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Energy use and maintenance costs of upscale hotels in Hong Kong

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Abstract

Energy use and facilities maintenance have been widely studied but empirical research across the two aspects of buildings has been limited. Aimed at examining the relation between energy use and maintenance costs of hotels, a study was carried out based on 30 upscale hotels in Hong Kong, including those in the 4-star and 5-star classes. Through face-to-face interviews, reliable energy and cost data of the hotels were gathered. Analyzing the data revealed that for both normalized energy consumptions and maintenance costs, they were not significantly different between the two classes of hotels. Charts for benchmarking energy performance and maintenance costs were established. Electricity prevailed over diesel oil and town gas among the types of energy used by the hotels and, among their maintenance cost elements, capital project cost dominated. The incremental energy use and maintenance costs of the large hotels were economized by virtue of their scale. Total energy use was uncorrelated with the cost for capital projects or that for routine repair and maintenance. Causes for such missing links between energy use and maintenance costs, which are crucial information for formulation of energy reduction measures, require further investigations.

Keywords

Benchmarking; cost; energy; facilities management; hotel; maintenance

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1. Introduction

The global energy use, with buildings being the dominant consumers, has continued to rise [1, 2]. Energy use in cities, especially for those with a high density of buildings, has become progressively intensive. This has resulted in various environmental issues, including the increase in greenhouse gas emission, which is central to the global warming problem.

Hong Kong, a metropolis in Asia, is well-known for its overcrowded buildings. Being a popular tourist destination, it received over 54 million visitors in 2013, among them over 25 million were overnight visitors and their average length of stay was 3.4 nights [3]. Accommodating these visitors were many sizable hotels built with quality facilities. Apart from engineering facilities (e.g. chiller, boiler, lift, lighting, etc.), amenities such as swimming pool, sauna and gym equipment are common provisions in the hotels.

According to the government's statistics [4], the biggest share (42%) of the total energy use of Hong Kong was due to the commercial sector. Hotels belong to the commercial segments that used 63,962 TJ (Terajoule; 1 TJ = 10^{12} J) in 2010, a substantial increase from 40,255 TJ in 2000. As such, it is necessary to minimize the energy use of the hotels in order to help reduce the growth of energy consumption.

The energy use of hotels is dependent on a multitude of factors over their building life cycles, including designed efficiency of their facilities; installation workmanship and hence constructed quality of the facilities; whether the facilities have been properly tested and commissioned before use; and how well the facilities are operated and maintained. Among the different stages of a building life cycle, the operation stage accounts for over 80% of energy consumption [5]. The long term costs of building operations also far outweigh the costs incurred during the design and construction stages of buildings [6]. Yet little research work has been made to examine the relation between energy use and maintenance costs of hotels. Aimed at contributing knowledge to this techno-economic area, a study was carried out. After completing the preliminary work for the study [7], more comprehensive and meticulous analyses of its findings were made, as reported in the current article.

The next section is a review of the past research works that are relevant to the present study. Section 3 describes the theory based on which the study was formulated and the method used for data collection and analysis. Shown in section 4 are the analysed findings, which include the physical and operational characteristics of the hotels, comparisons of the findings between two classes (4-star, 5-star) of hotels covered in the study, benchmarking curves of their energy consumptions and maintenance costs, and relations among the hotels' characteristics, energy use and maintenance costs. The final section consolidates the conclusions drawn from the study results and the future works needed.

2. Past relevant studies

Over the years, numerous studies have been carried out to study the energy use in buildings, including many focusing on hotel buildings. In studying the efficiency of hotels, some research works [8, 9] investigated parameters such as business performance (e.g. revenue, return on investment), management or administrative expenses (e.g. labour cost, front-of-the-house hours) associated with hotel operations. In view of the limited findings about operation and maintenance (O&M) costs of hotels, Lai and Yik [10] carried out a benchmarking study based on 10 luxury hotels, which unveiled the considerable amounts of resources used for maintenance and the predominance of energy cost over the other O&M expenditures.

Among the resources used in hotels, energy has attracted the greatest attention. In Hong Kong, Deng and Burnett [11] studied the energy use of 16 quality hotels and revealed that electricity consumption was dominant. The study of Bohdanowicz and Martinac [12], which covered a sample of 184 Hilton International and Scandic hotels in Europe, investigated the utilizations of energy and water in the hotels. Based on a survey of 29 quality hotels in Singapore, Rajagopalan et al. [13] found that the average total energy use intensity of the hotels was 427 kWh/m^2. In Taiwan, Wang [14] collected the data of 200 hotels and showed that on average electricity consumption accounted for 84% of their total energy use.

In recent years, research probing into the maintenance performance of hotels has emerged. The study of Lai and Yik [15], conducted based on the computerized maintenance management data of a 618-room hotel, identified the existence of a significant correlation between equipment downtime and amount of maintenance work orders, and developed a range of performance curves for assessing maintenance performance of hotel engineering facilities. Moreover, Lai [16] introduced a model enabling analysis of maintenance data according to the period, place, and physical installation (“3P”) of maintenance works. The analyses carried out in that study showed that the maintenance works for the hotel were highly correlated with their demands but had little correlations with the manpower input.

The above studies have delved into either the energy use or the maintenance issues of existing hotels. The study of Chan et al. [17] was among the few that attempted to explore both the maintenance practices and energy performance of hotels. Performance-based models that can link built asset maintenance with the strategic performance of buildings, however, have yet to be developed [18]. Not long ago, three case studies covering a college district, a laboratory building and a medical center were completed [19], which showed the existence of an interdependent link between energy use and maintenance management of the buildings. To date, analyses focusing on the empirical relation between energy use and maintenance costs of hotels remain unavailable. In order to provide findings for bridging this knowledge gap, the study as reported in this article was initiated.

3. Approach and data collection

The theory based on which the study was formulated is that the level of energy use of hotels is subject to a variety of factors, including those associated with the physical and operational properties of the hotels as well as how well the hotels are maintained. For instance, a bigger hotel would consume more energy and, when a hotel is occupied by more users, its energy consumption would be larger. This link between the properties and energy use of a hotel, denoted as *L1* in Figure 1, is the first premise of the study. Besides, the resources needed for maintaining a bigger hotel, including maintenance works and manpower, would be more than that required for a smaller one. The link between such properties of a hotel and its maintenance costs is indicated as *L2*. Furthermore, *L3* represents a link between maintenance costs and energy use where, for example, given a higher level of maintenance resources input for a hotel, it would allow more and better maintenance work to be carried out, enabling the energy-consuming facilities of the hotel to perform more efficiently, thus using less energy.

