1,120,102 MWh, and a 95% confidence interval is

$$943,722\,\text{MWh} < T < 1,296,482\,\text{MWh}$$

In the same way, electricity consumption of the hotel industry is estimated at 935,881 MWh, which is about 17.6% of yearly electricity consumption in buildings, and 2.8% of total electricity demand in 2004 [14].

3.4. Electricity consumption and occupancy rate

Yearly average occupancy rate in the 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. In baselining facility level monthly energy use, Reddy et al. [15] acknowledged the necessity of normalizing for changes in number of occupants. It was also noted by the researchers that number of occupants is a nebulous parameter to measure and keep track of. Fortunately, recording of occupancy rate is the normal practice in hotels as a management requirement. 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. However, 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 [16]. Papamarcou and Kalogirou [17] postulated an exponential regression model for monthly electricity use and number of guests in a Cyprus hotel with an R^2 of 0.95. In this study, monthly electricity consumption was plotted against number of occupied rooms for the 29 hotels as shown in Fig. 2. However, no clear exponential relationships could be perceived. This was further confirmed by adding exponential trend lines to the scatter plots. Only a few of these trend curves are statistically significant, and their R^2s are much lower than that of the Cyprus hotel, 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 cannot be generalized to other hotels. Secondly, as was noted in the 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% [7]. In our dataset, the hotels' monthly occupancy rates are 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 °C). This is especially true for high-class hotels, in which thermal

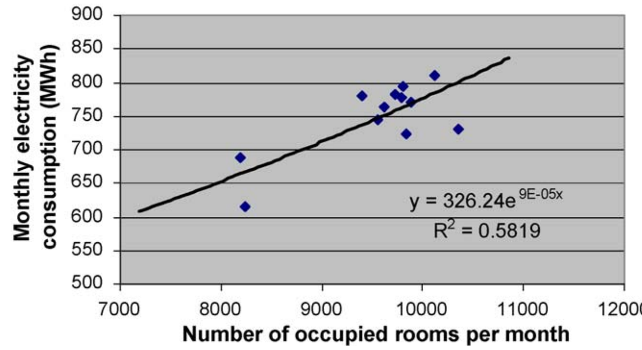

Fig. 2. Monthly electricity consumption vs. number of occupied rooms.

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 have resulted in the electricity consumption's insensitivity to occupancy rate.

4. EUI and secondary determinants

In order to identify the secondary drivers, which result in the variations of energy use intensity across hotels, Pearson correlations of EUI with a total of 21 potential secondary drivers were calculated as shown in Table 4. Some of these potential drivers are data collected directly from the hotels such as standard guest room area, building age, while others are derived variables like percentage of retail area in GFA. The highest figures are seen in STAR3 (dummy variable, differentiating three-star from four- and five-star hotels), WKDENS (worker density which is the number of workers on main shift per 1000 m² of GFA), RETROFIT (number of years after the last major retrofit) and WORKER (number of workers on the main shift), all significant at the 0.01 level; three correlations, FLOOR (number of floors), SDRMAREA (area of standard guest room) and AUDIT (dummy variable, energy audit performed during the last 5 years), are significant at the 0.05 level, while the others are insignificant. The correlation coefficients show that three of them are most highly correlated with hotel building

Table 4
Pearson correlations between energy use intensity and secondary energy drivers.

Variable name	Description	Pearson correlation
GFA	Gross floor area	0.165
FLOOR	Number of floors	0.437*
ROOM	Number of guest rooms	0.298
GFARM	Gross floor area per guest room	−0.003
SDRMAREA	Area of a standard guest room	0.430*
AGE	Building age	−0.205
RETROFIT	Number of years after the last major retrofit	0.529**
WORKER	Number of workers on the main shift	0.473**
OCPRATE	Yearly occupancy rate	0.254
PTDINING	Percent of GFA for dining facilities	0.017
PTCONVEN	Percent of GFA for convention centers and offices	−0.004
PTRETAIL	Percent of GFA for retail shops	−0.268
BOILER	Diesel boiler used	0.217
DISCOOL	District cooling system used	0.217
BMS	Building management system used	0.309
WKDENS	Worker density	0.669**
AUDIT	Energy audit performed in the last 5 years	0.367*
LAUNDRY	Presence of laundry facilities	0.366
STAR5	Five-star hotel	0.354
STAR4	Four-star hotel	0.166
STAR3	Three-star hotel	−0.673**

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

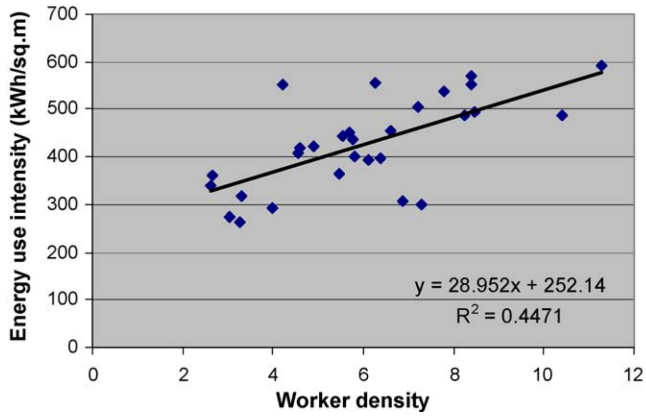

Fig. 3. Energy use intensity vs. worker density.