"Insert Figure 1 here"

Quantification of the energy use in a building can be made by referring to the amounts of utilities the building consumed. Costs for maintaining a building include those needed to hire maintenance staff, execute routine repair and maintenance work, and implement some capital projects (e.g. replacement of air-cooled chillers with energy efficient water-cooled chillers) to improve the conditions of the existing facilities. Such utilities and costs data are sensitive and, as experienced before, it is difficult to collect them from the data owners [20]. Therefore individual face-to-face interviews with the hotels' representatives, which assure keeping the identities of their hotels and data owners confidential, were adopted to collect reliable data for the study. To facilitate the data collection process, a data template was devised. The types of data solicited include: grade of hotel (star rating); building age; gross floor area; number of guestrooms; occupancy rate; costs of maintenance staff, repair and maintenance work, and capital project; and consumptions of utilities including electricity, diesel oil, town gas, and water. The maintenance costs cover all those required for the builder's works (e.g. façade, roof, and ground) and building services installations (e.g. electrical, air-conditioning, and fire and piped services) in the hotels.

The template was provided to the interviewees well before the interviews so as to allow sufficient time for them to gather the necessary data. During the interviews, the interviewer explained the coverage of the types of data needed. In cases where such coverage was found to be different from that of the data provided by the interviewees, minor revisions were made at the time of the interviews. For revisions that were too substantial to be made within the limited interview periods and for data that could not be made available during the interviews, follow-up contacts were made to ask the interviewees to supplement the outstanding data. Afterwards, the data collected were organized and checked for completeness and any abnormality. For incomplete data and those detected as unreasonable, clarifications were sought from the respective interviewees before the data were consolidated for analysis.

The analysis was started with working out the descriptive statistics of the data, including those about the characteristics of the hotels, their utilities consumptions and maintenance costs. Then the data were processed to generate benchmarking charts for different kinds of utilities consumptions and maintenance costs. Finally correlations between different energy consumptions and cost elements were tested to identify any relation between the energy use of the hotels and their maintenance costs.

4. Results and discussions

4.1 Characteristics of the hotels

A total of 30 interviewees who were senior staff (e.g. Director, Assistant Director, and Chief Engineer) of the hotels provided useful data for the study. All the hotels were in the upscale category, with sixteen in the 5-star category and fourteen being 4-star. The newest hotel had been in operation for 2 years; on average the hotel buildings were 18.5 years old (standard deviation: S.D. = 9.8) and their mean gross floor area exceeded 42,000m^2 (Table 1). Collectively there were 16,718 guestrooms in the hotels, and their occupancy rates were generally high, spreading across a range of 29%.

"Insert Table 1 here"

The total energy use of the hotels was enormous, with a yearly aggregate amount of over 2,157 TJ. Among the samples the annual maximum total energy consumption was 133,567 GJ (Gigajoule; 1 GJ = 10^9 J). As for electricity consumption, the biggest consumer used 109,101 GJ a year, which was more than double of the mean consumption level (Table 2). The consumptions of town gas varied from 500 GJ to 55,317 GJ. All the hotels used electricity and town gas while diesel oil was not used in 11 of the hotels; the largest diesel oil consumption among the samples was 40,007 GJ a year. The annual total amount of water consumed by the hotels was 4,858,000 m^3, or 291 m^3 per room.

"Insert Table 2 here"

Table 3 further shows the key statistics of energy and water consumptions normalized by number of guests. On average, the total energy use per guest was 232.1 MJ, a substantial portion of which was due to electricity consumption (17.2.2 MJ/guest). The amounts of town gas and diesel oil consumptions per guest were variable, as evidenced by the large standard deviations (36.9 to 46.5) relative to the respective mean consumption values (21.3 to 38.6). Comparatively, the variations in water consumptions per guest were less variable. Ranging between 0.203 m^3/guest and 1.133 m^3/guest, the average water consumption was 0.501 m^3/guest.

"Insert Table 3 here"

Considerable amounts of resources were deployed to maintain the operations of the hotels. The relevant cost data of a hotel and the capital project cost data of six others, which the respective data owners were reluctant to disclose, were not made available for analysis.

Despite this constraint, calculations were made to obtain statistics of different categories of maintenance costs, namely repair and maintenance, capital project, maintenance staff, and their overall total. Table 4 shows the calculation results.

"Insert Table 4 here"

The annual cost of repair and maintenance work per hotel, on average, was over HK$7.4 million (US$1 ≈ HK$7.8). The counterpart for financing capital projects, including improvement and refurbishment works, was significantly more – close to HK$13 million. The greatest capital project cost was as high as HK$40.9. Whereas the average amount of maintenance staff payroll was less than those of the preceding two kinds of costs, the minimum level of the payroll was actually the highest among the three categories.

Normally a hotel of a larger scale would be equipped with more facilities and hence its energy use would be more than that of a smaller hotel, and vice versa. Since the sizes of the hotels were not identical, it would not be fair to directly compare the levels of energy consumptions or maintenance costs between the hotels. Before making such comparisons, therefore, it is necessary to normalize the relevant parameters with respect to the scale of the hotel buildings.

Drawn upon the experience gained from an earlier study [10] where trials were made to identify an appropriate factor for normalizing the O&M costs for the air-conditioning systems of some commercial buildings, an attempt was made in the current study to investigate if the levels of energy consumptions were dependent on the number of hotel guestrooms. As the scatter plot in Figure 2 shows, the total energy consumptions of the hotels generally increased with the number of their guestrooms. But the former varied widely in the middle range of guestrooms. The *R*-squared value of the trend line was small, reflecting a low goodness of fit. This shows that number of guestrooms is not a good parameter for normalizing the total energy consumptions of the hotels.

"Insert Figure 2 here"

A further attempt was made by plotting the total energy consumptions against the gross floor areas of the hotels, as shown in Figure 3. It shows that the energy consumptions increase exponentially with the floor areas, and the *R*-squared value of the trend line is much greater than that of the previous attempt. Thus, gross floor area is comparatively a better normalization factor than number of guestrooms.

"Insert Figure 3 here"

4.2 Comparisons and benchmarking

A previous study found that the difference between the O&M costs of 4-star and 5-star hotels in Hong Kong was not obvious [10]. That study, however, was based on a limited number of samples. With a much larger sample available for investigation under the current study, and in a bid to examine whether there exists significant difference between the energy consumptions of the two classes of hotels, the collected cost and energy use data were analyzed. The population means of the data are defined as follows:

μ_1 = mean energy use (or maintenance cost) of 4-star hotels

μ_2 = mean energy use (or maintenance cost) of 5-star hotels

Assuming that no difference exists in energy use (or maintenance cost) of the hotels, the null hypothesis (H_0) and alternative hypothesis (H_1) can be written as:

$$H_0 : \mu_1 - \mu_2 = 0$$

$$H_1 : \mu_1 - \mu_2 \neq 0$$

The above hypotheses were tested by a 2-tailed *t*-test, for a 95% confidence interval estimate (i.e. α = 0.05) of the difference between two population means. Based on the raw amounts of annual energy and water consumptions, the sample means and variances of the two classes of hotels were calculated. The probabilities of obtaining test statistics, i.e. the *p*-values, were also computed. As can be seen from the results summarized in Table 5, the *p*-value for the test on the total energy consumptions was smaller than α. Therefore, the null hypothesis is rejected. μ_1 and μ_2 are not equal and the two classes of hotels differed in their total energy consumptions.

"Insert Table 5 here"

Further tests were made on the electricity, diesel oil, town gas and water consumptions. The *p*-value pertaining to electricity, similar to the result for total energy consumption, was found to be smaller than α. This implies that the electricity consumptions of the 4-star and 5-star hotels were different. It is not hard to predict this result because for both groups of hotels, the amount of electricity consumption was the major share of their total energy use.

For the test result for the water consumptions, the *p*-value is smaller than 0.05. This indicates that the two hotel groups differed in terms of water consumptions. On the other hand, the *p*-values of the remaining types of energy consumptions exceed α. On this basis, H_0 could not be rejected; the corresponding consumptions (i.e. diesel oil and town gas) of the 4-star and 5-star hotels were not different.

The energy and water consumption levels were normalized by the gross floor areas of the hotels. Using such normalized data, a series of *t*-tests was carried out and the results are shown alongside those obtained above based on the raw consumption data (Table 5). Unlike the results drawn from the raw data, the *p*-values computed based on the normalized data, ranging from 0.0710 to 0.7120, are all greater than α. This shows that the null hypothesis could not be rejected. Thus, the normalized energy and water consumptions of the two classes of hotels were not different.

Another series of *t*-tests was conducted on the annual maintenance costs of the two groups of hotels, firstly based on the raw cost data, followed by the maintenance costs normalized by the hotels' gross floor areas. Table 6 summarizes the results. Inspections across the tabulated *p*-values obtained based on the raw cost data found that two were smaller than 0.05 (α). One of them, being 0.0159, was found with repair and maintenance cost; the other (0.0177) was for staff cost. The null hypotheses for these two types of costs, but not for the remaining cost categories, could be rejected. In other words, the total maintenance costs as well as the capital project costs of the two hotel groups were not different.

"Insert Table 6 here"

The *t*-test results drawn from the normalized cost data, also summarised in Table 6, show that the computed *p*-values range from 0.0851 to 0.8383. Given that they all exceed 0.05, the corresponding hypotheses could not be rejected. Therefore, the 4-star and 5-star hotels were not different in their normalized total maintenance cost, repair and maintenance cost, capital project, and staff cost.

The above two sets of test results prove that apparently there were differences in some of the energy use and maintenance cost categories between the 4-star and 5-star hotels. Yet such differences were found based on the raw energy use or cost data. When the normalized data were used for the tests, no significant differences were found between the two hotel groups. This is the case not only for all kinds of the energy and water consumptions, but also for all the maintenance cost categories.

In order to construct benchmarking charts for the hotels, the various types of normalized energy and cost levels were grouped into bin values and the corresponding cumulative frequencies were plotted. This was done collectively based on the data of all the hotels, followed by segregating the data with respect to the two classes of hotels, i.e. 4-star and 5-star.

Ranging between 620.2 MJ/m^2 to 2,506.0 MJ/m^2, the average value of the normalized electricity consumptions of the hotel was 1,283.8 MJ/m^2 and their cumulative frequencies were as depicted in Figure 4(a). Most parts of the distribution line pertaining to the 5-star hotels lie below that of the 4-star hotels, indicating that most samples of the former group used more electricity per unit area. Besides, diesel oil was used in 11 hotels; its maximum consumption level, at 929.9 MJ/m^2, was much lower than the counterpart of electricity. The diesel oil consumptions of the 5-star hotels were generally larger than those of the 4-star hotels, as evidenced by the higher position of the entire distribution line of the latter group (Figure 4(b)).

While the use of town gas was as common as that of electricity, its consumption levels, with an average value of 269.5 MJ/m^2, were much lower. The small gaps between the distribution lines in Figure 4(c) imply that town gas consumption levels of the two classes of hotels were comparable. The cumulative frequency distributions of the normalized water consumptions, as displayed in Figure 4(d), are apparently different from the patterns of the preceding figures. Unlike the wide-ranging energy consumptions, the variations in the water consumptions were confined - between 1.61 m^3/m^2 and 7.04 m^3/m^2. Coincidentally, there are overlaps of the distribution lines at around the 20^{th}, 80^{th} and 90^{th} percentiles.

"Insert Figure 4 here"

Following the way in which the above benchmarking charts were constructed, the resources deployed for maintaining the hotels were normalized by their respective gross floor areas. Such normalized values, including those for repair and maintenance cost, capital project cost, maintenance staff cost and the total maintenance cost, are plotted in Figure 5.

With its minimum value being HK\$66.9/m^2, the annual repair and maintenance cost based on all the sampled hotels reached a maximum value of HK\$908.2/m^2. The 50th percentile, for instance, was approximately HK\$170/m^2 (Figure 5(a)). For most of the 5-star hotels, their repair and maintenance costs were higher than those of the 4-star group. Referring to Figure 5(b), however, the entire distribution line of the former group is at the top. This shows that the capital project costs of the 5-star group were generally lower. Furthermore, the ranges of capital project costs and repair and maintenance costs were of the same order of magnitude, but the 50th percentile of the former costs was much higher, at around HK\$250/m^2.

"Insert Figure 5 here"

The amounts of maintenance staff cost, ranging between HK\$79.5/m^2 and HK\$287.2/m^2 (Figure 5(c)), were significantly smaller than the preceding two categories of maintenance costs. The percentile values of the two hotel groups were comparable at the low staff cost levels (up to HK\$130/m^2); the biggest difference between the staff costs of the two groups was found at the 90th percentile. Overall, the total maintenance cost of more than 80% of the hotels exceeded HK\$1,200/m^2 (Figure 5(d)). The small gaps between the distribution lines of the two hotel groups imply that the levels of their total maintenance costs were similar.