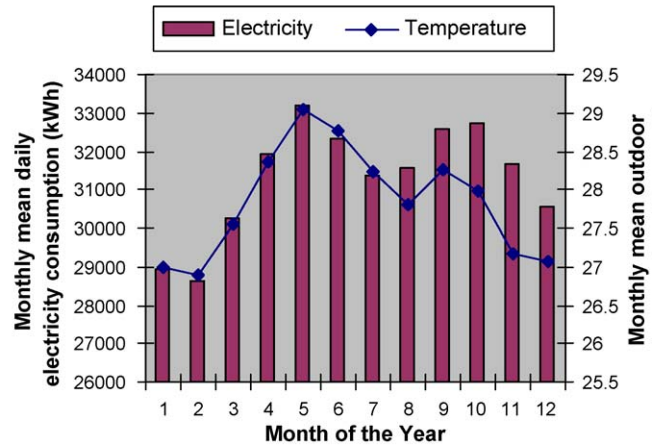

Fig. 4. Electricity consumption and outdoor temperature.

EUI: worker density (number of workers on main shift per 1000 m^2 of GFA), years after the last major energy retrofit, and star rating (differentiating three-star hotels with four- and five-star ones). The relationship of hotel star rating and energy use intensity has been discussed before, the other two factors are detailed as follows.

Fig. 3 shows a positive correlation between EUI and worker density. As one can expect, with the increase of worker density, energy use intensity of a hotel also increases. The R^2 of 0.45 means worker density alone is able to explain 45% of the variation of energy use intensity. Superficially, it is because hotel workers add energy demand in hotels. A less obvious but more important reason is that worker density actually reflects the level of business activities in a hotel. The hotels with more patronage (not only hotel room guests) and providing more services usually need to consume more energy. At the meantime, they also need more workers to support the guest activities.

As we described previously, most old hotels have had major energy retrofit during the last decade or so. In most cases, these retrofits equipped them with advanced technology one can find in new constructions. A good example is replacement of old chiller units with new and more efficient ones, which often result in great savings in cooling energy demand. Hence, it is not surprising to find that 'years after last major retrofit' is a highly correlated factor with the hotel's energy use intensity. This also shows that energy retrofits undertaken in the hotels have generally been effective in reducing energy use and improving energy performance.

5. Weather conditions and energy use

The relationships between energy consumption and weather conditions have been studied by many researchers. As a result, a world of literature can be retrieved, in which various models were developed mainly to facilitate accurate measurement of energy savings and prediction of future energy use. Some of the proposed models include simple linear regression model correlating monthly mean outdoor temperature with heating or cooling energy use, and more complicated change-point model considering the combined effects of temperature, humidity and solar radiation [15,18].

Weather conditions in Singapore are uniform and constant throughout the year. But monthly variations do exist. Mean outdoor temperature, for example, usually reaches its peak in May, and drops to the nadir in December or January. Relative humidity is high with the monthly average above 80% throughput the whole year. Analysis of the relative humidity with the energy consumption showed that there is no significant correlation between them. Previous studies about commercial building energy consumption showed that outdoor temperature had a significant correlation with building energy consumption whereas relative humidity and global solar radiation did not have any significant correlation [19]. Fig. 4 shows the profile of monthly mean outdoor temperature of a whole year. Also plotted is the monthly mean daily electricity consumption of the same period for hotel no.12. As can be seen here, electricity consumption generally follows the fluctuations of outdoor temperature, which indicates that outdoor temperature is able to explain a large proportion of its variation. Besides, it is also worth noting in the figure that monthly outdoor temperature never falls below 26 °C. In change-point methods like PRISM, there is a break-even temperature for every building, which is sometimes arbitrarily designated as a constant such as 18.3 °C or in variable-base methods treated as a variable. This reference temperature, as discussed by Fels [20], is actually a reflection of interior temperature settings, and heating (cooling) is first required when the outdoor temperature drops below (rises above) the reference temperature. Since cooling is required throughout the year, and set-point temperature in hotels is usually kept around 23 °C, it becomes obvious that change-point models are not applicable in this case. There will be no 'change-point' unless an unreasonably high reference temperature is specified, but if that is the case, it will no longer be able to reflect interior temperature settings.