4.3 Relations among hotels' characteristics, energy use and maintenance costs

To identify whether the physical/operational characteristics, energy consumptions and maintenance costs of the hotels are linked with each other and, if so, the relations among them, a series of correlation analyses was carried out.

4.3.1 Energy use and hotels' characteristics

The first group of analyses was made based on the energy use data and the hotels' characteristics, and the results are summarised in Table 7 where the values of Pearson product-moment correlation coefficient (*r*) and significance (Sig.) are displayed.

"Insert Table 7 here"

Gross floor area was found to have significant, positive correlation with the raw total energy use of the hotels (r = 0.5530; sig. 0.0015), meaning that the bigger the hotel building, the greater the energy use. This result is in line with the observation from Figure 3. On the other hand, there were no significant correlations between the hotels' total energy use and the remaining parameters. As revealed earlier, number of guestroom is not a good normalization factor so the absence of significant correlation between this parameter and the total energy use is not unexpected.

Regarding the age of the buildings, it showed no significant correlation with the raw total energy use. This may be because improvement works for hotels, which cover replacement of energy-inefficient facilities, are typically implemented on a cyclical basis [15]. Older hotels provided with sufficient improvement works might not be less energy efficient than the newer ones. Figure 6 shows a scatter plot of the raw total energy consumptions against the ages of the hotel buildings.

"Insert Figure 6 here"

Whereas it is reasonable to hypothesize that a greater occupancy rate (i.e. higher user density) of the hotels would result in more energy use, this is not supported by the analysis result. Similar to the case of Lai and Yik [21], the occupancy rates covered in the current analysis, which ranged between 65% and 94%, are not wide enough for revealing the effect of variations in occupancy rate. This is a probable reason for the absence of correlation between the total energy use and the occupancy rates.

After the above analyses which were conducted based on the raw energy use data, further work was carried out to investigate the correlations between the normalized energy consumptions of the hotels and their physical/operational characteristics. The results of this part are also shown in Table 7. But different from the results of the preceding part, none of the characteristics parameters showed significant correlation with the normalized energy use. Nevertheless, the negative *r* values, especially for those pertaining to GFA, guestroom and occupancy, suggest the existence of the economies of scale effect. The energy use per unit area of the hotels generally decreased with incremental increase in their gross floor area, number of rooms and occupancy rate.

4.3.2 Maintenance costs and hotels' characteristics

Similar to the above correlation analyses, Pearson's coefficients were calculated for testing if there were correlations between the total maintenance cost of the hotels and their physical/operational characteristics. The calculation results, as summarised in Table 8, show that none of the tested characteristics parameters was significantly correlated with the raw total maintenance cost. When the same test was applied to detect any associations between the characteristics parameters and the normalized total maintenance cost, a significant, negative correlation was found between the normalized cost and the gross floor area (r = -0.6241; sig. 0.0015). This indicates the existence of economics of scale - the larger the hotel, the smaller the incremental total maintenance cost.

"Insert Table 8 here"

As revealed earlier, number of guestroom is not a good normalization factor and the range of occupancies studied is rather narrow. Coherent with these revelations, there were no significant correlations between the total maintenance cost and the two characteristics parameters, namely guestroom (r = -0.3847; sig. 0.0699) and occupancy (r = 0.1131; sig. 0.6073). But the observation that the total maintenance cost was not correlated with the age of the hotels (r = -0.3847; sig. 0.0699) does not support the premise that older hotels require more resources for maintaining their ageing facilities. In view of this finding, two scatter plots were made to visualize how the maintenance costs vary with the age of the hotels: Figure 7(a) shows the variation of total maintenance cost; Figure 7(b) shows the variations of the constituent costs for repair and maintenance, capital project, and maintenance staff.

"Insert Figure 7 here"

The scatter plot of the normalized total maintenance costs, instead of exhibiting a continuous upward trend with the age of hotels, resembles a bell-shape pattern (Figure 7(a)). It is similar to the distribution pattern of the chiller maintenance costs found in the study of Lai et al. [22], where the costs peaked in the middle-age range while minimal resources were devoted for new installations and those approaching the end of their life span. Except an outlier in the low-age range, the normalized total maintenance costs of the hotels mostly lied between HK$200/m^2 and HK$1000/m^2. Figure 7(b) further shows that the cost variations were mainly due to the large fluctuations in the levels of capital project cost. For maintenance staff costs, on the other hand, their variations were relatively small, with none of the samples exceeding the level of HK$300/m^2.

4.3.3 Energy use and maintenance costs

At the stage of formulating the hypotheses for the study, it was anticipated that the energy use of hotels would be dependent on the effort made in maintaining their facilities. More resources deployed to maintain the facilities, in principle, should retain them in a proper state or even improve the efficiency of energy-consuming facilities, and vice versa. Along this line, the relations between the hotels' normalized total energy consumptions and each category of the normalized maintenance costs were examined by preparing a series of scatter plots, as shown in Figures 8(a) to (d).

"Insert Figure 8 here"

The plots, however, show that the goodness of fit of all the trend lines was low and there were no apparent patterns of the scattered data points. These observations suggest the absence of significant correlations between the normalized total energy use and the various maintenance costs.

In order to scrutinize if the total energy use was associated with any of the maintenance cost categories, further correlation tests were carried out for each of the parameters. The first series of such tests was made based on the data of normalized total energy consumptions and raw maintenance costs. As the results in Table 9 show, the correlation between the normalized total energy consumptions and the normalized repair and maintenance costs was not significant (r = 0.2262; sig. 0.2381). The same conclusions can be drawn from the results between the normalized total energy consumptions and: (i) the normalized capital project costs (r = 0.1355; sig. 0.5377); (ii) the normalized maintenance staff costs (r = 0.3947; sig. 0.0341); and (iii) the normalized total maintenance costs (r = 0.3103; sig. 0.1495).

"Insert Table 9 here"

A further series of correlation tests was conducted between the normalized total energy consumptions and the four categories of raw maintenance costs. The results, with the values of r varying between -0.0012 and 0.2895, show that there were no significant correlations between the four pairs of parameters. Similar results (r ranges from -0.3220 to 0.0677) were obtained from the tests between the raw total energy consumptions and the same sets of raw maintenance cost data.

Carried out based on the data of the hotels' raw total energy consumptions and the raw amounts of the four maintenance cost categories, the final series of tests revealed no significant correlations except for one of the tested cases. A moderate, positive correlation was found between the raw total energy use and the raw maintenance staff cost (r = 0.6244; sig. 0.0003). This implies that more maintenance manpower was required for hotels that consumed more energy.

The above results inform that there was little linkage between the maintenance costs and the total energy consumptions of the hotels. Factors leading to this finding may include the following. First, the physical/operational characteristics instead of the maintenance resources of the hotels predominated in determining the amounts of energy they consumed. For instance, if a facility is used profligately or left running even after the venue it serves is unoccupied, its energy consumption would be high regardless of the amount of resources input for its maintenance. Second, the maintenance resources used, including those for hiring maintenance manpower, executing routine repair works and implementing improvement projects for the hotels, were not effective. Third, the amounts of energy used by the hotels were insensitive to the effort and hence the resources devoted on maintenance. This is the case, for example, for an air-conditioning system with a faulty design, poor installation workmanship or improper commissioning, providing it with ordinary, routine maintenance work would have little effect on improving its energy efficiency. In addition, the energy use of the hotels may hinge on parameters beyond those covered in the current research, which are yet to be studied in future.

5. Conclusions

Research on the link between energy use and maintenance costs of hotels has been limited. The above study is one that made use of face-to-face interviews to collect reliable maintenance cost data and energy consumption records of 30 hotels. The study results show that among the various kinds of energy use, electricity consumption dominated. The amounts of resources deployed for maintaining the hotels were enormous, with the cost for implementing capital projects being generally more than the cost for hiring maintenance staff or executing repair and maintenance works. Instead of number of guestrooms, gross floor area is a better parameter for normalizing energy consumptions of hotels.

Apparently the raw amounts of energy consumptions and maintenance costs of the two groups of hotels, i.e. 4-star and 5-star, were different. But analyzing their normalized energy use and maintenance cost data unveiled that there were no significant differences between the two groups. Benchmarking charts, which were established based on the normalized energy and cost data, can facilitate building professionals and researchers to compare and evaluate energy performance and maintenance cost effectiveness of similar types of hotels.

Gross floor area, which represents the scale of hotels, was a physical characteristic exhibiting a significant, positive correlation with the raw total energy use of the hotels. While larger hotels generally consumed more energy, the energy use per unit area, by virtue of economies of scale, tended to drop with increase in the size of hotels. For total maintenance cost, likewise, it could be economized for hotels of a larger scale. Despite the absence of a notable relation between the hotels' total energy use and their building age, the maintenance costs of the new and old hotels, as compared with those of the middle-aged hotels, were lower.

The costs of maintenance manpower were greater for hotels with larger energy consumptions. Except this correlation, there were no apparent associations between the other maintenance cost items and the total amounts of energy consumed by the hotels. This highlights the missing links between the total energy use of the hotels and the resources used for their routine repair and maintenance works, and improvement projects. This phenomenon may be ascribed to, as suggested above, various factors including: improper operation of the hotel facilities; ineffective maintenance works; and problems arising from faulty design, poor workmanship, or improper commissioning. Further studies, therefore, need to examine the effects of these factors on the energy use of hotels and whether there are other influential parameters.

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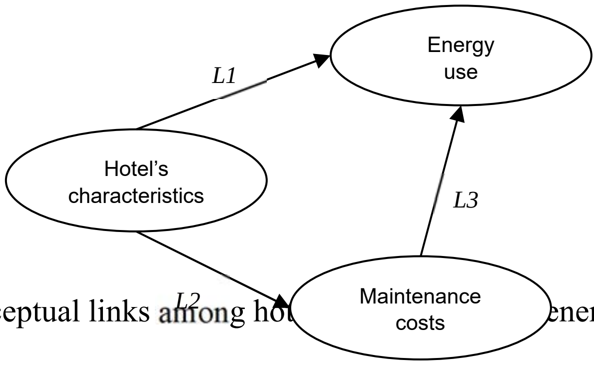