Therefore, in this study, a simple linear regression model was adopted in an attempt to correlate electricity use with outdoor dry bulb temperature. As in most studies of similar nature, R^2 and CV-RMSE were used as criteria to evaluate the goodness of regression models. CV-RMSE is defined as follows [15]:

$$\mathrm{CV-RMSE} = \frac{100 \times \left[\sum (Y_i - \hat{Y}_i)^2/(n-p)\right]^{1/2}}{\bar{Y}} \qquad (2)$$

where $\hat{Y}_i$ is the value of Y predicted by the regression model, $\bar{Y}$ is the mean of Y_i, n is the number of observations, and p is the number of model parameters. At the 95% confidence level, however, statistically significant correlations were only found in 13 hotels. R^2 and CV-RMSE of these models are summarized in Table 5. Besides, the correlation in one of the hotels was plotted in Fig. 5 as an example. The resulting R^2s were found to be much lower than those obtained in office buildings [19]. However, if CV-RMSE is to be adopted as the criterion, as was suggested by Reddy et al. [15] that models with CV-RMSE less than 5% can be considered excellent models and those less than 10% can be considered good models, then nine regression models would be in the excellent group, with the rest fall into the good model category. Nevertheless, whether it is a degree–day method or the simple regression model we adopted in this study, their limitations

Table 5
R^2 and CV-RMSE of baseline models.

Hotel	12	13	15	5	8	18	19
R^2	0.68	0.44	0.42	0.59	0.49	0.41	0.58
CV-RMSE (%)	2.75	5.27	3.08	1.67	5.55	3.65	3.24
Hotel	H	I	J	K	L	M	–
R^2	0.53	0.64	0.67	0.36	0.48	0.34	–
CV-RMSE (%)	6.82	2.24	3.63	3.67	3.23	8.61	–

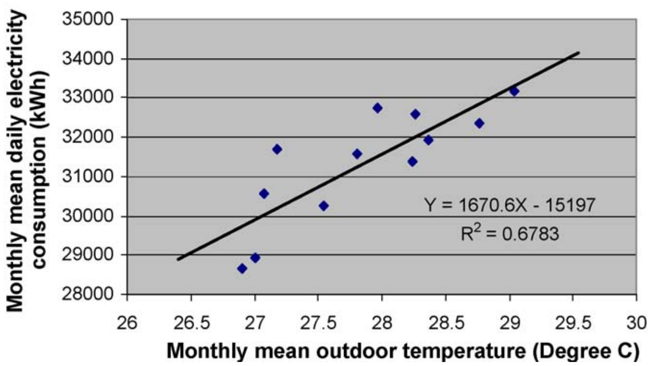

Fig. 5. Monthly mean daily electricity consumption vs. monthly mean outdoor temperature.

should be well aware of, especially when applied in a cooling dominated climate. Unlike heating, linear relationship can generally hold for energy use and outdoor temperature in the case of cooling. Studies have shown that cooling is a non-linear phenomenon [21]. In this sense, it is more appropriate to deem the linear models as a makeshift simplification with practical usage.

6. Conclusion

Energy consumption data and other significant information were collected from 29 quality hotels in Singapore through a national survey. Building features and operational characteristics contributing to the variations in hotel energy performance were discussed. Mean energy use intensity in the surveyed hotels was found to be 427 kWh/m^2, which is lower than that reported in Ottawa and Hong Kong, but higher than that of Hellenic hotels. A comparison with hotels in APEC database shows a difference of 41 kWh/m^2. This decrease may represent energy performance improvement achieved during the last decade or so, provided the two samples are truly representative of the same hotel industry in different times. 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. At the end, the relationship between electricity use and weather conditions was investigated, and a simple regression model developed for the surveyed hotels.

However, to better understand energy performance in hotels, more work still needs to be done. Firstly, the sample should be expanded, so that hotels with homogeneous features can be grouped together. Separate analysis conducted for different groups will probably reveal some distinct patterns. By doing inter-group comparison, the desirable features contributing to energy efficiency of certain groups may be identified. The possibility of incorporating these features in both new constructions and to-be-retrofitted existing buildings can be explored subsequently. Secondly, information regarding energy consumption of each hotel should be obtained through auditing major systems like air-conditioning, lighting and ventilation in individual hotels. This is a costly process involving sophisticated equipments. Comparison of system-level energy performance enables pinpointing inefficiencies existing in individual systems, rather than stating building's overall energy use intensity. Hence, corrective measures can be quickly directed to certain systems when they are found to be inefficient.

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