Figure 1 Conceptual links among hot[illegible] energy use and maintenance costs

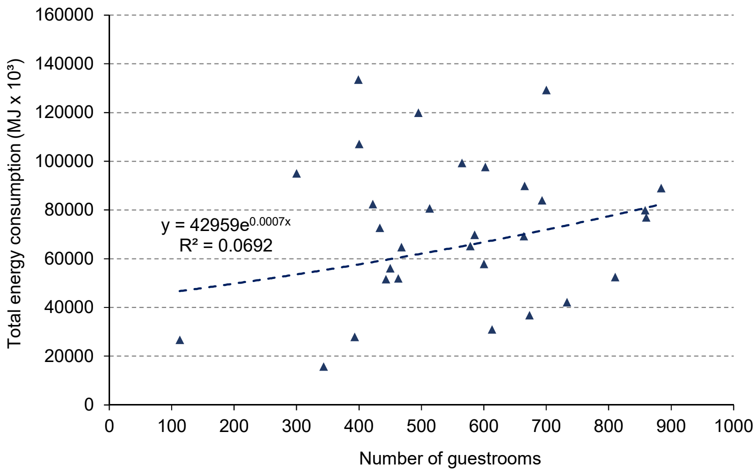


Figure 2 Relation between total energy consumption and number of guestrooms

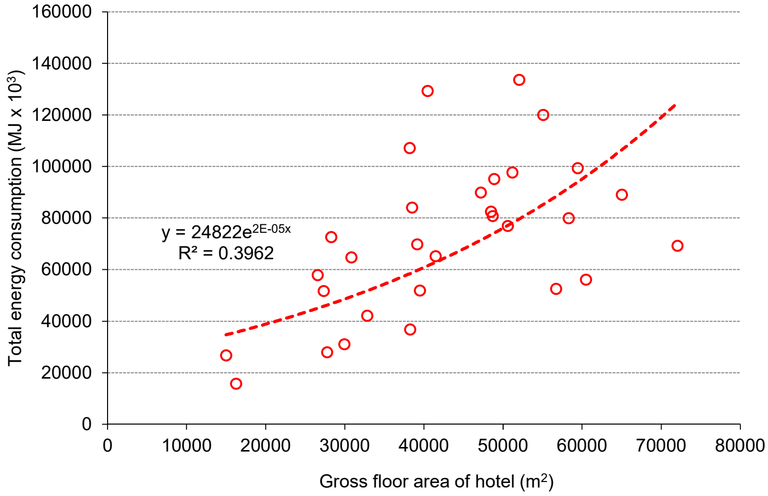


Figure 3 Relation between total energy consumption and gross floor area

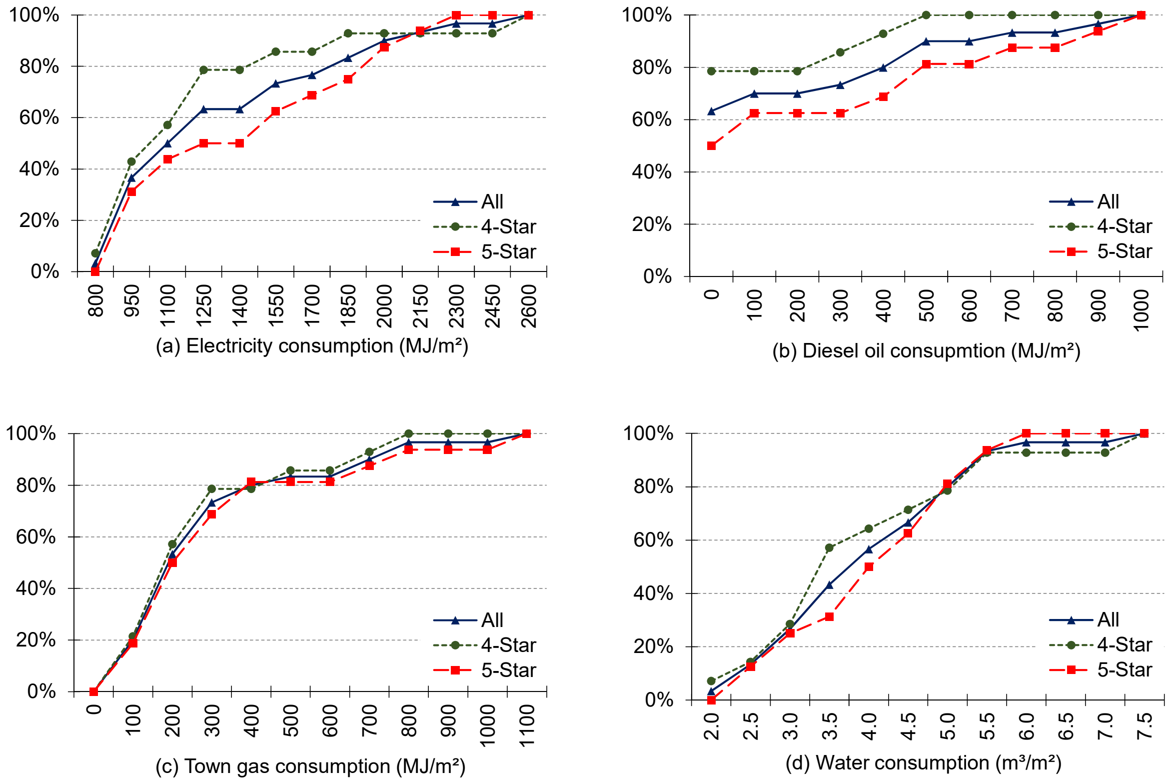


Figure 4 Benchmarking charts for utilities consumptions

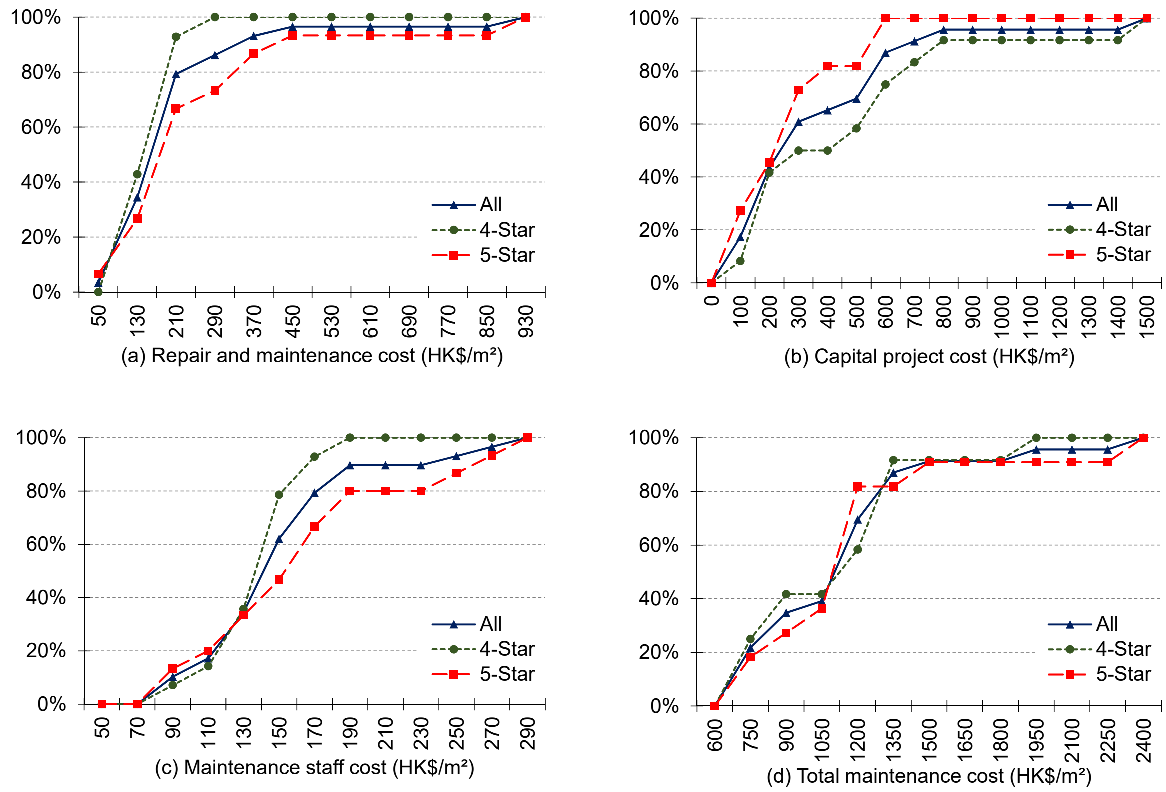


Figure 5 Benchmarking charts for maintenance resources

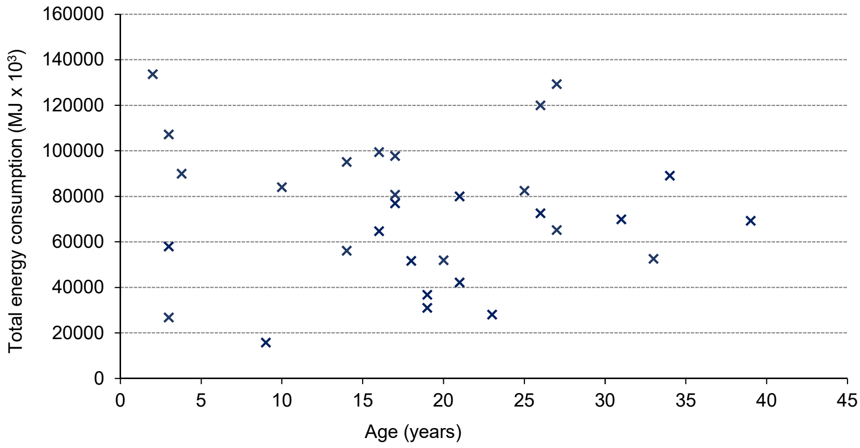
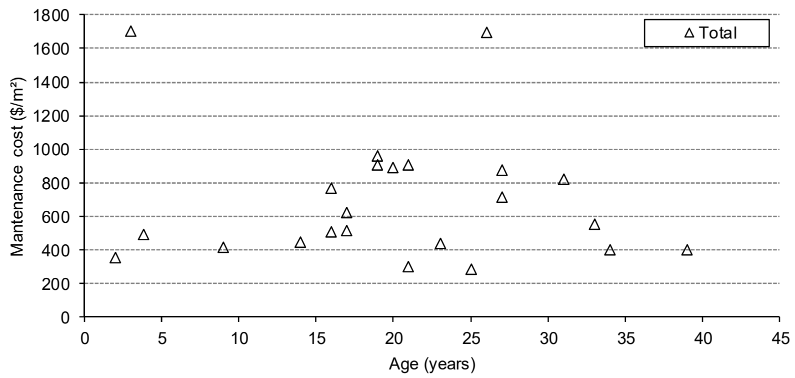
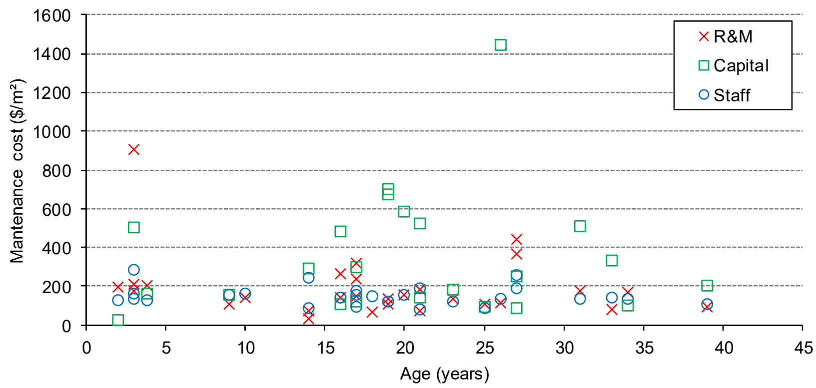


Figure 6 Variation of raw total energy use against building age



(a)



(b)

Figure 7 Distribution of maintenance costs over age of hotel buildings

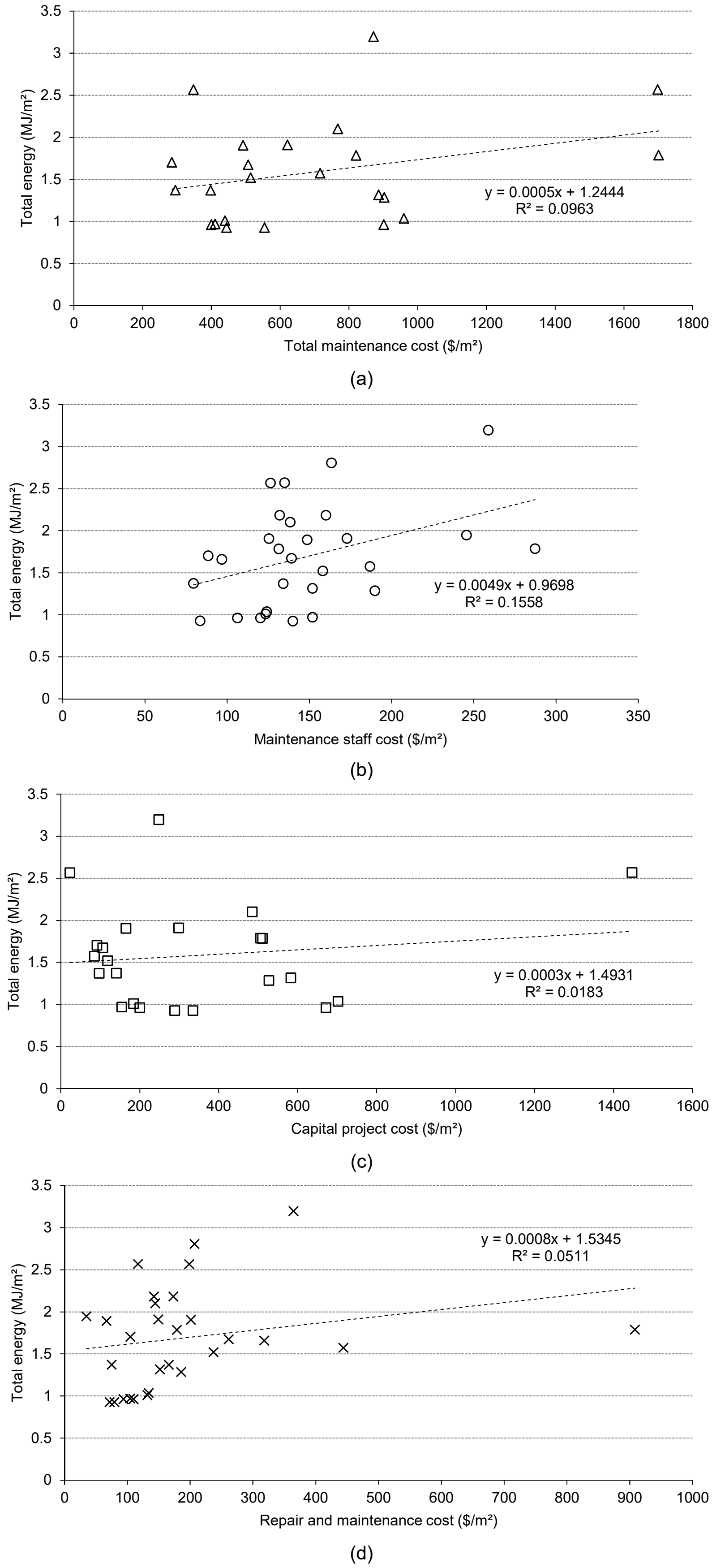


Figure 8 Scatter plots of normalized total energy use against maintenance costs

List of tables

Table 1 Characteristics of the hotels

	Mean	Min.	Max.	S.D.
Building age (year)	18.5	2	39	9.8
Floor area (m^2)	42,815	14,975	72,062	14,124
Guestroom (nos.)	557	113	884	179
Occupancy rate (%)	85.8	65.0	94.0	6.7

Table 2 Annual energy and utilities consumptions of the hotels

	Mean	Min.	Max.	S.D.
Total energy (GJ)	71,913	15,759	133,567	30,114
Electricity (GJ)	53,353	15,259	109,101	22,350
Town gas (GJ)	10,884	500	55,317	10,678
Diesel oil (GJ)	7,676	0	40,007	13,073
Water (m^3)	161,933	43,305	297,000	60,322

Table 3 Normalized annual energy and utilities consumptions of the hotels

	Mean	Min.	Max.	S.D.
Total energy (MJ/guest)	232.1	74.0	564.5	137.0
Electricity (MJ/guest)	172.2	71.0	484.5	108.7
Town gas (MJ/guest)	38.6	1.6	211.0	46.5
Diesel oil (MJ/guest)	21.3	0.0	118.3	36.9
Water (m^3/guest)	0.501	0.203	1.133	0.228

Table 4 Annual maintenance costs of the hotels

Cost	Mean	Min.	Max.	S.D.
Repair & maintenance (HK$)	7,415,790	1,698,857	18,414,369	4,617,953
Capital project (HK$)	12,959,763	1,191,000	40,900,900	9,389,463
Maintenance staff (HK$)	6,026,539	2,469,018	12,000,000	2,281,128
Total (HK$)	43,874,195	12,253,324	62,898,628	12,315,203

Table 5 Results of *t*-tests on energy and water consumptions

		4-star (raw)	5-star (raw)	4-star (normalized)	5-star (normalized)
Total energy	Mean	56117621.2	85734242.9	1500.4	1890.3
	Variance	4.9E+14	8.9E+14	276812.4	373955.9
	t Stat	-3.1076		-1.8771	
	P(T<=t) two-tail	0.0044*		0.0710	
Electricity	Mean	42846720.2	62546734.8	1180.7	1374.1
	Variance	2.6E+14	5.5E+14	236582.8	248173.9
	t Stat	-2.7132		-1.0740	
	P(T<=t) two-tail	0.0115*		0.2920	
Diesel	Mean	3820503.7	11049261.4	68.7	230.5
	Variance	6.1E+13	2.5E+14	20266.4	108730.8
	t Stat	-1.6136		-1.7826	
	P(T<=t) two-tail	0.1209		0.0891	
Town gas	Mean	9450397.4	12138246.6	251.0	285.7
	Variance	5.8E+13	1.7E+14	49856.5	81533.1
	t Stat	-0.7046		-0.3730	
	P(T<=t) two-tail	0.4876		0.7120	
Water	Mean	134047.4	186333.6	3.7	4.0
	Variance	2.2E+09	3.8E+09	2.0	1.1
	t Stat	-2.6416		-0.6319	
	P(T<=t) two-tail	0.0136*		0.5334	

Notes: *p*-value = P(T<=t) two-tail; *< $\alpha = 0.05$.

Table 6 Results of *t*-tests on maintenance costs

		4-star (raw)	5-star (raw)	4-star (normalized)	5-star (normalized)
Total maintenance	Mean	26120377.8	27344169.0	708.9	675.1
	Variance	1.2E+14	4.6E+13	154106.0	153003.0
	t Stat	-0.3293		0.2067	
	P(T<=t) two-tail	0.7455		0.8383	
Repair & maintenance	Mean	5340529.8	9352700.2	137.0	242.5
	Variance	9.0E+12	2.6E+13	2249.5	46741.3
	t Stat	-2.6038		-1.8432	
	P(T<=t) two-tail	0.0159*		0.0851	
Capital project	Mean	15202887.6	10512717.5	436.4	248.2
	Variance	1.2E+14	5.1E+13	151275.8	31876.3
	t Stat	1.2316		1.5119	
	P(T<=t) two-tail	0.2331		0.1501	
Staff	Mean	5016804.7	6968957.4	133.8	161.8
	Variance	3.6E+12	5.1E+12	646.8	3734.2
	t Stat	-2.5264		-1.6299	
	P(T<=t) two-tail	0.0177*		0.1196	

Notes: *p*-value = P(T<=t) two-tail; *$< \alpha = 0.05$.

Table 7 Correlations between total energy use and characteristics of the hotels

Characteristics	Raw		Normalized	
	r	Sig.	*r*	Sig.
Age (years)	0.1051	0.5803	-0.1488	0.4327
GFA (m^2)	0.5530	0.0015**	-0.1510	0.4259
Guestroom (nos.)	0.1580	0.4043	-0.1990	0.2917
Occupancy (%)	-0.3903	0.0330	-0.3716	0.0432

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

Table 8 Correlations between total maintenance cost and characteristics of the hotels

Characteristics	Raw		Normalized	
	r	Sig.	*r*	Sig.
Age (years)	0.3511	0.1005	-0.0969	0.6599
GFA (m^2)	0.0810	0.7132	-0.6241	0.0015**
Guestroom (nos.)	0.2168	0.3204	-0.3847	0.0699
Occupancy (%)	-0.2404	0.2693	0.1131	0.6073

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

Table 9 Correlations between total energy use and maintenance costs

Cost	Total energy (normalized)		Total energy (raw)	
	r	Sig.	*r*	Sig.
Repair and maintenance (normalized)	0.2262	0.2381	-0.0458	0.8135
Capital project (normalized)	0.1355	0.5377	-0.3220	0.1340
Maintenance staff (normalized)	0.3947	0.0341	0.0677	0.7273
Total maintenance (normalized)	0.3103	0.1495	-0.2871	0.1841
Repair and maintenance (raw)	0.2598	0.1734	0.4138	0.0257
Capital project (raw)	-0.0012	0.9958	-0.2280	0.2955
Maintenance staff (raw)	0.2339	0.2220	0.6244	0.0003**
Total maintenance (raw)	0.2895	0.1803	0.1665	0.4477

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